Developing a methodology for the evaluation of acute and critical care outcomes in resource-limited settings



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Abstract

The burden of acute and critical illness in LMICs is high, and proportionally higher with poorer outcomes than in HIC. Structured surveillance, enabling systematic evaluation of acute and critical care outcomes, is largely lacking in LMICs. Many tools, including but not limited to prognostic models and decision-support tools, developed in HIC are mostly not validated in LMICs. In addition, acute and critical care skills training, necessary for improving the quality of care and outcomes, is not readily accessible for many healthcare workers. This thesis describes a baseline profile of acute and critical care services in Sri Lanka; the development and implementation of a national, electronic, critical and acute care surveillance system and an assessment of the feasibility of HIC decision-support tools in LMIC settings. It further describes a co-designed, sustainable, national acute and critical care training programme, supported by the surveillance platform.

Baseline profile: Overall ICU mortality was 17% but no severity of illness data was available. Overall, only 5.1% of those who had CPR attempted in hospital were alive after 24 hours, with most arrests anticipated by the junior medical team. Only 4.4% of wards use DNAR instructions. The 99 national ICU's had relatively (to other LMICs) good staffing; 790 doctors (1.6 per bed) and 1989 nurses (3.9 per bed, 87.9% ICUs had 1:1 nurse to patient ratio). Evaluation of the applicability of APACHE II was hampered by arterial blood gases and electrolytes being available in only 18.7% and 63.4 % of ICU admissions respectively, and complete case records (for APACHE II) was only available in 1.6% of instances.

A surveillance platform for acute and critical care, fusing mobile data entry with visual analytics, was developed and implemented in 56 Sri Lankan hospitals, supporting clinicians in finding ICU beds. The dataset confirmed the low availability of variables commonly used to detect deterioration in acutely unwell ward patients; respiratory rate (65.24 %), mentation (32.89%) and oxygen saturation (23.94%), in a cohort of 16,386 patients. The platform was used for the validation of prognostic models and EWS tools, which showed that the performance of single variable trigger systems was comparable to more complex EWS's regarding identification of at-risk patients. A simpler critical care prognostic model, (TropICS), based on variables more commonly available in LMICs and collected through the platform, was derived and evaluated, and shown to outperform APACHE II in this setting. The platform can also support critical care training; the thesis describes the development, execution, and evaluation of two clinically focused training programmes. A 2-year modular programme in Bangladesh, India and Nepal showed a positive impact on patient outcomes. In Sri Lanka, a peer-delivered, acute and critical care structured training programme was delivered to over 4,500 nurses, physiotherapists and doctors, increasing knowledge and confidence.

In summary, the work in this thesis describes a setting-adapted acute and critical care surveillance system, enabling the evaluation of the feasibility and performance of prognostication and decision-support tools, providing a template for LMIC settings. The studies show the importance of evaluation of clinical and benchmarking tools for feasibility and performance, and their adaptation where necessary, prior to their implementation in LMICs. In addition, the studies show that locally developed, sustainable training programmes aimed at improving outcomes in critically ill patients are possible in resource-limited settings. This thesis provides evidence that a clinician-led data platform in a LMIC can provide opportunities to evaluate (and potentially improve) outcomes by an inter-dependent cycle of enhanced information availability, quality improvement, capacity-building, training, and research.

It always seems impossible until it’s done

Nelson Mandela

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List of abbreviations

ALS	Advanced life support
APS	Acute physiology Score
APACHE	Acute physiology and chronic health evaluation
ASCOT	A severity characterisation of trauma
AUROC	Area under the receiver operating characteristic
BUN	Blood urea nitrogen
CI	Confidence intervals
CKD	Chronic kidney disease
CPR	Cardiopulmonary resuscitation
CRF	Case report form
CVP	Central venous pressure
CVVHF	Continuous veno◊venous haemofiltration
EWS	Early Warning Score
FBC	Full blood count
GCS	Glasgow coma score
GOSE	Glasgow outcome score-extended
HCT	Haematocrit
HIC	High Income Country
GCP	Good clinical practice
ICTA	Information and Communication Technology Agency

ICU	Intensive care unit
INR	International normalisation ratio
IV	Intravenous drug administration
LMIC	Low or Middle Income Country
MICE	Multiple imputation by chained equations
MOH	Ministry of health
NCAS	National cardiac arrest study
NICE	Netherland intensive care evaluation
OR	Odds ratio
RTS	Revised trauma score
TBI	Traumatic brain injury
TRISS	Trauma and injury severity score
RCT	Randomised controlled trial
ROC	Receiver operating characteristic
RRT	Renal replacement therapy
SBP	Systolic blood pressure
SLNC	Sri Lanka nursing council
UCFM	University of Colombo Faculty of Medicine
WHO	World Health Organization

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Author’s contributions

The author’s contributions to the original research contained in this thesis includes: (1) design, ethical approval, coordination, funding, analysis and manuscript writing for all studies described in Chapters 3, 4 and 5. (2) conception, design, negotiation and implementation of the NICS registry (3) conception, development and delivering iterations of the NICS software applications and data platform except as described below. (4) direction, funding, oversight and responsibility for the NICS and NICST projects including data protection. (5) design, training and delivery of courses described in sections 5.2, 5.3 and 5.4, though not in actual delivery of every course.

Rashan Haniffa was not involved in: (1) patient recruitment prior to 2011 for the South Asian training study described in Section 5.1 (2) advanced statistical analysis for the same study (3) software coding for the NICS registry applications. (4) data entry for patients recruited to the registry or data platform.

1.0 Introduction

1.1 Aim

The main research question was to determine whether a setting-adapted registry cum data platform would enable the evaluation of acutely unwell patient outcomes in LMIC.

The primary aim of this thesis was to develop a methodology for the evaluation of acute and critical care outcomes in resource-limited settings.

The following hypotheses were proposed:

- Critical care prognostic models from HIC are impractical for routine use in resource-limited settings.
- A simplified prognostic model can predict critical care outcomes in a resource-limited setting.
- Single parameter (non-aggregate) EWS are comparable to multi-parameter (aggregate) EWS in detecting deterioration in a resource-limited setting.
- A clinician-led national acute and critical care surveillance data platform enables the evaluation of process and outcome measures in a resource-limited setting
- The introduction of a modular training program can lead to improvement in ICU performance indicators in a resource-limited setting.
- A locally sustainable, predominantly peer-led practical national training programme in acute care skills can be established in a resource-limited setting.

The specific components of the thesis were:

- A cross-sectional survey of critical care services in Sri Lanka (3.1)
- Outcomes following cardiopulmonary arrest and availability of clinical observations in a LMIC DGH. (3.2)
- Cardiopulmonary resuscitation practices in Sri Lanka; a national cross-sectional survey. (3.3)
- Improving ICU services in resource-limited settings: perceptions of ICU workers from LMIC and HIC. (3.4)
- Performance of critical care prognostic scoring system in LMIC settings; a systematic review (4.1)
- An evaluation of the feasibility and performance of APACHE II in Sri Lanka (4.2)
- TBI outcomes in an LMIC tertiary centre and performance of trauma scores. (4.3)
- A simplified prognostic model for resource-limited settings South Asia (4.4)
- Data availability for critical care prognostic models in Sri Lanka utilising a setting-adapted national critical care registry and data platform (4.5)
- An evaluation of the feasibility and performance of EWS in a Sri Lankan DGH (4.6)
- Experiences of ICU survivors in a LMIC; a multicentre study. (4.7)
- Critical care junior doctors' profile in a LMIC (5.1)

- Impact of a structured ICU training programme on outcomes in resource-limited settings in South Asia (5.2)
- A locally-delivered national acute and critical care nursing training programme in Sri Lanka (5.3)
- A peer-led national acute care training programme for newly qualified doctors in Sri Lanka (5.4)

1.2 Background

There have been impressive gains in public health in low- and middle-income countries [2] in recent decades, which are contributing to significant reductions in infant mortality, malaria attributable mortality and a general improvement in life expectancy in these countries. With basic public health needs better addressed, improvements in curative care, in particular for the critically ill, are becoming more important for saving lives. The recent and continuing outbreaks of severe acute respiratory infections due to emerging infections give further political and media attention to critical care. Examples include the SARS coronavirus (2002-2003), avian influenza H5N1 (2004 and onward), pandemic influenza A(H1N1) (2009), the MERScoronavirus (2012 and onward), and Ebola virus disease (2014-2015).

When defined as all aspects of care for patients with sudden, serious, reversible disease, critical care is not disease or age specific and includes triage and emergency medicine, hospital systems, quality of care and ICUs. Critical or intensive care is the provision of clinical care for those afflicted by any immediately life-threatening disease or injury, which if left untreated, almost inexorably leads to death. Critical illness strikes across all age groups and specialties. CCUs (CCU and ICU are used interchangeably in this thesis) are defined in this thesis as units, which have at least one ventilator and where patients are expected to be admitted for at least 24 hours, in order for the findings relating to CCUs to be comparable to previous studies [3, 4] and to exclude the following facilities: ad hoc “high dependency” areas in a ward with some extra monitoring, post anaesthetic (“recovery”) care areas where a patient maybe ventilated for a few hours, and emergency treatment units similar to resuscitation areas in accident and emergency departments in HICs (where

treatment is limited to initial stabilization before transfer to a definitive critical care area). However, it is important to note that acute and critical care, especially in LMICs is often, and perhaps predominantly, delivered outside such dedicated CCUs.

The burden of critical illness is especially high in LMICs [5]. Severe infections such as pneumonia, diarrhoea and malaria are endemic and traffic accidents, obstetric complications and surgical emergencies are all common. Ninety per cent of the 10 million children below 5 who die each year worldwide are in 42 of the poorest countries [6]. More than half of all maternal deaths occur on the African continent [7]. And 90% of trauma deaths occur in low or middle-income countries [8]. Nearly half of child deaths in hospitals occur within 24 h of arriving at the hospital [9]. A survey from South Africa found that as many as 25% of medical admissions were sufficiently ill to merit admission to a higher care unit [10]. Treatments such as surgical operations can cause life-threatening complications that increase the demand for escalated care meaning 80% of peri-operative Caesarean section deaths occur on general wards in the postoperative period [11]. As the majority of critically ill patients in developing countries are children and young adults, there is a good potential for recovery [12].

Increased awareness of the importance of critical care is reflected in an increase in availability of dedicated ICUs in low-middle-income and middle-income countries. An important impediment for capacity planning in resource-restricted settings is the limited data on critical care usage and capacity [13]. However, with the scarce data available, it appears that severity adjusted case fatality in ICUs in these settings remains much higher than in higher income countries. [14, 15]. For example, mortality for head injury in Benin is 70% and mortality for eclampsia in Senegal and Nigeria is 40% [16]. The care that critically ill patients receive in

hospital is often informal and uncoordinated or even absent [17, 18]. Improving these outcomes will require evaluation of setting specific factors adversely affecting performance and identification of investments and interventions to address them.

In general, ICUs in low- and middle-income countries must function with important limitations in material and human resources, although that is advantageous in some countries [14, 18, 19]. Laboratory support is limited, supplies of consumables and medication can be unpredictable, and proper maintenance of crucial equipment for monitoring and treatment is often a challenge. Nevertheless, many of the basic principles of good critical care are as applicable (or are even more so) to resource poor settings, but are often not practiced. These include management and organizational aspects, such as regular ward rounds, empowerment of nurses, proper and frequent documentation of vital signs, structured handover to the next shift of doctors and nurses, admission and discharge policies, the use of both short-term and long-term treatment plans, and adherence to strict hygiene rules.

The ‘Surviving Sepsis Campaign’ guidelines for severe sepsis and septic shock management [20] have been implemented widely in ICUs in high-income countries and have, together with timely administration of essential therapies, contributed to improved survival. Many of these recommendations can be applied to more resource-limited settings at low or no extra costs. These include the use of low tidal volumes for mechanical ventilation, prompt start of appropriate empirical antibiotic treatment, restricted use of fluid therapy after the initial phase in septic shock and restricted use of sedation. From the limited data available, these practices are often not implemented [21].

However, an important drawback of the ‘Surviving Sepsis Campaign’ guidelines

is that the evidence for the recommendations has been mainly gathered from studies in high-income countries. This evidence may not be directly translated to the resource-poor setting [22]. The causes of severe sepsis are different in tropical countries and often require different approaches for their management. Examples are severe falciparum malaria and severe dengue, which require more restricted fluid therapy than recommended for bacterial sepsis [22, 23]. Also, some of the widely accepted recommendations for well-equipped ICUs can be dangerous in a resource-poor setting. An example is the early start of enteral feeding, including in sedated and comatose patients. In resource- poor settings, intubation for airway protection in patients with reduced consciousness is commonly not possible because of limited availability of mechanical ventilation. Early start of enteral feeding through a nasogastric tube in this group of patients results in aspiration pneumonia in an unacceptably large proportion of patients [24] and should be reconsidered. Thus, guidelines may require careful setting-adjusted re-evaluation.

A basic requirement for improving critical care in resource-poor settings are tools for evaluation of baseline ICU facilities, practices and performance, which also enables assessment of improvement over time when changes are implemented. In rich countries, ICU registries, utilising severity of illness scores, have proven to be essential tools for monitoring ICU performance.

Critical care prognostic models such as APACHE derived during the first 24 hours of ICU stay, and the SOFA derived from sequential data are in widespread use, especially in HIC. These models are used for risk stratification of critically ill patients, benchmarking of ICUs, recruitment of patients to clinical trials and gauging the response to interventions. APACHE II, one of the simplest models, is the most widely used, especially in LMICs and is often used as a reference for

the evaluation of other models([25]. Performance of critical care prognostic scoring systems in low and middle income countries – A systematic review, unpublished). However, studies validating and refining existing models in LMICs are limited and mostly from single centres using relatively small datasets. [19, 26-28].

Current critical care prognostic models have been almost entirely developed in HICs and are usually based on hospital outcomes, which may not be feasible in LMIC ICUs due to the lack of electronic records or follow-up systems. Existing prognostic models cannot be imposed without validation in LMICs as the diseases encountered in these settings (e.g. malaria, snake bite and poisoning), treatment modalities and available resources may be different. A major shortcoming in using models such as APACHE in LMIC settings is the unavailability of required measurements. Missing measurements can be due to scarcity of equipment (e.g. blood gas machines, pulse-oximetry), or logistical difficulties in systematic data collection, especially, for sequential data. Further, the absence of accessible electronic patient information systems and devices may challenge the feasibility of performing probability calculations, for example, when recruiting to research studies or for triage.

Clinical information, essential for the detection and management of critical illness, is often incomplete or disparate [19, 29]. This applies, not only to information generated by well-equipped laboratories or point of care devices, but also to clinical bedside observations such as heart rate, respiratory rate and measure of mentation [30]. If measured, such observations are recorded on disparate paper systems, decreasing their utility in assisting clinicians in the timely detection of patient deterioration and in decision making regarding diagnosis and treatment [29].

Furthermore, patient records are often not portable as patients move through the healthcare system within or between hospitals. This often renders already existing information obsolete, disempowers patients and leads to clinicians working with incorrect or incomplete information. In addition, information pertaining to patient experience and recovery following critical illness, is virtually non-existent in LMIC settings [31, 32].

Medical registries can be defined as a systematic collection of a clearly defined set of health and demographic data for patients with specific health characteristics, held in a central database for a predefined purpose. (2) A limited number of low- and middle-income countries are using such registries, and a wider roll-out is clearly warranted. Such registries (local, national or regional across borders) will also enable inventorying existing ICUs and availability of equipment and other resources. Minimum standards for equipment, monitoring and treatment required for critical care adjusted to low- and middle-income countries have not been described and a registry can help make these recommendations. Monitoring of nosocomial infections and antimicrobial resistance patterns in the ICU could be an important part of the registry, but facilities for microbiology are unfortunately underdeveloped in these countries. Training of both doctors and nurses working in the ICU is another important area for sustained improvement of care. Collaboration between countries where ICU medicine has been established, and countries where critical care as a separate specialty is still at its early stages, can facilitate this. International networks and linked registries can help identify priority areas for improvement and training, develop communication channels and contribute to create a critical mass of critical care trainers.

Currently there is only a limited body of literature available for this area and the

usual funding schemes rarely focus on this important need. At the same time there is widespread interest on the topic of critical care as a global need, as witnessed by an increasing number of professional organizations with active working groups on the topic. It is clear from the multitude of these issues, that research and quality improvement initiatives at different levels targeted towards critical care in resource-limited settings are warranted. The potential gains for the individual, families, ICU, hospital and healthcare systems are likely to be large and potentially of greater magnitude than is currently possible in high-income countries.

2.0 Methods

2.1 Study settings

The sites for studies described in this thesis were in Bangladesh, India, Nepal and Sri Lanka. The study to assess the impact of a modular ICU training programme (Section 5.2) was conducted in one ICU each in Bangladesh (Chittagong), Nepal (Patan, Kathmandu) and India (Rourkela), sites which are described below. The dataset from this study contributed to the development of a simplified prognostic model for South Asia described under section 4.4. A systematic review is described under section 4.1. All other studies are from Sri Lanka.

The study sites in Sri Lanka arose from a new collaboration between MORU, the MOH in Sri Lanka, UCFM, NICE and Sri Lankan collaborators described below. Sri Lanka is an island nation in South Asia with impressive public health indices [21] having recently emerged from a prolonged and brutal military conflict. The country's Gross Domestic Product per capita for 2011 was US $

2,836 [22]. The state health system in Sri Lanka, the focus of this thesis is free at the point of access.

Critical care services commenced in Sri Lanka in 1968 [23], which is not long after they were first established in HICs [24] and have expanded rapidly since then [23, 13]. Over the past 50 years, CCUs have developed rapidly with nearly a 100 units available by the year 2011. Unlike many other LMICs in Sri Lanka the vast majority of in-patient health care including critical care is provided by the state sector free of charge at the point of delivery [18, 19, 22]. This achievement, though impressive, has implications for the health care burden borne by the state, as the need and pressure to expand these services increases.

State hospitals in Sri Lanka are classified according to their level of treatment, ranging from TH through DGH and BH down to rural hospitals and peripheral units. Tertiary care hospitals are TH (university affiliated) with tertiary referral centres. The Ministry of Health has further divided the secondary care hospitals as BH and DGH depending on their function and resource availability. All 20 tertiary care hospitals are TH, they are the largest hospitals and are generally the best-equipped. TH can be considered equivalent to level 3 of the WHO classification [33], while BH and DGH are higher than or equivalent to level 2 of the classification. BH are the smallest hospitals to have consultant level specialist doctors in the four major disciplines: internal medicine, surgery, paediatrics and gynaecology/obstetrics. Critical care units are only present in hospitals with consultant or specialist doctors (BH and above) as per state policy. ICU registries are uncommon in resource poor countries [25–27] and no such system has existed in Sri Lanka.

The studies described in Chapters 3, 4.2, 4.5, 4.7 and 5 were conducted in sites

across secondary and tertiary care hospitals in Sri Lanka; further details are under each section. The Sri Lankan training programmes described in Chapter 5 were predominantly conducted in Colombo with participants from hospitals across the country, as detailed in the results.

The single centre studies described in 3.2, 4.6 were conducted at Moneragala DGH. This retrospective study was conducted at the state DGH Monaragala in the Uva province of Sri Lanka. This hospital has approximately 450 beds and receives over 50000 admissions per year to 4 medical and 2 surgical wards. The hospital is staffed by approximately 200 nurses and doctors [34].

The single centre study described in section 4.3 was conducted at the neurotrauma unit of the National Hospital of Sri Lanka in Colombo, the premier TH and referral centre in the country.

The study to ascertain the Impact of a modular ICU training programme (Chapter 13) was conducted in one ICU each in Bangladesh, India and Nepal. The simplified prognostic model (Chapter 11) was developed by combining the dataset derived from this study with the dataset from the study evaluating of the feasibility and performance of APACHE II in Sri Lanka (Chapter 6).

The selection of the non- Sri Lankan study sites - Rourkela, India (11 bed ICU at Ispat General Hospital), Chittagong, Bangladesh (9 bed ICU at Chittagong Medical College Hospital) and Patan, Nepal (6 bed ICU at Patan Hospital) was motivated by existing research links between MORU and these institutions. The participating ICUs in the three countries all had facilities for ventilation but not for bedside haemodialysis. Peritoneal dialysis and intermittent out-of-ICU haemodialysis was available in all three hospitals. Multi-parameter electronic patient monitoring including non-invasive blood pressure monitoring was

present in all three units along with infusion pumps for drug administration, though resources were often limited, and equipment shared between patients. ICU nurses staffed the three units with 1: 1 to 1:2 nurse-to-patient ratios during the day and a minimum ratio of 1:3 at night. The doctors in charge of the ICUs were primarily anaesthetists in Rourkela and Chittagong, with internal medicine specialists in charge of the unit in Patan. Junior medical staffing, similarly, was predominantly by trainee anaesthetic doctors in Rourkela and Chittagong with internal medicine trainees in Patan. All ICUs had around the clock coverage of doctors.

The ICU and hospital in Rourkela, a steel–mining town, is funded by the steel company employing a large proportion of the town's population. Employees of the company and their relatives enjoy free medical care at the ICU while others were required to pay. The ICU in Chittagong was publicly funded (though patients paid a subsidised daily fee for occupancy and for disposables/drugs when these were not available in the hospital). In Patan the ICU and hospital were based on a "fee for service" model. In all three sites, but to varying extents, a "poor patient" fund was in place to provide limited support for those unable to afford care.

2.2 NICS registry

NICS, the national electronic critical care registry for Sri Lanka, was set up in 2012 under the purview of the Ministry of Health as a collaboration between MORU, UCFM, NICE/AMC, Sri Lankan Professional Colleges (anaesthesiologists, physicians, paediatricians, obstetricians and gynaecologists), ICTA, the doctors trade union (GMOA) and the nurses regulatory body (SLNC). The remit was to build, operate and maintain the critical

care registry including all hardware, software and human staffing requirements as per the initial memorandum of understanding (Appendix C). NICS was preceded by a baseline survey of ICU facilities (Section 3.1) and a paper-based pilot study (Section 4.2).

2.2.1 Registry outline

An electronic system was proposed to overcome the challenges of paper-based systems, including the difficulties encountered during the paper-based pilot study [35]. This was despite the poor baseline telecommunication infrastructure in the setting; direct telephone lines being available in only 23.2% of ICUs and internet access being available in only 4.1% of ICUs[36, 37].

In order to ascertain the registry system requirements, views were obtained from consultant anesthetists, physicians, junior doctors, nurses and administrators. An electronic prototype was proposed with the minimal dataset constructed to enable the calculation of APACHE II probabilities. The decision to base the dataset on APACHE II was motivated by requests from local stakeholders and due to challenges from missing variables in LMIC settings for even the simplest of prognostic models[35]. Optional variables allowing APACHE IV estimation could also be recorded in the system. The system allowed entry of patient details at admission, at 24 hours after admission and at discharge, in addition to ICU bed state three times a day. The system also needed to have offline capability and transmit data when connected to the internet. The prototype was piloted in the 3 ICUs in the Kurunegala Teaching Hospital and then expanded to every state hospital in the country with a functioning ICU by deploying both hardware and software. All software (prototype and definitive) and hardware were provided free to all critical care units. Six months after the commencement of the pilot, the prototype was replaced by the definitive software.

2.2.2 Software development and implementation

The objective of the software and the network was to provide a secure data collection system to support the country's first web-based registry, thus minimising the delays and logistical problems.

The following objectives were identified:

- Entire application should be web based.
- The software should function online and offline
- The software should utilize open source technology
- No installation should be necessary
- The software can be enabled remotely
- The software should be adaptable easily – ie fields to be added/removed
- The software should enable secure data transmission
- A local copy of the data transmitted should be stored in a PDF format
- The software should enable and support data validation

The availability of equipment and facilities had already been assessed[37]. The prototype development was led by two Bachelor of Medical Informatics undergraduates from the University of Amsterdam. They were involved in the development of the mock-ups, whilst also participating in the conduction of interviews with the stakeholders.

The system was MySQL based; PHP and HTML were used for the development process. The platform and programming languages were chosen after consideration of the locally-available facilities and the capabilities required for the software to function effectively.

The user interface was designed to operate through a browser-based javascript client that was capable of offline operation. The system also had a syncing option. When an internet connection became available users could sync recorded data.

Figure 2.2.1 Prototype admission screen

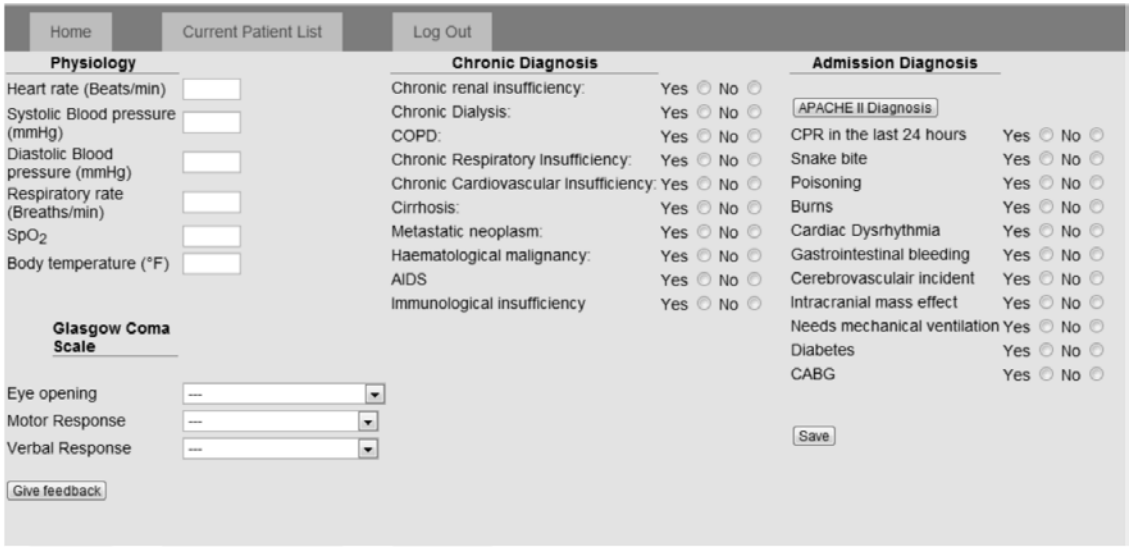
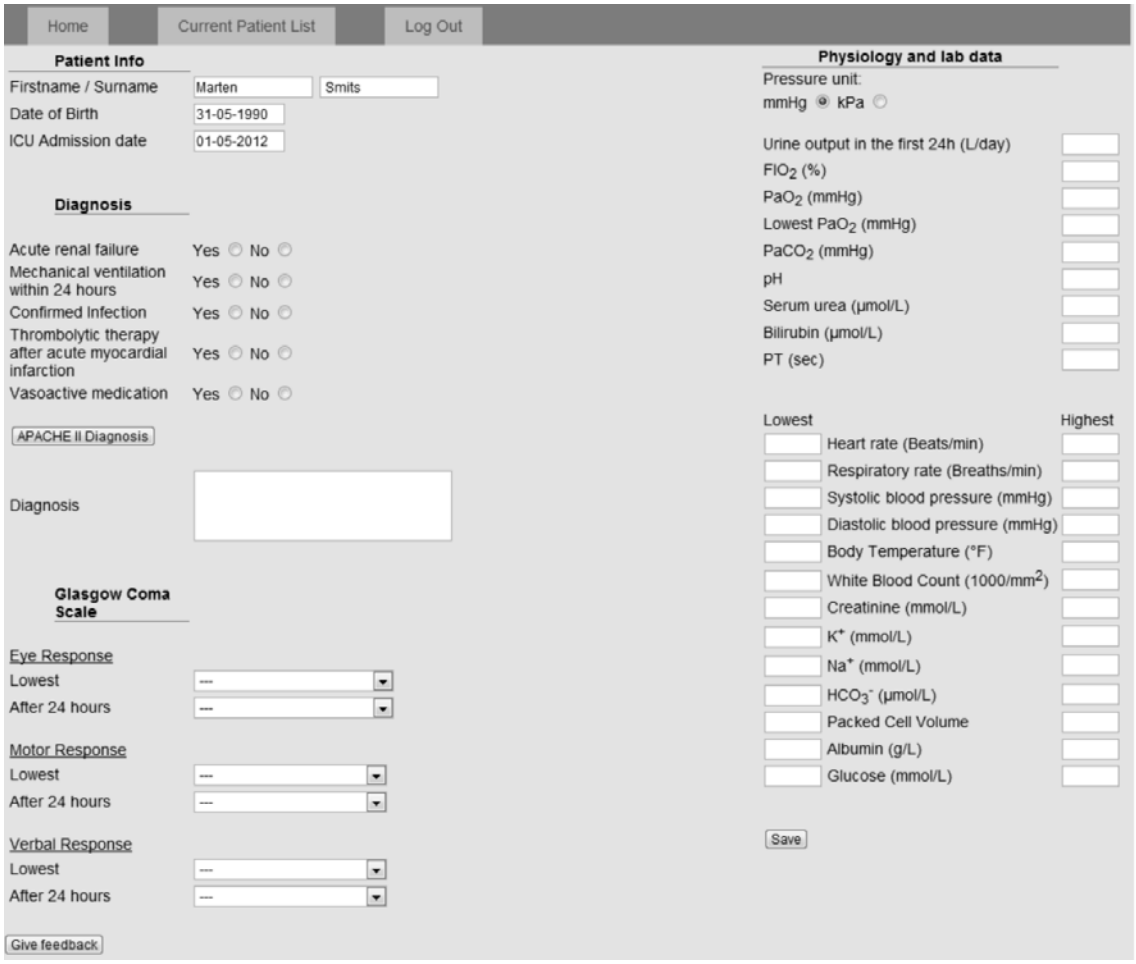


Figure 2.2.2 After 24 hours form of the prototype

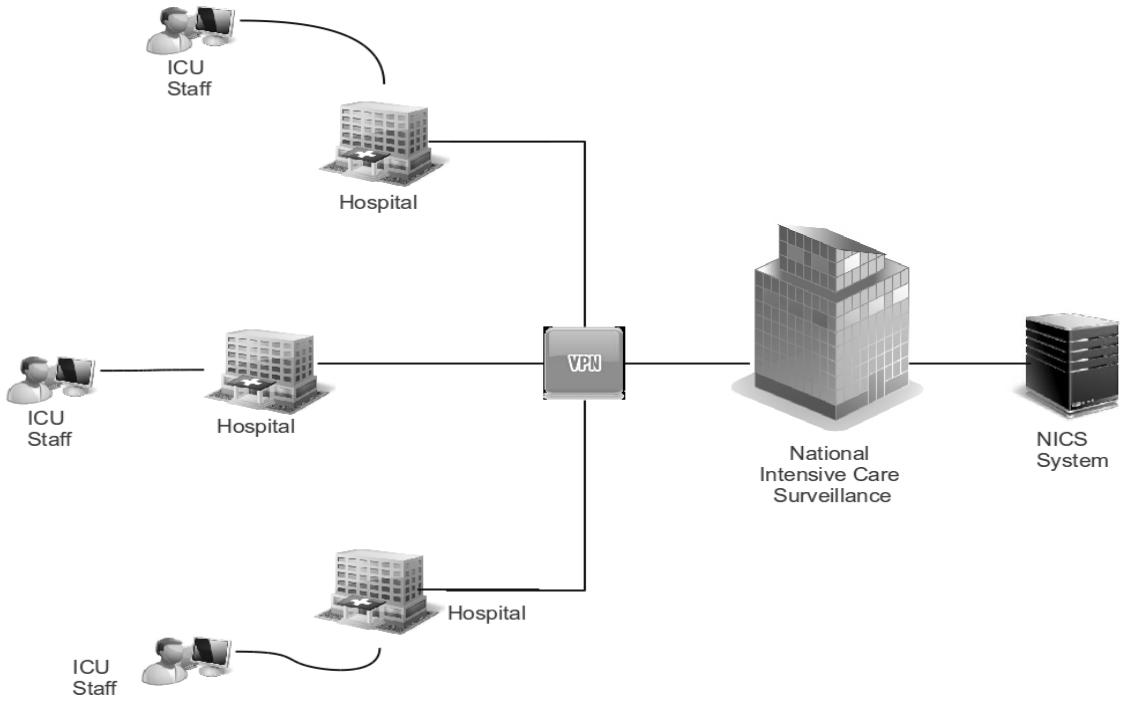


The prototype was tested at three ICUs in the Teaching Hospital Kurunegala, which is situated in the North Western Province. Feedback was obtained from the doctors and nurses at each unit. Each of these units were provided with a computer system and data-collectors were training for data entry. The computers provided were pre-installed with Windows. The operating system was later changed to Linux.

Firefox was chosen to be the default browser as it was the preferred browser for JavaScript based user-interface due to security considerations. Users where instructed to only access the system through it.

NICS also provided the ICUs with internet access through USB dongles or broadband.

Figure 2.2.3 Schema of the NICS network



Final software development was undertaken with the collaboration of the national ICT solutions provider ICTA and a local, privately-owned software company, Respere. It was designed using the client server architecture.

Components of the server included a MySQL 5.1 based data warehouse, a Symfony 2 based back-end server, and a BIRT based reporting engine. The client was a browser-based JavaScript applet that would be stored in the browser cache following initial download from the central server.

The client was capable of offline operation through HTML 5 standards and all data collected during offline operation was stored in browser cache until it was synced to the central server once connection was re-established. The default cache size was set at 5mb and could be increased from the browser settings if needed. In line with the agile development concept, only the core elements were created initially. This meant that the reporting engine was slated for later development. Figure 2.2.4 illustrates the basic system architecture.

Figure 2.2.4 Basic system architecture

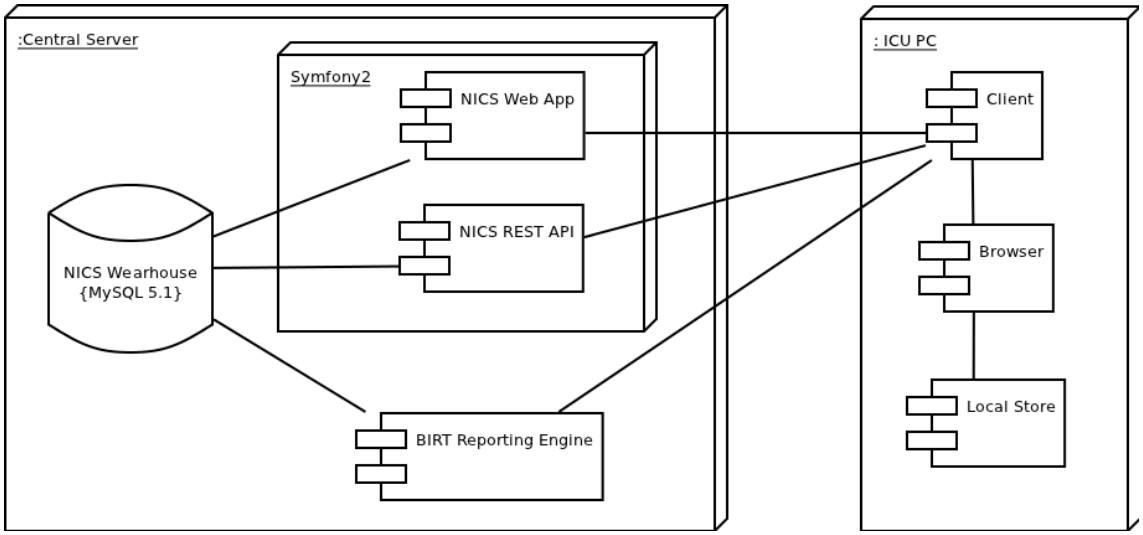


Table 2.2.1 Characteristics of software

Characteristics	**Number of fields in form (Percentage%)**				
Type of field	**Admission**	**24 Hour**	**Daily**	**Discharge**	**Bed**
Free numeric text	7 (15.2%)	22 (57.9%)	0	0	18 (100%)
Drop down	6 (13.0%)	9 (23.7%)	0	2 (33.3%)	0
Radio buttons	24 (26.1%)	6 (15.8%)	12 (100%)	2 (33.3%)	0
Date and time	3 (6.5%)	0	0	2 (33.3%)	0
Free text	6 (13.0%)	1 (2.6%)	0	0	0
Total	46 (100%)	38 (100%)	12 (100%)	6 (100%)	18 (100%)
Approximate time taken to fill the form	10 minutes	10 minutes	5 minutes	2 minutes	2 minutes

Figure 2.2.5 Admission screen of definitive software (the information shown is test data)

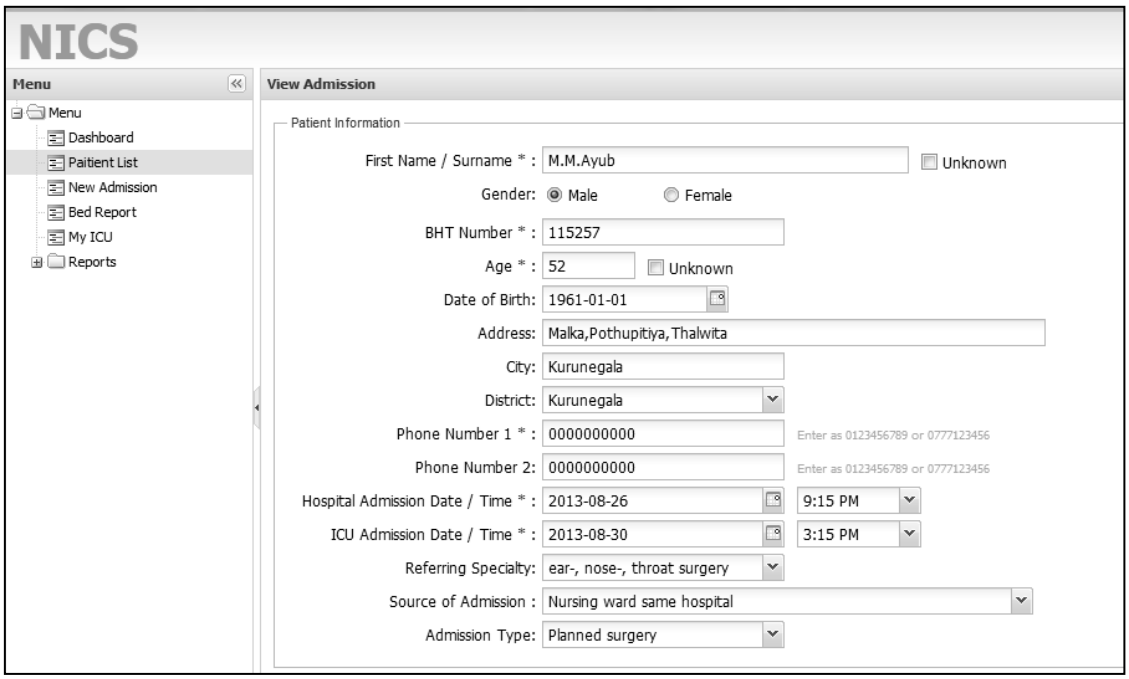
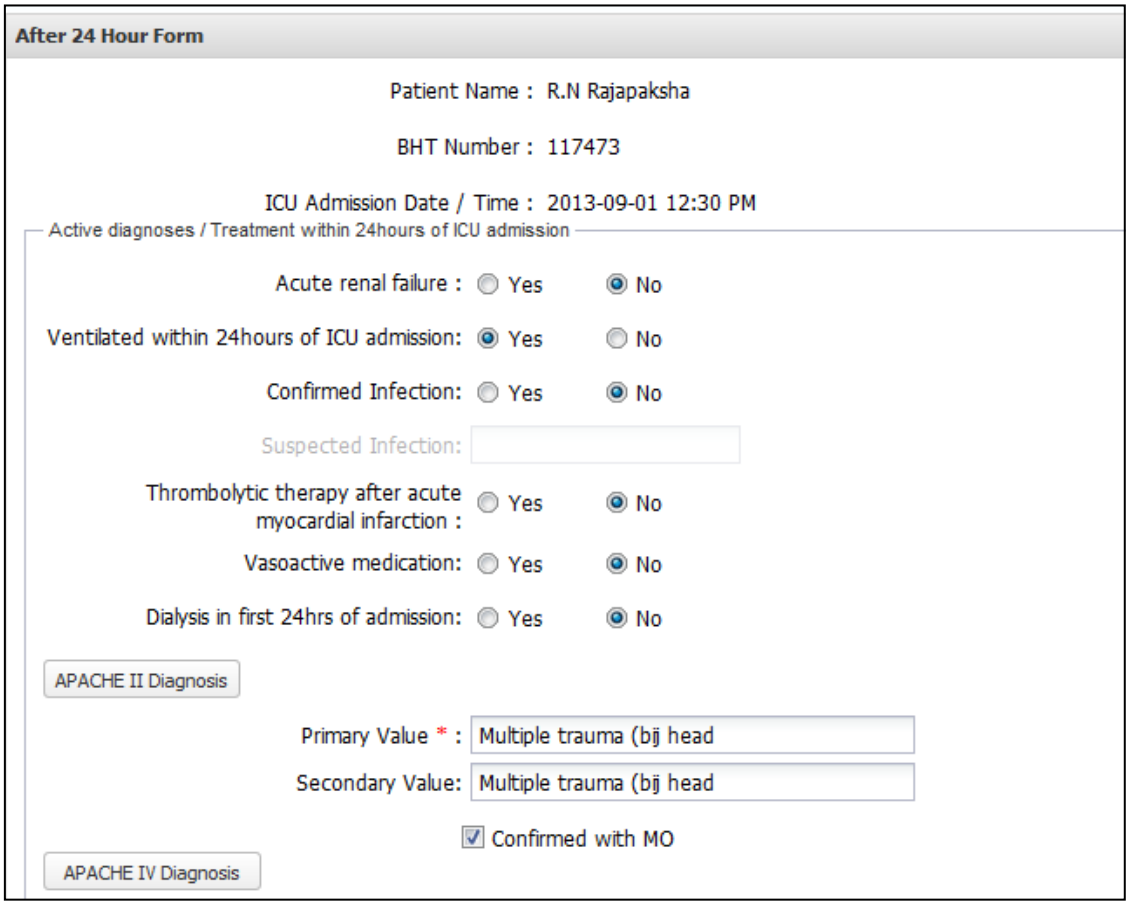


Figure 2.2.6 24 hour screen of definitive software (the information shown is test data)



Data security was ensured by partnering with the ICTA who provided secure hosting for the database management system. Access for the ICUs was via a virtual private network. The servers-side components were hosted by ICTA, and data collected by the system was curated in a manner similar to other sensitive government data. The data flow was mainly unidirectional; from the ICUs to the central data-warehouse.

Data was stripped of personal identification details. ICUs could only access data entered by their own unit, and permission to do so was granted on a case-by-case basis. These measures were implemented in response to concerns regarding large-scale data downloads and abuse of data by individuals with access to the system.

The Symfony Guard plugin was used to create module and role-based access controls. Login details are communicated through HTTPS for enhanced transport-level security and the passwords themselves are securely stored by adding a 32byte salt to each before hashing them with SHA1.

All data communicated by the ICU clients is filtered for SQL injections before storage. In addition, to prevent cross-site-scripting (XSS) attacks, all user-entered data is subjected to a data-escaping process configurable by the system administrators. Escaping of special characters before page creation was used as the default method. To prevent cross-site request forgery (CSRF), all forms used in the system were designed to contain CSRF tags also known as Cookie-to-Header tokens.

Audit logs of the system captures all changes made for a given set of records along with the date, time, and the name of the user responsible for the change. Audit history is stored in tables using the MySQL archive engine and can be viewed by administrators when necessary. Figure 4 illustrates the high-level architecture of the system.

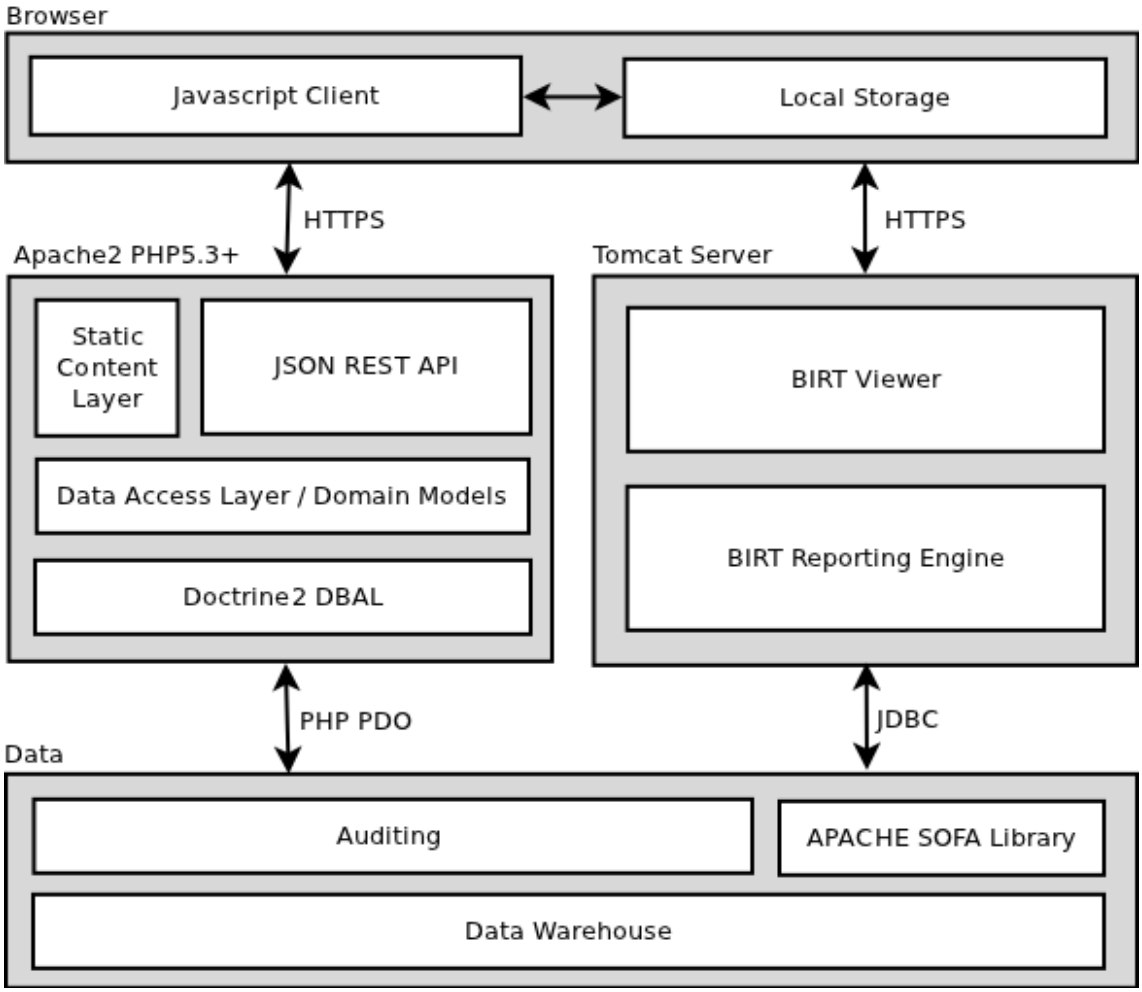
The following equipment was procured for implementation.

Table 2.2.2 Equipment procured and utilised for the NICS network

Equipment type	**Number**
ICUs	
Desktop computers	67
Dongles	79
Telephone lines	57
ADSL Modems	55

NICS Office	
Desktop computers	07
Telephone lines	02
Fax machine	01
Wireless ADSL Modems	01
Dongles	02

Figure 2.2.7 High level architecture of the system



2.2.3 Data processing

All units were provided with data dictionaries (Appendix C) and training for the data collectors. During the initial rollout data validators employed by NICS contacted the ICUs daily to validate data including checking for inconsistencies and errors.

The software does not allow incomplete forms to be saved; ICUs could denote “not available” or “not measured” when appropriate. In order to improve compliance, NICS called each ICU and recorded the admissions, discharges and deaths; any prevailing issues that prevented the ICUs from using the system were also gathered.

NICS provided a data quality report for each ICU at the end of quarter (Appendix C). The collected data was analyzed and benchmarked based on APACHE II. In order to provide feedback for each unit, each unit received a report which included anonymised, aggregate data from every other ICU. This was done to ensure that unit staff and administrators could obtain a clear idea of the performance of their own unit in comparison to others, without the identity of the other units being revealed. All patient data remains confidential to its own unit, and only anonymised and grouped data is used for comparative purposes.

With the passage of time, based on feedback from the ICUs, Ministry of Health requests, and in an effort to make the data more relevant and improve accountability, publicly visible electronic dashboards with aggregate data were hosted at www.nicst.com.

2.2.4 Data collectors

During the paper-based pilot, data collection by different staff members -ICU doctors, ICU nurses, non-ICU nurses and nursing students- was explored. Each unit could nominate any member(s) of staff to perform data entry. However, it was

anticipated that it would predominantly be the ICU nurses who would be best placed for data entry. Representations were made with administrators and senior staff to consider whether data collection should be part of the staff's routine duties. The close collaboration between registry initiators, the Ministry of Health, the national nursing union (Sri Lanka Nursing Council) and the national postgraduate nursing school (Post Basic College of Nursing) was crucial in securing this agreement. A national critical care nurse training program (Section 5.3) was also introduced to incentivize this partnership[38, 39].

2.2.5 Data ownership, collaboration and governance

From the outset, contributing ICUs retained ownership of submitted data, with NICS providing contributors with reports based on collated de-identified data. However, the ultimate ownership and governance of the data lies with the Ministry of Health, which owns and operates all state hospitals. Data could be obtained for research purposes by permission from the appropriate working and steering committees; bodies set up to oversee and guide the registry. Examples of such output are described in Sections 4.3, 4.5 and 4.7.

2.2.6 Maintenance and sustainability

Recognising the need for clinical ICU training (Section 5.1) as staff entering data for registry use are not additionally remunerated for it, NICS instituted training programs for doctors and nurses in collaboration with local and international collaborators (Section 5.3 and 5.4). The courses focused on ICU skills training for nurses across the country based on a train-the-trainer capacity building model seeking to link the registry process to this benefit. NICS also recognized that the registry network should facilitate the conduct of audits and research focused on acute and critical care as described in Section 4 of this thesis.

In addition, the registry network requires maintenance and entails recurrent

expenditure, as detailed in the following table.

Table 2.2.3 Maintenance and staffing requirements

Staffing at NICS	Staff member salaries
Maintenance of hardware at ICUs	86 Computers in working condition
Software maintenance	IT team
Telephone bill	Maintain 86 telephone connections including rentals
ADSL bills	Maintain 50+ ADSL connections
Dongle top ups	Providing top ups when necessary for the dongles in ICUs
Travel to ICUs	Travel to ICUs for training, monitoring and trouble shooting

2.3 Ethics and consent

The ICU training programme evaluation (described in section 5.2) was focused on the basic tenets of intensive care and was analogous to the continuing professional training for doctors and nurses carried out in most ICUs in HIC. No direct patient interventions were performed and no additional tests or new data collection implemented. Approval for the programme was obtained from the relevant units and institutions, and a waiver for ethical approval, was obtained from the Oxford Tropical medicine Research Ethical Committee. (OXTREC).

The peer-led training programme for newly qualified graduates (Section 5.4) was entirely voluntary, with assessments and feedback also voluntary and anonymised. All candidates had the option to opt out of their information being used for analysis and research. No further ethical review was sought.

For all other studies described in this thesis, ethical review was sought from the Ethical Review Committee of the Faculty of Medicine. The committee required individual patient consent only for the studies evaluating post discharge

outcomes after TBI (Section 4.3) and ICU experiences (Section 4.7).

For the TBI study (Section 4.3) patients were recruited while being treated in the ICUs. Informed verbal consent was obtained from those patients who were adjudged to have capacity. Capacity was determined independently by the ICU team caring for the patient. If patients did not have capacity, assent was obtained from the next of kin and the study details were explained to them. Where assent was obtained and patient thereafter recovered to have capacity, informed written consent was obtained from patients. Any patients who subsequently declined consent were to have their data retrospectively removed.

In the patients' satisfaction study (Section 4.7) eligible patients were contacted by the first author one month after ICU discharge in order to obtain informed verbal consent. As the study used a telephone administered data instrument, patients who were unable to communicate over the telephone at first contact were again contacted one week later. If the patient was still unable to communicate at this time, they were excluded from the study.

Permission to conduct the studies in Sri Lanka was obtained from the Ministry of Health, Sri Lanka and, where instructed, individually from the directors of the hospitals concerned.

2.4 Analysis

Normally distributed data were compared using the Student's *t*-test. Non-normally distributed data were compared by Mann-U Whitney test, unless otherwise specified. Categorical gender variable was compared using Fischer's exact test. *P*–values of less than 0.05 were considered significant. Statistical software used were STATA14 (STATA, USA) and SPSS 10. Prognostic model and scoring system performance was evaluated using discrimination, calibration, accuracy,

sensitivity and specificity as defined below. Missing data in prognostic models and scoring systems were imputed also as described below. The reproducibility within the test-retest method was expressed using Cohen's kappa coefficient

2.4.1 Discrimination

Model discrimination reviews the ability of the scoring model to distinguish between patients who die from those who survive, based on the predicted mortalities. Discrimination was assessed by the Area under the Receiver Operator Curve (AUROC) when reported (21). Discrimination was considered excellent, very good, good, moderate or poor with AUROC values of 0.9 to 0.99, 0.8 to 0.89, 0.7 to 0.79, 0.6 to 0.69 and ≤0.6, respectively (22, 23).

2.4.2 Calibration

Calibration assesses the degree of agreement between the estimated probability of mortality and the observed outcome, including comparisons of observed and predicted event rates for risk groups of patients. Calibration was assessed by the Hosmer-Lemeshow C-statistic (significant departures from perfect calibration were inferred when p-values were less than 0.05 (21, 23)).

2.4.3 Accuracy

Assessment of accuracy helps to verify predicted and observed events at the individual level, Accuracy was assessed by the Brier score (the mean-squared error between outcome and prediction) [40].

2.4.4 Imputation

Predictor variables that are routinely available in HICs – for example arterial oxygenation- are often not obtainable or reliable where resources are limited (7, 8). The presence of missing values, if imputed as normal (normal value imputation) as per convention (3, 4, 9-12) will lead to underestimation of the scores and mortality.

Multiple Imputation (MI) generates several values reflecting the uncertainty in the estimation of the imputed value. MICE was performed using Predictive Mean Matching (PMM) of the “mi impute chained” command in Stata (version 14, Stata Corp, College Station, TX, USA). The number of imputations (M) was set at 30 and “k-nearest neighbours” [41] was 10 [30].

3.0 A profile of acute and critical care services in Sri Lanka and suggestions for improvement

3.1 A cross-sectional survey of critical care services in Sri Lanka

3.1.1 Background

The worldwide demand for critical care services is growing and dedicated critical care units (CCUs) are ecoming increasingly available in lower income countries (LICs) and lower middle income countries (LMICs) [42]. In LICs/LMICs, partly due to geopolitical reasons (disasters, both natural and manmade) and scarce resources, the burden of critical illness exceeds existing capacity [43]. This burden comprises mainly of children and young adults, in contrast with high income countries (HICs) where older age groups predominate [43, 44]. This younger age group suffers high mortality in the LICs/LMICs, mostly caused by reversible illnesses [26]. Improving access to critical care and the quality of care can thus potentially save many lives.

Research aimed at improving critical care in LICs/LMICs is limited [27, 28, 43]. There is however, increased interest and demand for work in this area [19, 26]. A CCU registry, which collects basic patient data on disease severity and patient outcome, would provide valuable baseline information to compare quality of care between CCUs. This will be a valuable aid to initiate and evaluate quality improvement interventions [45-47]. Studies describing critical care services are a starting point for the establishment of such a CCU registry in a region or country by providing an understanding of staffing, equipment, service distribution and other similarities or differences of CCUs.

Assessing the capacity and technical levels of existing facilities through a census of CCUs is also important for planning and delivery of critical care at the

national and regional level [19, 43]. Knowledge of the distribution of critical care resources is essential for optimal use of this scarce resource [26, 43].

There have been only few detailed descriptions of CCU services at a national level in LICs/LMICs and those available do not usually cover the entire breath of such services, such as specialist CCUs, support staff and CCU equipment [44, 48, 49]. In this detailed survey we describe the extent and variation of critical care services in state hospitals in Sri Lanka.

3.1.2 Study design

A list of state hospitals was obtained from the Planning Division of the Ministry of Health [50]. All government hospitals from “base” level and above were contacted by telephone, to determine availability of a CCU in the hospital. A directory of hospitals with CCU facilities was then compiled [51].

Neonatal CCUs and CCUs of private sector hospitals were not included in our survey. Neonatal CCU facilities and distribution in Sri Lanka have already been extensively described [52]. The non-state sector CCUs were not included due to commercial sensitivity and lack of feasibility.

All CCUs catering exclusively to paediatric patients were grouped as “paediatric”. The medical subspecialty CCUs such as coronary care and neurology were categorised as “medical sub”. The surgical subspecialty CCUs such as obstetrics, neuro surgery, neuro trauma, accident service, cardio thoracic and dental were categorised as “surgical sub”. The General CCUs accommodate both medical and surgical patients.

We designed a data extraction sheet (see Supplementary File 3.1.2) to obtain information about the following broad areas:

1. The demography of CCUs (including hospital type, administration, supervision, specialism, etc.)
2. The availability of facilities including equipment for monitoring, treatment and communication (desktop computer, telephone and internet connectivity)
3. The staffing: consultants (specialists), non-specialist doctors, nurses, allied health staff and services accessible
4. Patients: sources, types, numbers and overall CCU outcomes (for 2010 and 2011 from admission and discharge register in the CCUs)

The data collection tool was pre-tested in 5 CCUs and feedback from users was incorporated in the final version. Data collection was performed by a trained pre-internship doctor during January and February of 2011, from the Sister/Nursing Officer in charge of the CCU, either through personal visits (13 CCUs in Northern and Eastern Provinces and 15 CCUs in the National Hospital of Sri Lanka) or by telephone (71 CCUs). The overall CCU outcomes for 2011 were collected separately during the first week of January 2012.

The quality of the data collected was validated by the “test retest” method. Three months after completion of the survey, 10 randomly chosen CCUs were contacted by telephone and eleven selected fields from the study tool were re-surveyed and compared with the initial assessments, which were not disclosed to those contacted. We were aware that some parameters were likely to change, e.g. staff numbers. The original data was used for analysis.

3.1.3 Results

We identified 99 CCUs among 50 hospitals at the time of the survey and information was obtained from all units (response rate 100%). Four CCUs did not

have admissions and deaths recorded separately since these units were functioning as part of larger general wards. The admission and deaths for these CCUs were thus not obtained. All available data was used in the analysis.

The Cohen's kappa coefficient of the data items collected after test retest method was >0.94 (see Table 3.1.2).

Table 3.1.1 summarizes the main characteristics of CCUs. The distribution of CCU functionality (total and per population 100,000) by province is described in Table 3.1.2.

A total of 75 (75.8%) CCUs were managed directly by the Ministry of Health at national level, with the remainder being administered by various provincial authorities, as part of devolution.

On average, there were 2.5 CCU beds per 100,000 population (total number of CCU beds in Sri Lanka divided by total population of Sri Lanka, ranging from 0.89 to 4.42 between provinces), and 13 CCU beds per 1000 hospital beds. The median number of beds per CCU was 5 (range 2 to 10). Larger CCUs with seven beds or more were concentrated in the Western, Southern and Central Provinces. On average, tertiary hospitals had 17 CCU beds per 1000 hospital beds, while base hospitals had 7 beds per 1000 hospital beds, and provincial and district general hospitals 12 beds per 1000 hospital beds.

The overall bed turnover (defined as the number of admissions per bed per year) was 76.5. According to type of CCU, the lowest turnover was in the neurological CCU (31.4) and highest in the coronary care units (146). The overall number of CCU admissions per 100,000 population per year was 194 (range 87.7 to 348.8 between the provinces).

Overall CCU mortality was 17% with mortality in medical CCUs being significantly

higher ($p<0.001$) than surgical CCUs. General CCUs (mixed medical and surgical) had a mortality rate significantly lower ($p<0.05$) than Medical CCUs, though the proportion of medical/surgical admissions in these CCUs is not known.

The lowest mortality rate was observed for Obstetric CCUs (1.6 %). Surgical CCUs with emergency surgical admissions (trauma and other emergency services) had higher mortality (27.2%). Within the surgical CCUs, the mortality rate was highest in patients with neuro trauma (21.6%) or those who underwent neuro surgery (21.8%). In medical CCUs the highest mortality was observed in neurological patients (24.2%).

Staffing

A majority (72,72.7%) of CCUs were headed by a consultant anaesthetist. An anaesthetist was head in 33/35 (94.3%) of the general CCUs and 9/10 (90%) of the surgical CCUs. A consultant physician was head in 6/10 (60%) medical CCUs while in all 6 medical sub-specialty CCUs the consultant in the relevant sub-specialty was the head.

There was a total of 790 non-specialist doctors employed in the surveyed CCUs (1.6 per bed, range 1.34 to 2.25 between provinces). There were a total of 1989 nurses, (3.9 per bed, range 2.17 to 4.87 between provinces), and 626 healthcare assistants/“attendants” (1.2 per bed, range 0.71 to 1.65 among provinces). There was a “nursing sister” (specially trained clinical nurse manager) as “in charge” CCU nursing officer in 52 (52.5%) of the surveyed CCUs.

In a majority (87, 87.9%) of CCUs, the nurse to patient ratio was at least 1:1, while 11 (11.1%) CCUs had a ratio of 1:2, and one CCU a ratio of 1:3.

With regard to the training level of nursing staff, 226 (11.4%) of nurses had

received formal ICU training while 56 (56.6%) of “nurses in charge” had received similar training. The majority (114, 48.2%) of trained nursing staff were in the Western Province. Surprisingly, tertiary hospitals, in comparison, had the lowest proportion of nurses with formal ICU training (134, 10.6%).

Self-declared participation in continuous professional development activities during the last six months by CCU nursing staff was 265 (13.3%) and by healthcare assistants 49 (7.8%). Figures for doctors were not collected.

Available facilities

All CCUs had electricity, running water, oxygen cylinders, pulse oxymetry, wall based suction units, multi parameter electronic monitors, electrocardiogram (ECG) monitoring, thermometers and electric infusion pumps as part of their facilities. All CCUs were equipped with ventilators (as this was an inclusion criterion for the study) and a ventilator:bed ratio of 1:1 was observed in 62 (62.6%) of the CCUs.

Table 3.1.3 describes the availability of paramedical staff/support staff in the CCUs. In allied health services, more than 75% of CCUs had ECG and radiology technicians providing around the clock coverage.

Table 3.4 describes the equipment available in the CCUs. Blood gas machines were available in 65 (65.6%) of CCUs, of which 48 (72.7%) could measure haemoglobin levels, while only 27 (40.9%) could measure lactate. When communication facilities were considered (important for the development of an emergency bed system and CCU registry); 46 (46.5%) CCUs reported access to a computer of some description and 23 (23.2%) had a direct telephone line. There were four CCUs reporting an asymmetric digital subscriber line (ADSL) for internet connection.

Table 3.1.1 The demography of intensive care units by selected factors

Demography	No. of Critical care units (%)	No. of Functioning Beds (%)	2010				2011			
			No. of Admissions (%)	No. of Deaths (%)	Mortality rate[a]	A/B[b]	No. of Admissions (%)	No. of Deaths (%)	Mortality rate[a]	A/B[b]
Hospital category										
Base Hospital	23 (23.2)	91 (17.9)	6004 (15.4)	1413 (21.3)	23.5	65.9	5858 (15)	1491 (22.5)	25.5	64.4
District Hospital	9 (9.1)	44 (8.6)	3879 (10)	871 (13.1)	22.4	88.1	3464 (8.9)	713 (10.8)	20.6	78.7
Provincial Hospital	05 (5.1)	26 (5.1)	2386 (6.1)	457 (6.9)	19.1	91.7	2172 (5.6)	402 (6.1)	18.5	83.5
Tertiary (Mixed)	49 (49.5)	281 (55.2)	22145 (56.9)	3341 (50.4)	15.1	78.8	22756 (58.5)	3479 (52.5)	15.2	80.9
Tertiary (Special)	13 (13.1)	67 (13.2)	4512 (11.6)	549 (8.3)	12.2	67.3	4680 (12)	545 (8.2)	11.6	69.8
Total	99 (100)	509 (100)	38926	6631	17.0	76.5	38930	6630	17.0	76.5
CCU Category										
General	35 (35.4)	169 (33.2)	13589 (34.9)	2791 (42.1)	20.5	80.4	13390 (34.4)	2829 (42.7)	21.1	79.2
Medical	10 (10.1)	52 (10.2)	4075 (10.5)	1154 (17.4)	28.3	78.3	3865 (9.9)	1097 (16.5)	28.4	74.3
Surgical	10	56 (11.0)	4792 (12.3)	705	14.7	85.5	4684 (12)	699	14.9	83.6

	(10.1)			(10.6)				(10.5)		
Paediatric	11 (11.1)	64 (12.6)	3797 (9.8)	598 (9)	15.7	59.3	3868 (9.9)	556 (8.4)	14.3	60.4
Medical sub	6 (6)	41 (8)	5170 (13.3)	484 (7.3)	9.3	126.1	4958 (12.7)	471 (7.1)	9.5	120.9
Surgical sub	27 (27.3)	127 (25)	7503 (19.3)	899 (13.6)	11.9	59.1	8165 (21)	978 (14.8)	11.9	64.3
Total	99 (100)	509 (100)	38926	6631	18.7	76.5	38930	6630	17.0	76.5

[a]Number of deaths per 100 admissions per year, [b]Admissions per bed per year.

Table 3.1.2 Functionality of CCUs by Province (total and per population 100,000)

Province	Critical care units (Total)	Functioning Beds (Total)	Ventilators (Total)	2010				2011			
				Admissions (Total)	Deaths (Total)	D/A[a] (Total)	A/B[b] (Total)	Admissions (Total)	Deaths (Total)	D/A[a] (Total)	A/B[b] (Total)
Western	0.799(43)	4.42 (238)	3.74 (202)	342 (18402)	57.5 (3094)	0.32 (17.1)	1.48 (79.6)	348.8 (18771)	55.4 (2979)	0.31 (16.9)	1.52 (81.8)
Southern	0.483 (11)	2.15 (49)	2.19 (50)	87.7 (1998)	16.2 (370)	0.86 (19.6)	2.62 (59.6)	100.3 (2284)	17.2 (393)	0.87 (19.8)	2.57 (58.5)
Central	0.619 (15)	3.05 (74)	3.05 (77)	262.5 (6362)	43.6 (1058)	0.88 (21.4)	3.23 (78.2)	265.4 (6434)	45.8 (1109)	0.81 (19.7)	3.43 (83.2)
Sabaragamuwa	0.167 (3)	0.89 (16)	1.05 (19)	140 (2522)	15.6 (281)	1.02 (18.4)	8.88 (159.8)	147.7 (2660)	15.7 (283)	1.00 (18.0)	9.47 (170.6)
Uva	0.425 (5)	1.95 (23)	2.38 (28)	132.5 (1560)	25 (294)	1.70 (20.0)	5.72 (67.3)	126.9 (1494)	30.6 (360)	2.19 (25.8)	5.33 (62.8)
North Western	0.277 (6)	1.52 (33)	1.34 (29)	137.5 (2983)	20.9 (454)	0.83 (18.0)	4.12 (89.4)	122.3 (2653)	23.4 (507)	0.99 (21.4)	3.60 (78.2)
North Central	0.453 (5)	2.08 (23)	1.18 (13)	123.5 (1364)	24.8 (274)	1.56 (17.2)	6.08 (67.2)	113.6 (1255)	23.4 (259)	1.58 (17.4)	5.76 (63.6)
Eastern	0.389 (6)	1.88 (29)	1.94 (30)	147.3 (2275)	32.3 (499)	1.46 (22.6)	5.00 (77.2)	127.8 (1974)	30.0 (463)	1.72 (23.6)	4.29 (66.2)

Northern	0.436 (5)	2.09 (24)	1.48 (17)	127.4 (1460)	26.8 (307)	1.62 (18.6)	4.94 (56.6)	122.6 (1405)	24.2 (277)	1.65 (18.9)	5.04 (57.8)

[a]Number of deaths per 100 admissions per year, [b]Admissions per bed per year

Table 3.1.3 Availability of paramedical staff / support staff in the critical care units[c]

Categories of paramedical staff / support staff	**Number of CCUs (n=99)**	**Percentage %**
Access to a physiotherapist (24 hours)	66	66.7
A dedicated ICU physiotherapist	91	91.9
Access to ECG technician (24 hours)	74	74.7
Radiology technician for portable X ray (24 hours)	81	81.8
Bio medical technician in the hospital	80	80.8
Dietician / Diet Clark (hospital)	88	88.9
CCU allocated cleaning staff	78	78.8

Table 3.1.4 Equipment available in the critical care units[c]

Types of machines (n=99)	Number of CCUs	Percentage %	Per bed availability
Blood gas machine available within the unit	65	65.7	
USS machine available within the unit	05	05.1	
Echo machine available within the unit	07	7.1	
Bronchoscope accessible in the unit	03	3.0	
Difficult or specialized airway trolley available in the unit	89	89.9	
Visible and audible alarms at each bed side	82	82.8	
Integrated monitor system present at central nursing system	06	06.1	
Availability of telephone (internal/intra hospital)	97	98.0	
Availability of emergency call system	06	6.1	
Paediatric ventilators / Paediatric mode	69	69.7	
Ventilators	99	100	0.91
Electrocardiogram (ECG) Monitoring	99	100	1.03
Infusion pump / Syringe pump	99	100	3.09

Electric power source	99	100	1.49
Wall suction / Vacuum	99	100	0.67
Pulse oximetry	99	100	0.99
Non-invasive blood pressure monitoring	99	100	1.02
Multi-parameter Monitor	99	100	1.06
Piped oxygen supply	88	88.9	0.96
Suction machines (portable)	68	68.7	0.43
Capnography	65	65.7	0.33
Invasive arterial pressure monitoring ability	46	46.5	0.39
Central Venous Pressure (electronic)	33	33.3	0.27
Cardiac output monitor	09	9.0	0.08

Table 3.1.5 Comparison of Sri Lankan critical care resources with other LICs/LMICs

Country	CCU Beds (per 100,000)	% of total hospital beds	Admissions (per 100,000)	Intensivist (% of CCU) [per CCU]	1:1 nurse care [nurses per bed]	Trained nurses	Mixed CCUs	Ventilators (% of CCU)	Mortality
Sri Lanka	2.5	1.3%	194	–[d]	87.9% [3.9]	11.4%	35.4%	100% [e]	17%
India	–	5%–8%	–	–	–	–	–	–	–
Dhaka (Bangladesh)	7.9	4.8%	–	12%	42%	36%	68%	100% [e]	–
Kathmandu (Nepal)	15.2	4.7%	–	–	4.2%–8.3%	–	62.4%	93.8%	–
China	3.9	1.8%	–	[6.4 per ICU]	[1.37–2.02]	–	34%–65%	–	13.1%
Mongolia	20.1	–	26.2	42.9%	[1.5]	–	52%	52.4%	10%
Zambia	0.2	0.4%	1.4	20%	[1.1]	–	-	50%	20.5
Malaysia	2.4	1.5%	116	8.3%	13%–21.2%	<33%	83%	–	–

[d]-Not determined, as only base specialty noted.

[e] All CCUs had a ventilator, as CCUs were defined as critical/intensive care units with ventilators

3.1.4 Discussion

Our comprehensive survey of CCUs in Sri Lanka, a LMIC in the Indian subcontinent, demonstrates that critical care facilities are widespread in Sri Lanka (with inequalities in distribution) and are better than many other LMICs [12, 44, 49, 53-55]. The island nation with impressive public health indices [56] recently emerged from a prolonged and brutal military conflict. The country's Gross Domestic Product per capita for 2011 was US $ 2,836 [57].

Critical care services commenced in Sri Lanka in 1968 [58], which is not long after they were first established in HICs [59] and have expanded rapidly since then [4, 58]. Over the past 50 years, CCUs have developed rapidly with nearly 100 units by the year 2011. Unlike many other LMICs in Sri Lanka the vast majority of in-patient health care including critical care is provided by the state sector free of charge at the point of delivery [53, 54, 57]. This achievement, though impressive, has implications for the health care burden borne by the state, as the need and pressure to expand these services increases.

State hospitals in Sri Lanka are classified according to their level of care, ranging from Teaching Hospitals through District General Hospitals and Base Hospitals down to Rural Hospitals and Peripheral Units. Tertiary care hospitals are teaching (University affiliated) hospitals with tertiary referral centers. Base Hospitals have consultant level specialist doctors in the four major disciplines: internal medicine, surgery, paediatrics and gynaecology/obstetrics. Critical care units are only present in hospitals with consultant or specialist doctors (base level hospitals and above) as per state policy.

A system monitoring the CCU bed availability centrally is not reported in LICs/LMICs and Sri Lanka is no exception. Further, though most CCU beds are

owned by the state, there has been no national CCU network to facilitate the emergency location of the closest available critical care bed should the need arise. Adikari et al report that “even in the developed world, epidemiological data for availability of CCU beds are sparse” [43].

CCU registries are well established in HICs, and in high middle income countries (HMICs) such as Malaysia [47, 60]. However, registries and critical care bed availability systems are less common in resource poor countries [61-63]. No such system has existed so far in Sri Lanka. In this detailed survey we described the extent and variation of critical care services in Sri Lanka as a first step towards the development of an emergency CCU bed capacity system and national clinical registry.

The overall CCU bed capacity was 13 CCU beds per 1000 hospital beds (1.3%) with 2.5 CCU beds per 100,000 population. These numbers compare favourably with other LICs, LMICs and HMICs as shown in Table 5 [44, 49, 53-55, 64, 65]. In Latin American countries this ranges from 1.8 to 29 while in Europe this varies between 5.38 and 29.2 [66, 67]. These figures for Australia, New Zealand and USA were 8, 4.8 and 20 respectively [68, 69].

In common with other LICs and LMICs, most CCUs in Sri Lanka are general units [49, 53-55, 64]. However, in contrast with most other LMICs, Sri Lanka has a wide array of specialty CCUs, comparable with HICs in Europe and the USA [70].

Most CCUs in Sri Lanka were managed by anaesthetists, which is similar to other Asian settings [53-55, 65]. In HICs, intensive care medicine has developed as a separate specialty, with dedicated intensivists in charge of the majority of CCUs in the USA (53%), Australia and Europe [68, 70, 71]. There is now a

dedicated local post graduate program, in critical care, for advanced trainees in anaesthesia and medicine (physicians) which can be expected to move Sri Lanka towards the same profile.

A ratio of 1.6 non-specialist doctors per CCU bed is a striking finding in our study and compares very favourably with other HMICs and HICs [65, 68, 70, 71]. However, we are aware that some doctors working in CCUs are trainees in a base specialty (medicine, anaesthesia, emergency medicine) and may be rotating amongst other clinical areas simultaneously. Others are non-specialist doctors who are exclusively assigned to CCUs. Further study in this area is justified,

In Sri Lanka a large proportion of CCUs have nurse to patient ratio of 1:1, which is better than most other LICs/LMICs in Africa and Asia, [44, 49, 53-55, 64, 65] and is similar to Australian, New Zealand, European and American advanced critical care units [68, 70, 71].

In Sri Lanka, similar to other LICs/LMICs, the participation for CCU training and continuous professional development by nursing staff was poor (13.3%) [49, 54, 64], though there are efforts to address this by improving CCU training of nurses centrally [72]. A higher proportion of nurses trained in critical care are based in the Western Province. This presence of a higher proportion of CCUs in the Western Province, which includes the political and commercial capitals, and is the most populous, is a possible explanation. The presence of most of the specialist CCUs (such as neuro surgery, neuro trauma, cardio thoracic) in the Western Province, maybe another contributing reason. This concentration of critical care services towards the Western Province is a recurring theme in our findings.

Compared to most other LICs/LMICs most Sri Lankan CCUs (and associated hospitals) have a higher proportion of allied health staff important for high quality care, such as physiotherapists (91.9%), ECG technicians (74.7%), radiology technicians (81.8%) and dieticians (88.9%) [44, 49, 53-55, 64]. This is a very promising finding and efforts should be made to further promote multi-disciplinary care in the CCUs and research directed to identify how these services can be protected and enhanced.

All CCUs had essential infrastructure (electricity, running water, oxygen cylinders) and basic medical equipment (pulse oxymetry, wall suction units, multi parameter electronic monitors, ECG monitoring, thermometers and electric infusion pumps). However, more sophisticated equipment, such as bedside ultrasound, blood gas machines, invasive arterial/venous pressure monitoring ability, and capnography were less widely available.

The overall crude CCU mortality in Sri Lanka was 17%. Though this is comparable to other HICs, the mortality figures reported by LICs/LMICs are often prone to inaccuracies due to the absence of systematic process of data collection [70]. Mortality figures are also limited to CCU outcomes as opposed to hospital or 28 day outcomes. In addition, mortality rates will be influenced by the severity of illness on admission and the facilities available in the CCUs. This probably explains the lower mortality we observed in patients in surgical CCUs, which accommodate patients after elective surgery in comparison with CCUs of surgical subspecialties, which admit complex multiple trauma victims requiring emergency surgery. Unfortunately, severity of illness data was not available and hence case-mix corrected mortality in this instance could not be calculated. This is an area justifying further detailed investigation.

Our study is unique amongst surveys performed in LICs/LMICs in considering all state CCUs in the country thus removing selection bias. All identified CCUs cooperated in providing information and all data was collected by a single data collector avoiding inter observer variation [44, 49, 53, 54]. The high repeatability observed in the “test re-test” method (high kappa coefficient) supports the reproducibility of the data gathered, even if not guaranteeing the accuracy of the extracted data, allowing policy makers and others to use these results with increased confidence.

Two previous surveys conducted in Sri Lanka in 2004 and 2011, with different study aims, while excluding paediatric and subspecialty CCUs, were restricted to 49 and 51 CCUs [3, 4]. The survey from 2004, but not the one from 2011, identified similar distributions of CCUs among different hospital categories and mean bed strength of CCU. The comprehensiveness of our survey is important in the context of establishing services to improve accessibility and for quality improvement.

3.1.5 Conclusions

Our study gives a comprehensive description of the spectrum of critical care services in a LMIC and demonstrates that the availability of resources (staffing and material) for critical care is better in Sri Lanka, when compared to many other LICs/LMICs [44, 49, 53-55, 64] State critical care services are widespread, but with inequalities in their distribution. We believe our study highlights important areas for further investigation, locally and internationally, and provides important baseline information.

3.2 Outcomes following cardiopulmonary arrest and availability of clinical observations in a LMIC DGH.

3.2.1 Background

In High Income Countries (HIC's) Early Warning Systems (EWS) have been implemented to assist clinical teams detect patient deterioration with varying degrees of ability to stratify at risk populations [73-77][1–5]. Seven measures remain central to such systems[78, 79]; respiratory rate, urine output, saturation, temperature, systolic blood pressure, heart rate and a measure of mentation such as AVPU or GCS[75, 80]. In HIC's, EWS are increasingly mandatory and are often accompanied by training for nurses in the acute care skills to respond in the event of clinical deterioration or cardiac arrest [75, 80, 81].Even though evidence of the impact of such systems on improving outcomes is difficult to interpret, their importance on the process and delivery of care is increasingly acknowledged [82, 83].

In Sri Lanka, as in most LMIC's, EWS are not in use; though there is increasing interest in adopting tools designed and validated for use in HIC's[83, 84]. However in LMIC's outcomes for in-hospital cardiac arrest are largely unknown[85] availability of critical care remains limited, and dedicated cardiac arrest teams uncommon [36, 37, 58, 86][14-17, 18].Healthcare services are often overcrowded, and poorly resourced, making the systematic and accurate monitoring of vital parameters required to calculate multi-parameter scores impractical, and difficult to implement[87, 88][19,20].Despite on-going efforts to address inequalities, training for frontline staff in practical skills to recognise the deteriorating patient remains limited[39, 84].Understanding the current practices regarding observation reporting and response to deterioration is a necessary step

in evaluating the feasibility of EWS implementation in a LMIC setting

3.2.2 Study aim

This study describes the practices of observation reporting and the recognition and response to presumed cardiopulmonary arrest in a LMIC.

3.2.3 Design

This retrospective study was carried out at District General Hospital (DGH) Monaragala, Sri Lanka. All adult patients who had cardiac arrests and were reported to a nurse responder were included. Availability of 7 physiological parameters commonly recorded as part of EWS (described above), were analysed at admission, and at 24 and 48 hour time points leading up to the cardiac arrest [76]. Figures for total hospital deaths were extracted from the hospital register of deaths.

3.2.4 Results

There were a total of 393 and 417 adult deaths in the study setting in 2013- 2014 respectively. A total of 173 patients were reported to the nurse responder during the 18 month study period, of whom 150 were 18 years or older. Availability of parameters is described in table 3.2.1.

Table 3.2.1 Availability of EWS variables

Physiological variable	Availability (%)		
	Admission	**24 hrs prior**	**48 hrs prior**
	n=150	n=95	n=96
Respiratory rate	44(29.3)	10 (10.5)*	9 (9.4)
Urine output	52 (34.6)	20 (21.1)*	16 (16.7)
Saturation	86(57.3)	19 (20.0)*	9 (9.4)*
Temperature	89(59.3)	32 (33.7)*	28 (29.2)
Systolic (or diastolic BP)	106(70.6)	33 (34.7)*	27 (28.1)
Heart rate	108(72.0)	33 (34.7)*	27 (28.1)
AVPU	0 (0)	0 (0)	0 (0)

Availability of 6 parameters (excluding mentation) was significantly higher at admission ($p<0.05$) than at 24 and 48 hours prior to cardiac arrest. Mentation was not reported in any patients as part of admission observations. When availability at 24 hours prior to cardiac arrest was compared to 48 hours, only recording of saturations was significantly higher ($p<0.05$) at 24 hours prior to arrest.

Patients in this DGH had a 49.3% immediate Return Of Spontaneous Circulation (ROSC) and 35.3 % survival to hospital discharge. 48.6% of patients who had ROSC did not receive post-arrest intensive care. Intubation was performed in 46 (62.2%) of the patients who went onto have ROSC compared with 28 (36.8%) with no ROSC ($p<0.05$). Defibrillation, performed on 8 (10.8%) of the patients who had ROSC and 8 (10.5%) whom did not, was statistically insignificant

(p=0.995). Adrenaline was administered in 38 (51.4%) of patients who had ROSC, which was significantly lower ($p<0.05$) when compared to 60 (90.8%) in patients for whom there was no ROSC.

3.2.5 Discussion

This study highlights the incompleteness and limited frequency of observations in ill patients in this setting. The availability of 6 observations (except assessment of mentation) was significantly higher at admission compared to 24 and 48 hours prior to cardiac arrest. In common with other settings [89] respiratory rate had the lowest availability with under 30% being recorded even at admission.

Aggregate weighted EWS's usually require the availability of at least four parameters. As these EWSs are also used as trigger and track tools, frequency of parameters being observed affects the system's ability to detect. LMIC settings are known for incompleteness and unavailability of patient observations with a multitude of contributory factors [89, 90] Large proportions of missing observations in even one parameter used in a EWS, will lead to the particular parameter being imputed as normal, causing inappropriately low scores being generated. Unavailability of many of the component parameters is likely to completely disable EWS implementation.

Defibrillation featured in only 10.6% of resuscitation attempts and was not associated with increased survival. The low use is in keeping with the majority of in-hospital cardiac arrest rhythms to be non-shockable on presentation [91, 92] however poor availability of equipment and limited training for frontline staff in practical application may be confounding factors [84, 87, 88]. Adrenaline use was inconsistent with resuscitation guidelines highlighting the limited opportunity for resuscitation training [39, 84].An EWS in this setting will need to consider utilising

measurements with the greatest availability in this setting (for example heart rate and systolic blood pressure). Such a trigger system, at least initially, may need to be based on admission observations and on a single parameter as opposed to an aggregate weighted system.

3.2.6 Conclusion

Observations commonly used to detect deterioration are poorly reported and reporting practices would need to be improved prior to EWS implementation. Cardiac arrests are poorly reported. Adrenaline use was not consistent with advanced life support guidelines. These findings reinforce the need for training in acute care and resuscitation skills for health care teams in LMIC settings as part of a programme of improving recognition and response to acute deterioration.

3.3 Cardiopulmonary resuscitation practices in Sri Lanka; a national cross sectional survey

3.3.1 Background

Resuscitation following cardiac arrests occurring either as an end of life event, or after maximal treatment are unlikely to be successful, and may result in loss of patient dignity and futility [93-95]. In such situations, pro-active Do Not Attempt Cardio Pulmonary Resuscitation (DNACPR) orders are increasingly being used in High Income Countries (HICs) [96-99]. National data from Sri Lanka, a low-middle income country, indicates that the majority (87%) hospital deaths are preceded by resuscitation [100].

This suggests that some patients, for whom the likelihood of survival is minimal,

are receiving futile and unnecessary resuscitation attempts. Recent data from Intensive Care Units in low and middle income countries (LMICs) suggests formal DNACPR orders remain uncommon [95].

3.3.2 Study aim

This study reports on the results of a survey, in adults in acute hospital ward settings across Sri Lanka, to establish the characteristics of resuscitation attempts, immediate outcomes after cardiac arrest and DNACPR usage.

3.3.3 Study design

A cross-sectional survey was conducted in all adult general wards in Sri Lanka hospitals where medical or surgical patients are treated under the care of specialist (consultant) doctors (n=90). Specialty specific wards such as Obstetrics and Gynaecology were not included.

Wards were contacted by telephone. In each ward, a house officer (HO, a junior doctor undergoing internship training) was invited to participate in an anonymous, short, structured interview describing resuscitation attempts for which they were present, during their previous shift. These doctors typically cover shifts consisting of a day, followed by a night on call, followed immediately by a day shift. House officers in Sri Lanka are allocated to one ward for several months and invariably participate or lead in-ward resuscitation following cardiac arrest. Calls were made by the investigators and were repeated if the HO's were unavailable on initial contact. Responses were electronically collated.

The survey tool consisted of questions to determine the number of deaths in the ward, attempted resuscitations and their outcomes, post resuscitation status and prevalence of DNACPR orders. For each resuscitation attempt where the HO participated, the survey explored the objective practices of; defibrillation,

intubation, use of adrenaline, post resuscitation care and whether a senior doctor was contacted during the resuscitation attempt. Further questions ascertained the extent of surprise felt by the doctor regarding the event and the perceived probability of success following attempted resuscitation.

Descriptive analysis was undertaken based upon the characteristics of resuscitation attempts associated with the chain of survival. The study was conducted in collaboration with the Government Medical Officers Association, Ministry of Health and NICST.

3.3.4 Results

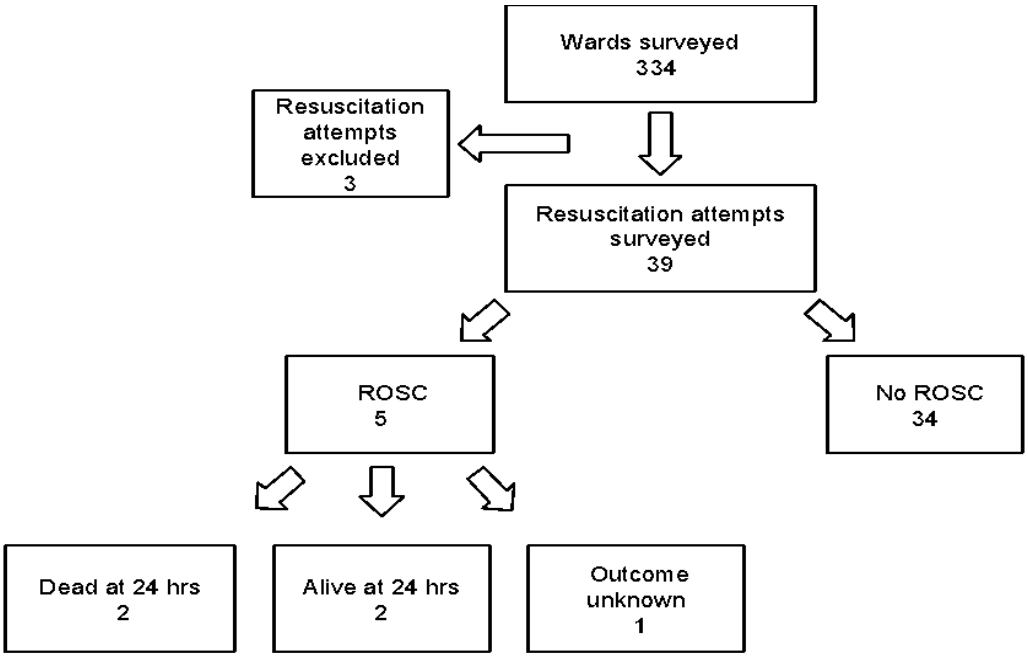
During the survey, 82 of the 90 target hospitals were successfully contacted. A total of 336 adult general wards in these 82 hospitals were contacted. HO's in two wards declined to participate. Study findings are summarised in figure 3.3.1 and table 3.3.1.

Table 3.3.1 Characteristics of resuscitation attempts.

Characteristics of resuscitation attempts (n=39)	Number	Percentage %
Alerted by:		
Staff member	26	66.7
Visitor / family member	11	28.2
Other	2	5.1
Family member(s) present during CPR:		
Present	29	74.3
Not present	10	25.6
Defibrillation:		

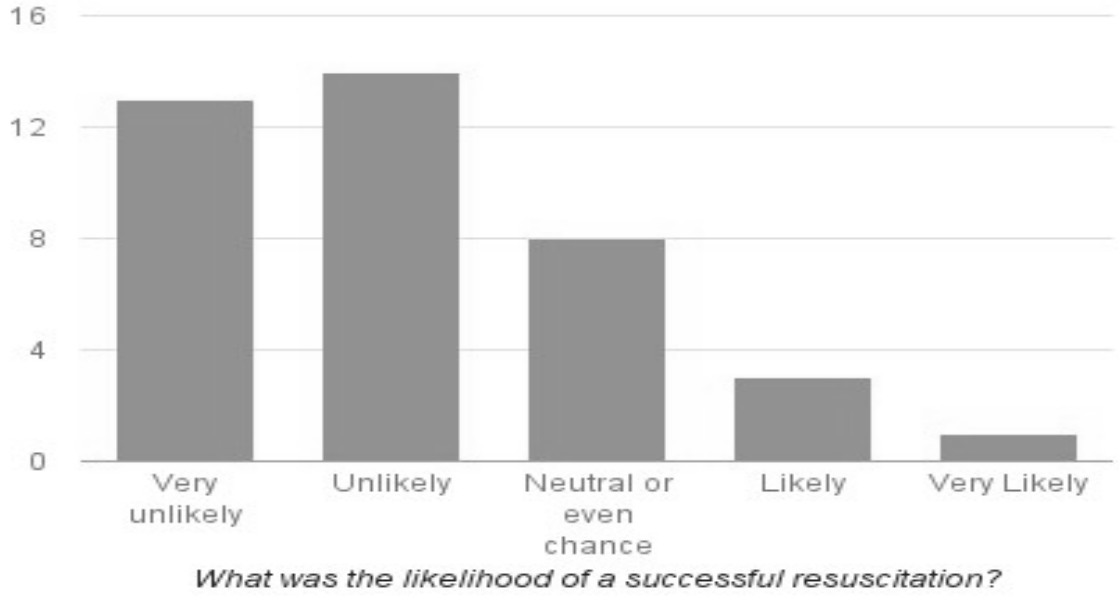
Attempted	5	12.8
Not attempted	34	87.2
Intubation:		
Attempted	3	7.7
Not attempted	36	92.3
Adrenaline:		
None	5	12.8
1 vial	9	23.1
More than 1 vial	25	64.1
Other drugs given during CPR:		
Atropine	11	28.2
Inotrope	4	10.2
Other	3	7.7
More senior doctor informed:		
No	9	23.0
Yes	30	77.0
SHO/Registrar	20	51.3
Consultant	10	25.7

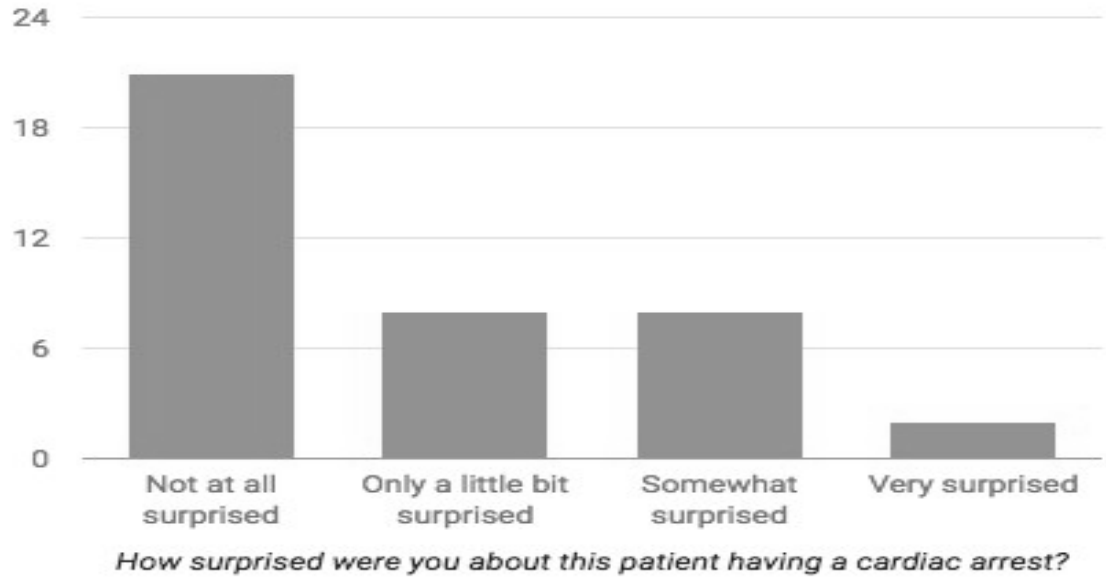
Figure 3.3.1 Outcomes of resuscitation attempts surveyed



A total of 39 resuscitation attempts were surveyed. A further three attempts had no further information available as the HO interviewed was aware of, but did not participate in the resuscitation attempt. Of these 39 attempts, 34 (87.2%) were immediately unsuccessful. Five (12.8%) attempts resulted in Return of Spontaneous Circulation (ROSC) with 3 patients being transferred to Intensive Care Unit (ICU) for post-resuscitation care, whilst the other 2 patients remained in the ward. HO were able to report that 24 hours from the time of resuscitation, only the two patients transferred to an ICU were still alive (5.1%), with outcome for the third patient in the ICU was unknown. Eight deaths occurred without a known resuscitation attempt. Of these 6 deaths occurred on wards where there were informal DNACPR instructions in place, though it is not known whether these particular patients had treatment limitations. In total, 15 wards (4.4%) in 12 different hospitals, had at least one patient with informal DNACPR instructions. Thirteen of these (86.6%) were medical wards.

Figure 3.3.2 HO perspectives regarding cardiac arrest occurrence and outcome





Of the 5 resuscitation attempts that resulted in ROSC, doctors reported that they were ‘somewhat surprised’ or ‘very surprised’ on all 5 (100%) of occasions. Conversely, 82% of respondents indicated little or no surprise in those patients who had unsuccessful resuscitation attempts. They further reported that they felt the likelihood of a successful outcome was an ‘even chance’ to ‘very likely’ in all

these ROSC instances.

3.3.5 Discussion

This national survey of resuscitation in Sri Lanka confirms that the majority (80.9%) of in-patient deaths in general wards are preceded by some attempts at CPR. In contrast, in Singapore this number may be as low as 33.8%, for patients outside the ICU [101]. The majority (87.2%) of patients were not defibrillated, suggesting non-shockable rhythms as the cause of arrest, though a question regarding cardiac rhythm or equipment availability was not included in the survey. These characteristics in combination with poor outcomes and limited use of DNACPR may suggest that attempted resuscitation remains a feature of end of life care in Sri Lanka. Sixty four percent of patients who did not have ROSC received more than one vial of adrenaline during the resuscitation attempt, suggesting that these attempts were of a concerted nature lasting at least 2 minutes.

Of the 8 patients who had no CPR attempted before death, 6 patients were in wards where informal DNACPR instructions were in use. This may suggest that the practice of DNACPR instructions, though reported to be informal, often unwritten and infrequent may be clinically effective. The cross-sectional nature of the survey precluded ascertaining the actual proportion of wards which utilise such instructions (as all doctors in a ward were not interviewed) and whether the patients who died without attempted resuscitation were the subject of these particular DNACPR instructions.

Junior doctors were “surprised” by the cardiac arrest in all the patients who went on to have ROSC but expressed “little” or “no surprise” at cardiac arrest in the vast majority of those who had unsuccessful resuscitation attempts. Even

allowing for bias due to the retrospective questioning and outcomes being known, opportunities for discussions regarding appropriateness of resuscitation or limitation of care may thus have been missed. Confounding influences on such decision-making in LMICs may include cultural norms, religious beliefs, public expectation, and lack of locally generated guidance [95, 102]. The impact, if any, of the family being present in nearly 75% of these attempts is not known and merits further exploration.

ROSC following resuscitation was low (12.8%). This poor survival rate mirrors limited data from other LMICs such as Uganda 7.4% [103] and is lower than those reported from HIC's [74, 93, 96]. Furthermore, an as yet unpublished NCAS [100] across 92 hospitals by the same research group confirmed that attempted resuscitation precedes most in-patient deaths, hospital outcomes after cardiac arrest are poor, doctors and nurses have often not received formal resuscitation training and defibrillators are not always available in acute care settings.

Though outcomes after resuscitation attempts for patients who have in-hospital cardiac arrests with non-shockable rhythms are poorer than when shockable, these findings highlight the need for urgent investment to improve resuscitation management in LMICs [19, 74]. Such efforts should be focused around early recognition and escalation of deteriorating patients where appropriate, combined with culturally appropriate efforts to research and implement the practice of appropriate DNACPR orders for patients where resuscitation is likely to be futile. In Europe, inter-disciplinary resuscitation programs now include sessions considering the appropriateness of resuscitation in an effort to reduce futile and undignified resuscitation attempts [43, 104]. Work is ongoing to provide similar training opportunities for nurses and doctors in Sri Lanka[86].

Further research and investment in this area is justified.

3.3.6 Limitations

This retrospective cross-sectional survey does not explore the underlying reasons for the cardiac arrests and subsequent resuscitations attempted. While suggesting a difference in perspectives of doctors between successful and unsuccessful attempts, it does not interrogate the appropriateness of resuscitation for each patient. Findings are difficult to generalise to all clinical staff on the ward.

3.3.7 Conclusion

CPR precedes the vast majority of in-patient ward deaths. Successful outcomes following resuscitation in Sri Lanka are lower than in HIC settings and similar to other LMICs. DNACPR orders (even informal) are not common in general wards. Most cardiac arrests were anticipated, nearly one third of unsuccessful attempts do not appear to be concerted in nature and the likelihood of ROSC overall is low. LMICs such as Sri Lanka, would benefit from better training and systems to care for the acutely deteriorating patient, further development of DNACPR orders, and from research and training in end of life decision-making.

3.4 Improving ICU services in resource-limited settings: perceptions of ICU workers from LMIC and HIC.

3.4.1 Background

Globally, the burden of critical illness is highest in low- and middle-income countries (LMICs). Despite an increasing number of intensive care units (ICU) in these areas, the mortality and long-term morbidity of critical illness is disproportionally higher than in high-income countries (HICs) [29, 105, 106]. Given that children and young adults make up a relatively large proportion of

critically ill patients in LMICs [106-108] the social and economic burden of critical illness, and the potential for gains, is enormous. Poor functioning of many ICU services, among other factors, contributes to adverse outcome of critical illness in LMICs [19, 29, 109, 110] .

Optimum ICU function depends on a delicate balance of staff availability and training, material resources and organizational processes [111]. Due to major differences in funding capacities, resource availability, cultural and social factors between LMICs and high-income countries (HICs), it is likely that strategies to improve ICU services differ between LMICs and HICs. ICU workers from LMICs have the best insight into which obstacles prevent optimum function of LMIC ICUs and which strategies would be most acceptable and useful to improve these services. They are also the ones who can best suggest how ICU workers from HIC may assist in this process. So far, however, no such data has been published. Knowledge of perceptions and ideas of ICU staff from LMICs would be of great importance to overcome obstacles, improve the care of critically ill patients in LMICs, and guide cooperation between LMIC and HIC ICU staff.

3.4.2 Study aim

Our survey aimed to collect perceptions of ICU workers from LMICs on barriers and strategies to improve LMIC ICU services and compare these with perceptions of ICU staff from HICs. We hypothesized that perceptions of ICU workers from LMICs and HICs differed.

3.4.3 Study design

This study was performed as an anonymous online, questionnaire-based survey over a three-month period in 2016. Ethical review was not sought as the survey was anonymous, voluntary and contained no patient material, and nor did it

allude to individual persons.

The survey targeted healthcare professionals (physicians and nurses) substantively employed in an ICU in a LMIC (as defined by the World Bank). In addition, ICU workers from HICs who have worked in a LMIC ICU could also participate in the survey. The survey was endorsed by the European Society of Intensive Care Medicine and the World Federation of the Societies of Intensive and Critical Care Medicine. Both societies publicized the survey to their members. In addition, individual and group invitations to participate in the survey were sent out by members of the Global Intensive Care working group of the European Society of Intensive Care Medicine. A reminder invitation was sent out after two weeks.

The study questionnaire was available on a dedicated webpage. The full survey tool can be downloaded from the electronic supplementary material. Briefly, it was composed of six sections which focused on the following topics: 1) characteristics of the respondent and associated LMIC ICU service; 2) availability of ICU resources); 3) barriers to LMIC ICU function; 4) strategies to improve LMIC ICU function; 5) importance of additional staff; 6) ways how HIC ICU staff can help to improve LMIC ICU services. Survey respondents were asked to rate their perceptions on a 6-point Likert scale for each question (0 being the lowest and 5 the highest). Free text responses were minimized to facilitate statistical analysis and interpretation. The survey tool was available in English, Spanish, Portuguese and French.

The questionnaire was developed by three authors (RH, MD, LdeA) and underwent pre- and pilot-testing by the other co-authors with regard to sequence, salience, acceptability and administrative ease. Interrater reliability

was assessed at the same time. Finally, clinical sensitivity testing and testing for internal validity was performed by experts of the European Society of Intensive Care Medicine Global Intensive Care working group which included health care workers from HICs and LMICs.

After study questionnaires had been completed, data were automatically transferred into the spreadsheet of a statistical software program. At the end of the study period, questionnaire accessibility through the study homepage was blocked and raw data checked independently by two authors for plausibility and quality. Open-ended questions were numerically coded.

3.4.4 Results

A total of 175 LMIC and 43 HIC ICU workers participated in the survey. Their geographic origin (Figure 3.4.1), age and professional distribution are presented in Table 3.4.1. Figure 3.4.2 summarizes perceived barriers and their relevance to ICU function. LMIC and HIC respondents differed in their perception of the relevance of lack of critical care training of ICU staff, leadership of physicians, ICU beds, drugs, supplies, leadership of nurses, ventilators, monitors, and water/electricity/gas, as well as low morale, poor laboratory and radiology support. LMIC respondents who worked in non-privately funded ICUs considered the lack of nurses and material resources a more relevant barrier to ICU functioning than LMIC respondents working in private ICUs (Table 3.4.3). Suggested strategies to improve LMIC ICU performance and their relevance are displayed in Figure 3.4.3. Group differences were observed for the perceived relevance of improving training of ICU physicians and nurses, equipment maintenance, gathering of outcome data, and the need for pulse oximeters, blood gas analysers, central venous pressure monitoring, and improved oxygen systems. LMIC respondents working at non-privately funded ICUs considered

equipment maintenance and increasing the availability of ICU resources of greater benefit to improve ICU services than LMIC respondents working at private ICUs (Table 3.4.4). Perceptions on the relevance of additional staff to improve LMIC ICU function are given in Figure 3.4.4. Respondents from LMICs and HICs differed in their perceived relevance of additional physicians and psychologists. Figure 3.4.5 displays proposed ways how HIC staff can help improve LMIC ICU performance. LMIC and HIC respondents differed in their perceived relevance of HIC physicians to train ICU staff in LMICs, access to journals, LMIC physicians to travel to HICs, online training, LMIC physicians attending HIC conferences, conductance of research, setting up ICU registries, and provision of electronic patient records.

Figure 3.4.1 Location of survey respondents.

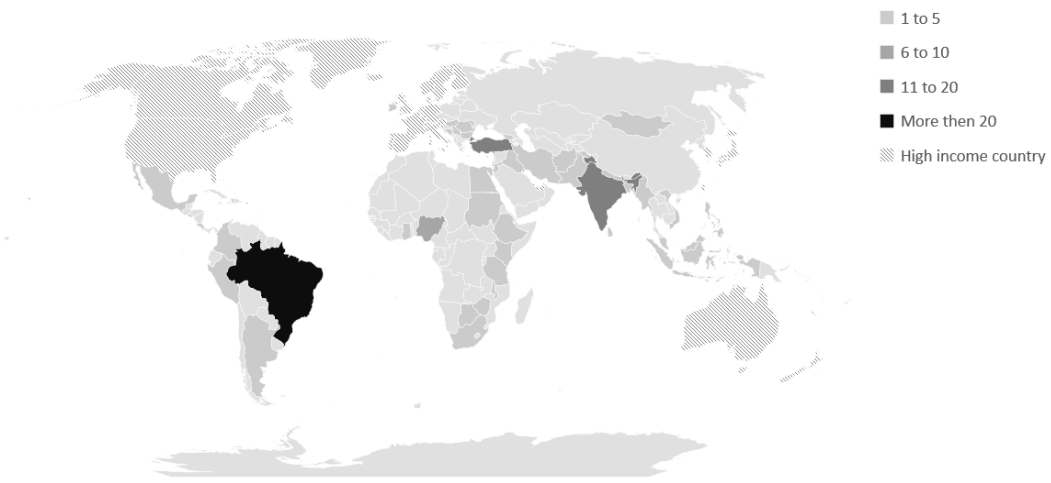


Figure 3.4.2 Barriers to LMIC ICU performance and their relevance.

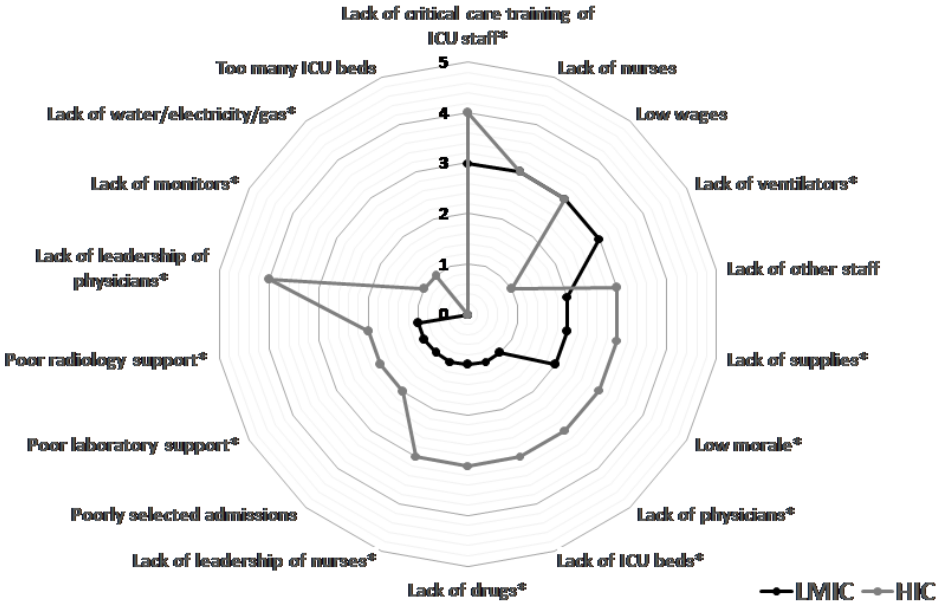


Figure 3.4.3 Strategies to improve LMIC ICU performance and their relevance.

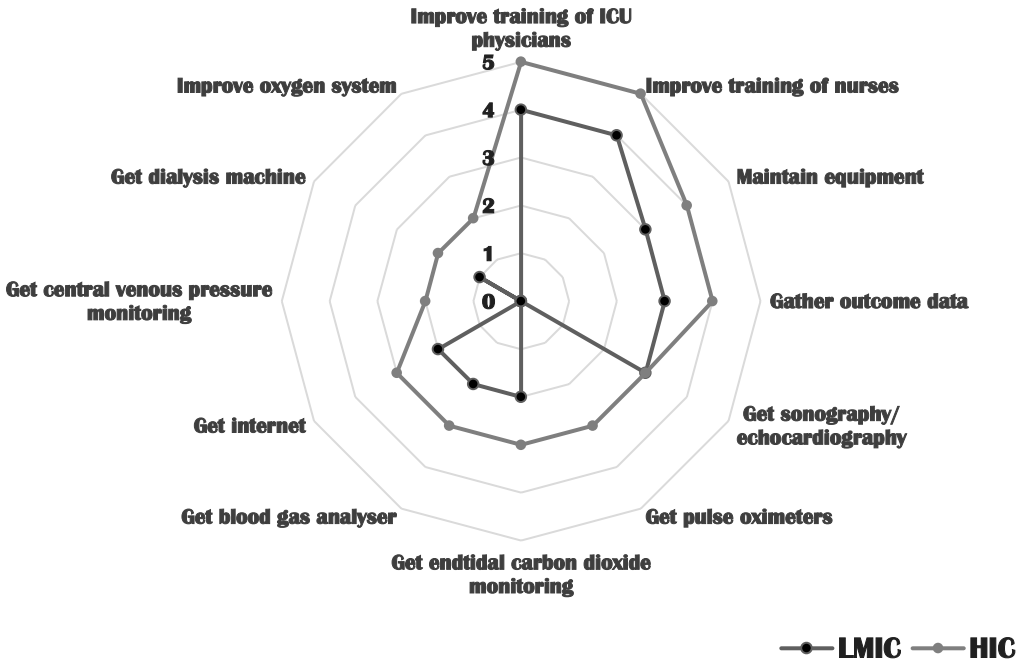


Figure 3.4.4 Benefit of additional staff to improve LMIC ICU performance.

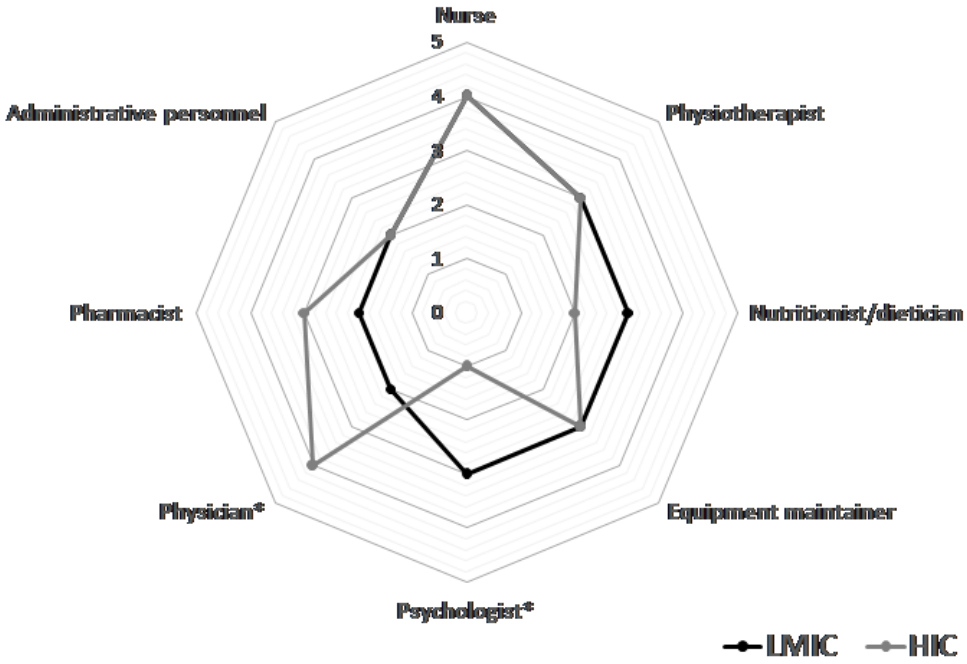


Figure 3.4.5 Perceptions on how HIC staff can help improve LMIC ICU.

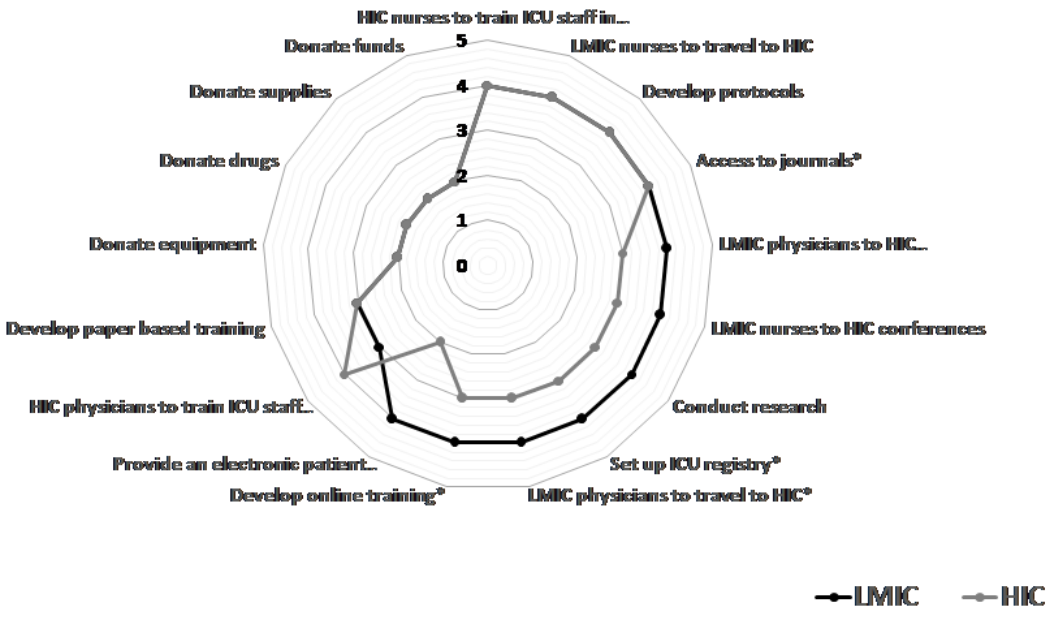


Table 3.4.1 Characteristics of respondents and associated LMIC ICU services.

Variable	LMICĪ (*n*=175)	HIC‡ (*n*=43)
Age		
<35 years	35 (20.1%)	6 (15%)
≥35-45 years	74 (42.5%)	15 (37.5%)
≥45-55 years	41 (23.6%)	12 (30%)
≥55-65 years	22 (12.6%)	7 (17.5%)
≥65 years	2 (1.2%)	0
Missing	1 (0.6%)	6 (14%)
Continent of residency		
North America	0	16 (37.2%)
Central America	4 (2.3%)	0
South America	80 (45.7%)	0
Europe	9 (5.1%)	24 (55.8%)
Africa	28 (16%)	0
Asia	54 (30.9%)	3 (7%)
Role		
Critical care specialist physician	142 (81.2%)	32 (74.4%)
Junior physician	19 (10.8%)	4 (9.3%)
Nurse	14 (8%)	7 (16.3%)
ICU† work experience		

<1 year	4 (2.3%)	1 (2.3%)
1–2 years	15 (8.6%)	2 (4.7%)
3–5 years	26 (14.9%)	8 (18.6%)
6–8 years	31 (17.7%)	8 (18.6%)
9–10 years	16 (9.1%)	3 (7%)
> 10 years	83 (47.4%)	21 (48.8%)
Duration of work in LMICĪ ICU†		
<1 month	-	19 (44.2%)
1–5 months	-	12 (27.9%)
6–12 months	-	5 (11.6%)
>12 months	-	7 (16.3%)
<1 year	20 (11.4%)	-
1–2 years	30 (17.1%)	-
3–5 years	43 (24.6%)	-
6–10 years	34 (19.4%)	-
>10 years	48 (27.4%)	-
Location of LMICĪ ICU†		
Central America	5 (2.9%)	0
South America	79 (45.1%)	2 (4.6%)
Europe	9 (5.1%)	2 (4.6%)
Africa	27 (15.4%)	12 (27.9%)
Asia	55 (31.4%)	27 (62.8%)

ĪLMIC, low- and middle income country; †ICU, intensive care unit; ‡HIC, high-income country

Table 3.4.2 Characteristics of the associated LMIC ICU services.

Characteristics	**LMICĪ** (*n*=175)	**HIC‡** (*n*=43)
Finance status		
Private	7 (16.3%)	70 (40.2%)
Government	32 (74.4%)	97 (55.8%)
Military	0	2 (1.2%)
Other	4 (9.3%)	5 (2.9%)
Type		
Medical	4 (9.5%)	13 (7.4%)
Surgical	1 (2.4%)	9 (5.1%)
Paediatric	1 (2.4%)	3 (1.7%)
Mixed	36 (85.7%)	144 (82.3%)
Special	0	6 (3.4%)
Missing	1	0
Admission policy		
Open	8 (20%)	46 (26.3%)
Closed	20 (50%)	90 (51.4%)
Mixed	12 (30%)	39 (22.3%)
Missing	3	0
Functioning beds		

1-3	0	6 (3.4%)
4-6	14 (33.3%)	28 (16%)
7-10	12 (28.6%)	49 (28%)
>10	16 (38.1%)	92 (52.6%)
Missing	1	0
Functioning ventilators		
0	3 (7.7%)	2 (1.1%)
1-3	5 (12.8%)	15 (8.6%)
4-6	20 (51.3%)	33 (19%)
7-10	7 (18%)	36 (20.7%)
>10	4 (10.3%)	88 (50.6%)
Missing	4	1
Functioning patient monitors		
0	2 (5.1%)	1 (0.6%)
1-3	5 (12.8%)	11 (6.3%)
4-6	14 (35.9%)	24 (13.7%)
7-10	9 (23.1%)	44 (25.1%)
>10	9 (23.1%)	95 (54.3%)
Missing	4	0
Functioning saturation probes		
0	0	2 (1.1%)
1-3	10 (26.3%)	11 (6.3%)

4-6	13 (34.2%)	26 (14.9%)
7-10	9 (23.7%)	43 (24.6%)
>10	6 (15.8%)	93 (53.1%)
Missing	5	0
Functioning end-tidal carbon dioxide monitors		
0	22 (71%)	36 (21.3%)
1-3	4 (12.9%)	61 (36.1%)
4-6	3 (9.7%)	25 (14.8%)
7-10	1 (3.2%)	17 (10.1%)
>10	1 (3.2%)	30 (17.8%)
Missing	12	6
Backup electricity generator	24 (72.7%)	166 (94.7%)
Piped Oxygen	31 (79.5%)	165 (94.3%)
Running water	43 (100%)	175 (100%)
Air conditioning	17 (41.5%)	85 (88.5%)
Wall suction	26 (70.3%)	147 (85%)
Portable ventilator	16 (43.2%)	140 (80.9%)
Mobile x-ray	20 (57.1%)	154 (88%)
Mobile sonography machine	17 (51.5%)	129 (74.1%)

Accessible hospital facilities		
Laboratory	40 (95.2%)	175 (100%)
Operating theatre	43 (100%)	173 (98.9%)
Emergency room	43 (100%)	167 (95.4%)
Blood bank	30 (85.7%)	158 (90.4%)
CT scanner	25 (64.1%)	160 (91.4%)
MRI	16(44.4%)	121 (69.9%)
Disruption to running water		
Frequent	4 (14.3%)	7 (4%)
Sometimes	9 (32.1%)	12 (6.9%)
Rarely	11 (39.3%)	50 (28.7%)
Never	4 (14.3%)	105 (60.3%)
Missing	18	1
Renal Replacement Therapy		
Peritoneal Dialysis	11 (25.6%)	60 (34.3%)
Haemodialysis	19 (44.2%)	136 (77.7)
Extended haemodialysis	4 (9.3%)	77 (44%)
Continuous haemodialysis / hemofiltration	7 (16.3%)	88 (50.3%)
None	15 (34.9%)	22 (12.6%)
Run out of medication		

Frequently	13 (35.1%)	20 (11.5%)
Sometimes	17 (46%)	51 (29.3%)
Rarely	6 (16.2%)	60 (34.5%)
Never	1 (2.7%)	43 (24.7%)
ICU equipment maintenance	13 (56.5%)	136 (81.4%)
Bed closures		
Frequently	2 (7.4%)	4 (5.5%)
Sometimes	5 (18.5%)	6 (8.2%)
Rarely	14 (51.8%)	22 (30.1%)
Never	6 (22.2%)	51 (56.2%)
Physicians available 24/7	24 (63.2%)	164 (93.7%)
Daily ICU rounds	26 (61.9%)	148 (86.6%)
Availability of staff		
Nutritionist	5 (15.6%)	126 (72.8%)
Physiotherapists (day and night)	0 (0%)	63 (36%)
Pharmacist (day and night)	1 (2.9%)	28 (14.2%)

ĪLMIC, low- and middle income country; †ICU, intensive care unit; ‡HIC, high-income country

Table 3.4.3 Barriers to LMIC ICU performance and their relevance as reported by LMICĪ respondents working in privately and non-privately funded ICUs.

Barriers	Privately funded LMICĪ ICU† (*n*=70)		Non-privately funded LMICĪ ICU† (n=105)	
	Median	IQR√	Median	IQR√
Lack of critical care training of ICU† staff*	2	2	3	3
Lack of leadership of physicians*	0	1	1	2
Lack of nurses	2	3	4	4
Lack of physicians*	1	3	2	4
Lack of other staff	2	2	3	3
Lack of ICU beds*	0	2	2	4
Lack of drugs*	0	1	2	2
Lack of supplies*	0	1	2	2
Lack of leadership of nurses*	1	2	2	4
Low wages	2	3	3	3
Low morale*	1	2	2	3
Poorly selected admissions	2	2	1	3
Poor laboratory support*	0	1	1	3
Poor radiology support*	0	1	1	3
Lack of ventilators*	2	2	3	3
Lack of monitors*	0	1	1	2

Lack of water/electricity/gas*	0	0	0	1
Too many ICU† beds	0	1	0	0

ĪLMIC, low-middle income country; †ICU, intensive care unit; √IQR, inter quartile range; ‡HIC, high-income country;*, significant difference between LMICĪ total and HIC‡ respondents (Mann Whitney-U test).

Each feature was ranked on a Likert scale from zero (not a barrier at all) to 5 (maximal barrier) and arranged from the highest to lowest median.

Table 3.4.4 Strategies to improve LMIC ICU performance and their relevance as reported by LMICĪ respondents working in privately and non-privately funded ICUs.

Strategies	**Privately funded LMICĪ ICU† (n=70)**		**Non-privately funded LMICĪ ICU† (n=105)**	
	Median	**IQR√**	**Median**	**IQR√**
Improve training of ICU† physicians*	3	3	4	3
Improve training of nurses	4	2	4	2
Maintain equipment	1	3	3	4
Gather outcome data	2	4	4	3
Get sono-/echocardiography	2	4	4	3
Get pulse oximeters	0	1	0	3
Get endtidal carbon dioxide monitoring*	1	3	3	3
Get blood gas analyser	1	3	2	4
Get internet*	0	4	2	5

Get central venous pressure monitoring	0	2	1	4
Get dialysis machine	0	3	2	4
Improve oxygen system	0	1	0	1

ĪLMIC, low-middle income country; †ICU, intensive care unit; √IQR, inter quartile range;‡HIC, high-income country;*, significant difference between LMICĪ total and HIC‡ respondents (Mann Whitney-U test).

Each feature was ranked on a Likert scale from zero (not helpful at all) to 5 (maximally helpful) and arranged from the highest to lowest median.

3.4.5 Discussion

Our survey collected perceptions on obstacles to the function of and strategies to improve ICU services in LMICs. Although respondents from LMICs originated from all continents, the absolute number of LMIC survey participants (n=175) was low given the number of ICUs and population in LMICs. Unlike in HICs where databases to approach ICU workers exist, this is not available in most LMICs. Reaching out to nurses turned out to be especially challenging and resulted in a low percentage of nurse respondents (8%). We deliberately included only HIC ICU staff who have worked in a LMIC ICU as they were likely to have some insight into the practice of intensive care in a resource-limited setting. While it is a general limitation of surveys that perceptions instead of objective data are collected, we chose this design as we specifically intended to collect ideas and views on how to improve ICU services in LMICs.

Lack of training, lack of nurses and low wages were considered the greatest barriers to adequate ICU functioning. In contrast to most HICs, no systematic curricula for intensive care training are available for physicians and nurses in many LMICs [19, 29, 109, 112]. Many ICUs in LMICs are run by physicians or

non-physician staff (e.g. nurse anaesthetists) with no formal undergraduate or postgraduate ICU training [29, 106, 113] Despite reports indicating a lack of both physician and non-physician ICU workers in LMIC ICUs [29, 106, 113], LMIC respondents only considered a lack of nurses as an obstacle to ICU function. The fact that >90% of survey participants were physicians might have influenced this result. Few data have been published on the income of ICU workers in LMICs. One study found that ICU physicians in Mongolia earned significantly less than their colleagues in Austria (140 vs. 2,300 €/month) [114] Interestingly, lack of equipment, drugs and supply materials was not regarded as a priority obstacle to ICU functioning. This finding contrasts with the unavailability of certain equipment such as patient monitors, mechanical ventilators or renal replacement machines in the associated ICUs of study participants (Table 3.4.2). Comparisons between respondents working in privately and non-privately funded ICUs suggest that resource availability in private ICUs in LMICs is considered adequate while this is not the case in non-privately funded ICUs in these settings.

Training of ICU staff, an increase of the number of ICU nurses, collection of outcome data as well as maintenance of equipment were judged important strategies to improve LMIC ICUs. These perceptions are in line with published reports. Training of ICU staff has been associated with improved functioning of ICU services in LMICs [31, 38, 86, 115]. The number of ICU nurses is an independent factor determining morbidity and mortality of critically ill patients [116] Although these data largely originate from HICs, it is likely that they can be extrapolated also to resource-limited settings. ICU registries are validated methods for quality improvement and are effective in LMICs, too [36].

Overall, ICU workers from LMICs graded cooperation with ICU staff from HICs as helpful to improve LMIC ICUs. The most important role of HIC ICU staff was

considered to be training of LMIC staff [31, 38, 115]. On-site training, training of LMIC staff in HIC ICUs, attendance to international scientific conferences and on-line training programs were suggested as potentially useful educational methods. Assistance with the development of clinical protocols, ICU registries, and conducting research were highlighted as other important fields where HIC staff can help to facilitate LMIC ICU functioning. Donation of equipment, drugs and supplies was felt to be of only limited usefulness by survey respondents. This perception may, however, critically depend on the availability of resources and once again varied between LMIC respondents working at privately vs. non-privately funded ICU services. Another reason could be that ICU equipment depends on specific supply materials and is difficult to maintain or repair in LMICs [117].

Against our hypothesis, the overall ranking of barriers and strategies to improve LMIC ICU services was largely comparable between LMIC and HIC respondents. Significant differences were, however, found in the grading of their relevance. HIC respondents, for example, considered the lack of equipment and training more serious barriers to ICU functioning than LMIC respondents. The most striking difference was observed in the perception on physician leadership as an obstacle to LMIC ICU functioning. The fact that the majority of LMIC participants were (senior) physicians likely explains divergent perceptions. Participants agreed on the usefulness of HIC staff to assist with training of LMIC ICU workers. A difference worthwhile to consider when planning training of LMIC physicians, is the location of training. In contrast to HIC respondents, LMIC respondents considered it more useful that LMIC physicians were trained abroad instead of on-site. It is surprising that LMIC respondents considered setting up ICU registries and conducting research more useful than HIC participants. Given the

widespread lack of data and scientific evidence from LMICs, research cooperation between HIC and LMIC staff seems to be more useful and welcome than assumed by HIC ICU workers.

3.4.6 Conclusions

ICU workers from LMICs perceived lack of training of ICU workers, lack of nurses, and low wages as major barriers to ICU functioning in LMICs. Training, increase of nurse workforce, and collection of outcome data were proposed as useful strategies to improve LMIC ICU services. LMIC respondents judged that assistance of HIC ICU staff would be helpful to train LMIC ICU workers, develop ICU registries and protocols as well as conduct research.

4.0 Tools for the evaluation of acute and critical care in LMICs.

4.1 Performance of critical care prognostic scoring systems in LMICs; a systematic review.

4.1.1 Background

Prognostic models used in critical care medicine for mortality predictions, benchmarking and for illness stratification in clinical trials, need to be validated for the relevant setting. An ideal model should be able to discriminate between high and low risk patients, have good calibration, and generate risk estimates close to actual mortality [118]. Acute Physiology and Chronic Health Evaluation (APACHE) or the Simplified Acute Physiology Score (SAPS) and the Mortality Probability Models (MPM) are some common prognostic systems used to predict the outcome of critically ill patients admitted to the Intensive Care Unit (ICU) [119, 120].

The performance of these models has been extensively validated, predominantly in high-income countries (HICs) [121-123]. These results may not be reproducible in low or middle income countries (LMICs) not only because of different case-mix characteristics but also because of missing predictor variables. Predictor variables that are routinely available in HICs – for example arterial oxygenation - are often not obtainable or reliable where resources are limited [124, 125]. The presence of missing values, if imputed as normal as per convention [120, 122, 126-129] will lead to underestimation of the scores and mortality. Additionally, the diagnostic categories in these scoring systems may not be suited to capture diagnoses more common in these countries, such as dengue, malaria, snakebite and organophosphate poisoning. Furthermore, hospital discharge outcomes may not be readily accessible [37, 58, 130]. These

and other factors influence the performance of the models, which may then require adaptation (addition and / or removal of parameters) or recalibration (adaptation of weights and/or equation) [131, 132].

4.1.2 Study aim

The objective of this paper is to systematically review literature on the use of critical care scoring systems in LMICs and assess their ability to discriminate between survivors and non-survivors of ICU admissions, their calibration and accuracy, and the manner in which missing values are handled.

4.1.3 Study design

The PubMed database was searched in March 2017, for research articles using the following search strategy: *(critical OR intensive) AND (mortality OR survival OR prognostic OR predictive) AND (scoring system OR rating system) AND (critical OR intensive) AND (mortality OR survival OR prognostic OR predictive) AND (*APACHE *OR* SAPS *OR* SOFA *OR* TISS *OR* MPM *OR* euroscore *OR* GCS *OR* IPS *OR* POSSUM *OR* ASA) in title, abstract and keywords (Supplementary Table 4.1.1).

No restrictions were placed on date of publication. Titles and abstracts returned were analysed for eligibility (RH, II). Abstracts reporting the performance of prognostic models were hand-searched in order to identify studies carried out in ICUs in LMICs (as classified by the World Bank [2]) and full-text copies retrieved. Full text articles were also retrieved when the title or abstract did not provide the country setting. Studies carried out in ICUs in LMICs were included in the review. Those carried out in HICs only were excluded. Where ICUs in both HICs and LMICs were included in a study, only data from the low/middle income country was to be extracted. Only studies that evaluated mortality, irrespective of ICU or hospital, as the primary outcome were included. Studies carried out in

paediatric ICUs were excluded for this systematic review of adult prognostic models but those that included paediatric patients in non-specialised ICUs were included. Studies that evaluated a scoring system in relation to a specific disease, for example liver cirrhosis were excluded, as were those limited to trauma patients alone. Studies that assessed a single prognostic factor, for example microalbuminurea, were similarly excluded. In studies where a single factor or disease specific scoring system and a non-specialty specific scoring system were evaluated, only the data pertaining to the latter was extracted.

Duplicate publications were excluded, as were studies published only as abstracts, editorials, letters and systematic or narrative reviews. Only articles published in English were included. The references of all selected reports were thereafter cross-checked for other potentially relevant articles.

The full text articles were reviewed to assess eligibility for inclusion in the report. Disagreements between the two reviewers were resolved by discussion. The list of extracted items was based on the guidance issued by Cochrane for data extraction [133] and critical appraisal for systematic reviews of prediction models (the CHARMS checklist ([134]). A second reviewer checked extracted items classed as “not reported” or “unclear,” or unexpected findings. If an article described multiple models, separate data extraction was carried out for each model.

Results were summarised using descriptive statistics. A formal meta-analysis was not performed as it was envisaged that the studies would be too heterogeneous, and a narrative synthesis was undertaken. Discrimination, calibration and accuracy were assessed as described under Section 2.4.

4.1.4 Results

Study characteristics

Out of 2237 studies obtained from PubMed searches, 477 were searched and 47 met the inclusion criteria. Seven further studies were included after cross-checking the reference lists of the selected studies (Fig 4.1.1). Fifty four studies reporting 160 model validations met the review criteria and were selected for analysis (Table 4.1.1, Supplementary Table 4.1.2). Three papers (4 evaluations) [135-137] described the development of a new prediction model in a LMIC setting. These four new models are presented separately from the remaining 156 evaluations that reported external validations of existing models (Supplementary file 4.1.3).

External validation of existing models

Twenty-five evaluations were carried out retrospectively [138-141], the others (n =131) were prospective in design. Seven different scoring systems (APACHE, GCS, MPM, OSF, SAPS, SOFA and TISS), or versions thereof, were validated (Table 4.1.1). Adaptations to existing models were attempted on seventeen occasions. These included first level customisation (n=3), exclusion and/or substitution of variables (n=4), temporal modification (n=7) and modifications to modelling techniques (n=3) (Table 4.1.2).

Model evaluation took place in twenty different LMICs with the largest number carried out in India (n=39), Thailand (n=18) and Brazil (n=17). Model adaptation was most frequent in India (n=7). Settings, hospital and ICU characteristics are presented in Supplementary Table 4.1.3.

The sample size for the validations ranged from 44 to 5780 and for ICUs ranged from 1-28 (Supplementary Table 4.1.3). Participant ages ranged from 1 month – 100 years. Of the 74 evaluations reporting a lower age limit, 38 reported participants under the age of 18 years.

Quality assessment

Study quality was assessed in accordance with the CHARMS guidelines. A number of variations existed in the conduct and reporting of the studies, especially with regard to missing value handling (Table 4.1.3 and Supplementary Table 4.1.2), inclusion and exclusion criteria (Supplementary Table 4.1.2), performance and outcome measures (Supplementary Table 4.1.4).

Missing value handling was explicitly mentioned for 26.9% (n=42 evaluations in n=18) studies. One evaluation stated that 26.4% patients did not have complete data but did not provide further details [142]. Of the remaining 41 evaluations exclusion of entire patients occurred in 21 [135, 136, 142-149], imputation by normal physiological value occurred in sixteen [150-153] and both exclusion (for missing variables such as chronic health status) and imputation by normal (for missing physiological values) occurred in four (two studies) [137, 154] (Table 4.1.4). No other methods of imputation were described. For the most commonly assessed models- APACHE II, SOFA and SAPS II - missing values were mentioned only 22.0%, 30.8% and 31.0% times respectively.

Model performance

Seventy evaluations (44.9%) reported hospital or post-hospital mortality, 75 (48.1%) ICU mortality and in eleven (6.9%), the type of mortality was not specified.

Discrimination

Discrimination was reported by 142 evaluations (91.0%) with 135 (95.1%) reporting AUROC and seven reporting other forms of discrimination (sensitivity/ specificity/NPV/PPV) only (Supplementary Table 4.1.4). Fourteen did not report any form of discrimination (Supplementary Table 4.1.5).

Where AUROC was reported in numerical form (n=129) - 6 evaluations (n=2 studies)[155, 156] figures were presented and numerical value couldn't be ascertained –, 27 (20.6%) reported excellent discrimination with one study reporting a discrimination of 1.0 for MPM II at 7 days after admission [156]. Eighty-six (65.7%) reported very good or good discrimination, fourteen (10.9%) moderate discrimination and a one (0.8%) [157] poor discrimination (Table 4.1.4).

Excellent discrimination was reported more frequently when hospital mortality (n=16, 22.9%) was the outcome in comparison to when ICU mortality (n =11, 15.7%) was considered as the outcome. Similarly, normal value imputation resulted in better discrimination (n=4, 23.5% excellent and n=5, 23.8% very good) than exclusion (n=1, 4.8% excellent and n=9, 52.9% very good) or where missing values were not reported (n=22, 19.1% excellent and 31.3% very good). Thirteen of the 17 evaluations with modifications (n=7 studies) compared them to the original model (Supplementary Table 4.1.6). In each case the modifications resulted in a better AUROC; however an independent validation set was employed in only one study (3 validations), which performed first level customization [158].

Calibration

Only 102 (65.4%) evaluations reported calibration (Supplementary Table 4.1.4). Hosmer-Lemeshow was reported for both C and H statistics 17 (16.7%) times, C-statistic only 21 (20.6%) times, H statistic only 11 (10.8%) times and without further detail 53 (52%) .

A p value greater than 0.05 was reported by 67 (65.7%) evaluations that reported calibration. Thirteen evaluations that reported excellent discrimination also reported good calibration (Supplementary Table 4.1.7). Of these, three

were for first level customisations of APACHE II, SAPS II, and SAPS 3 (calibration had resulted in a $p<0.05$ when the non-customised model was used). The other validations that reported excellent discrimination and good calibration were carried out in four studies; Halim et al (SOFA (maximum) and modified SOFA (maximum) [159], Juneja et al (APACHE III, APACHE IV, MPM II (initial), MPM III (initial) and SAPS 3) [118]. Sekulic (MPM II and SOFA both at seven days)[156] and XueZhong et al (SAPS 3) [160].

Accuracy

Accuracy was reported in 45 evaluations (28.5%) and ranged from 55.20% to 98.5% (Additional file 4). Decision criteria (risk level) was reported in only 10 evaluations (22.2%).

New model development

Three studies reported four new model developments –New score [135], Rwanda- MPM (R-MPM) [137] Simplified R-MPM [137] and Organ Failure Score [136] (Additional file 8). They were carried out in medical, multidisciplinary and respiratory ICUs of general hospitals in India [135], Rwanda [19] and South Africa [136] respectively. Hospital [135, 137] and non-specified mortality [136] were reported as outcomes. Missing values were only reported by Riviello et al (n=2 models) who substituted normal values [137].

No external validation was reported although Riviello et al carried out an internal validation with bootstrapping [137]. Ahluwalia et al [135] reported an AUROC of 0.90, a sensitivity of 98.2% and a specificity of 66.6% for the New Score and compared to APACHE II (after 48h) (AUROC -0.74, sensitivity - 92.8%, specificity - 23.6%) on which it was based; calibration was not reported. Likewise Riviello et al [137] reported an AUROC and Hosmer-Lemeshow chi square statistic of 0.81 and 11.94($p=0.154$) and 0.76 and 11.46($p=0.177$) for R- MPM

and Simplified R-MPM respectively and compared it to MPM –III (initial) (AUROC=0.72 and H-L chi square statistic of 17.66 (p=0.024)) on which it was based. Turner et al [136] did not report either discrimination or calibration but used summary statistics to report their findings (Supplementary Table 4.1.8).

4.1.5 Discussion

This systematic review of critical care scoring systems in LMICs reports good to excellent discrimination in 86.3% evaluations between survivors and non-survivors of ICU admission and good calibration in 66.3% of those reporting calibration. Three major findings, with special relevance to the LMIC settings, limit generalisability: missing values and their handling, was only reported in 27.8% evaluations; post ICU outcomes were not available for 48.1% where ICU mortality was the outcome; only 46.8% reported a lower age limit, with 51.4% of these including patients who were aged less than 18 years.

ICU risk prediction models, almost exclusively developed in HIC settings, are used to compare outcomes for risk stratification, quality improvement initiatives, benchmarking and research including enrolment into clinical trials [161]. For a critical care prognostic model to be effective it needs to be calibrated to the target setting and have an acceptable data collection burden. In HIC, these twin requirements are fulfilled by medical registries, which enable standardised, centralised, often automated, electronic data gathering, which is then validated. These registries include mechanisms for providing feedback on critical care unit performance and also enable regular recalibration of prognostic models, thus minimising the incorrect estimation of predicted mortalities due to changes in case-mix and treatment. The absence of such registries in LMIC settings, with important exceptions (for example in Brazil, Malaysia and Sri Lanka), is a significant barrier for the validation and recalibration of existing models, and the

development of models tailored to these settings. Accordingly, none of the validation studies included in this review are outputs from medical registries, no studies reported on model performance from different time points in the same setting and only three studies were conducted in two or more hospitals [137, 152, 162].

This paper highlights variations in the conduct and reporting of validation studies in LMICs. For example, missing values handling, which can lead to bias and thus influence model performance especially in LMICs settings [163], was only infrequently reported. Where reported, imputation by normal values (which is less justifiable in LMIC settings) and exclusion of incomplete records (leading to inefficient use of the dataset) were the methods frequently utilised. Missing values in prognostic models in LMIC settings are likely to be a persistent problem. As validation studies of prognostic models in LMIC settings become more common (17 of the 54 studies were published in 2015, 2016 or 2017) it is important for investigators to adhere to reporting standards, such as CHARMS- especially with regard to performance measures, outcomes and missing values- to enable robust interpretation.

Some of these difficulties may be alleviated by increasing efforts to efforts to improve the availability and recording of measures such as GCS and saturations or by effecting substitutions for the measurements that are more inaccessible in LMIC settings (for example urea for creatinine and saturations for PaO2). Likewise, research into the utility of other techniques of imputation (for example multiple imputation) may reduce bias and increase the interpretability of model performance. The development of models with fewer and more commonly available measures (for example simplified Rwanda MPM [137] and TropICS (under review for publication)) perhaps in conjunction with medical registries

promoting research may also be effective in improving mortality prediction in these settings.

This review, in keeping with findings from other reviews in predominantly HICs [120, 161, 164], found that while discrimination was generally at least good (86.3%), calibration was less so with only 67 of the 102 (65.7%) evaluations reporting a H-L p value of more than 0.05 and only thirteen (12.7%) evaluations reporting both excellent discrimination and good calibration [118, 156, 159, 160, 165]e. A possible reason for poor calibration in the LMIC setting could be the difference in the case-mix of the study population compared with that in which the model was developed. Additionally, three of the thirteen evaluations reporting both excellent discrimination and good calibration were from first level customised models [158] and in five [156, 159] the sample size was small (<150). It is known that a calibration measure such as the Hosmer-Lemeshow goodness of fit test might show high p-values in this circumstances, simply as a consequence of the test having lower power and not necessarily a good fit.

4.1.6 Limitation

This review was limited to a single database (PubMed). There is no MeSH for LMIC (non-HIC) and hence a hand search strategy was deployed. The review was intended to be for adult prognostic models used only in adult patients, however due to the manner in which the studies were reported it was not possible to exclude paediatric patients.

4.1.7 Conclusion

Performance of mortality risk prediction models for ICU patients in LMICs is at most moderate, especially with limitations in calibration. This necessitates continued efforts to develop and validate LMIC models with readily available prognostic variables, perhaps aided by medical registries. Robust interpretations

of their applicability are currently hampered by poor adherence to reporting guidelines, especially when reporting missing value handling.

Table 4.1.1 Studies and evaluated scoring systems

Study	Scoring system/s	Country	Study (continued)	Scoring system/s	Country
Abhinandan and Vedavathi (2013) [166]	APACHE II SOFA GCS	India	Liu et al (2016) [52]	APACHE II SOFA	China
Acharya et al (2006) [167]	SOFA (Delta) SOFA (Initial) SOFA (Maximum) SOFA (Mean)	Nepal	Mohan et al (2015) [53]	APACHE II SAPS II SAPS 3 SOFA	India
Aggarwal et al 2006) [124]	APACHE II SAPS II MPM II 0 MPM II 24	India	Nair et al (2016) [54]	SOFA SAPS	India
Ahluwalia (1999) [135]	APACHE II 48 hours [TM) New Score[a]	India	Namendys-Silva et al (2013) [8]	SOFA MexSOFA initial (VM) MexSOFA 48hours (VM)	Mexico
Celik et al (2014) [139]	SAPS II	Turkey	Naqvi et al (2016) [55]	APACHE II SAPS SOFA	Pakistan
Chang et al (2006) [168]	APACHE II	Taiwan	Nassar Jr, et al (2012) [56]	APACHE IV SAPS 3 MPM III	Brazil
Chiavone and Rasslan (2005) [169]	APACHE II	Brazil	Naved et al (2011) [57]	APACHE II 48 hours (TM)	Pakistan
Eapen et al (1997) [143]	OSF (VM) APACHE II (VM)	India	Nimgaonkar et al (2004) [58]	APACHE II Artificial Neural	India

				Network (ANN22) (MTM) Artificial Neural Network (ANN15) (MTM)	
Evran et al (2016) [155]	APACHE II APACHE IV SAPS 3	Turkey	Nouira et al (1998) [59]	APACHE II SAPS II MPM 0 MPM 24	Tunisia
Fadaizadeh et al (2012) [141]	APACHE II SAPS II	Iran	Ratanarat et al (2005) [27]	APACHE II SAPS I	Thailand
Faruq et al (2013) [170]	APACHE II SAPS II	Bangladesh	Riviello et al (2016) [26]	MPM III (0) R-MPM[a] Simplified R-MPM[a]	Rwanda
Galal et al (2013) [157]	APACHE II SAPS II, SOFA	Egypt	Sathe and Bapat (2014) (60]	APACHE II SAPS II,	India
Gilani et al (2014) [171]	APACHE II APACHE III SAPS II	Iran	Sekulic (2015) [61]	APACHE II MPM II (0) MPM II (24) MPM II (48) MPM II (72) MPM II (TM 7days) SAPS II SOFA (24) SOFA (48) SOFA (72) SOFA (7d)	Serbia

Godinjak et al (2017) [148]	APACHE II SAPS II	Bosnia and Herzegovina	Shoukat et al (2016) [62]	APACHE IV	Pakistan
Gupta and Arora (2003) [172]	APACHE II	India	Shrestha et al (2012) [63]	APACHE III SOFA	Nepal
Haidri et al (2005) [173]	APACHE II	Pakistan	Silva Junior et al (2010) [64]	SAPS 3	Brazil
Halim et al (2009) [159]	APACHE II SOFA (Initial) SOFA (Maximum) SOFA (Mean) Modifided SOFA (Initial) Modifided SOFA (Maximum) Modifided SOFA (Mean)	Indonesia	Soares and Salluh (2006) [65]	SAPS II SAPS 3 SAPS 3 (CSA)	Brazil
Hamza et al (2009) [174]	APACHE IV SAPS II MPM II0	Egypt	Soares et al (2004) [66]	APACHE II APACHE III SAPS II, MPM II 0 MPM II 24	Brazil
Hashmi et al (2016) [175]	APACHE II APACHE II (MTM)	Pakistan	Soares et al (2010) [67]	SAPS II SAPS 3 SAPS 3 (CSA) MPM III (24)	Brazil
Hernandez and Palo (2014) [140]	SAPS 3	Philippines	Sutheechet (2009) [68]	SAPS II MPM II (24)	Thailand
Hosseini and Ramazani (2015) [176]	APACHE II GCS	Iran	Teoh et al (1997) [69]	APACHE II	Malasiya
Jain et al (2016) [144]	SOFA (Initial) SOFA (Maximum) SOFA (Mean)	India	Turner et al (1989) [25]	APACHE II TISS Organ	South Africa

				failure (defined[a])	
Juneja et al (2012) [118]	APACHE II APACHE III APACHE IV SAPS II SAPS 3 MPM II (0) MPM III (0) SOFA	India	Wilairatana et al (1995) [70]	APACHE II APACHE III SAPS II TISS	Thailand
Khan et al (2015) [149]	APACHE II APACHE II 48 hours (TM) SAPS II SAPS II 48 hours (TM) SOFA (Mean at 24 hours) SOFA (Mean at 48 hours)	India	XueZhong et al (2015) [71]	APACHE II APACHE IV SAPS 3	China
Khawannimit and Geater (2007) [150]	APACHE II SAPS II	Thailand	Yamin et al (2011) [72]	APACHE IV	Pakistan
Khwannimit and Bhurayanontachai (2011) [158]	APACHE II SAPS 3 SAPS 3(AUS) SAPS II Customised APACHE II (First level customisation) Customised SAPS II (First level customisation) Customised SAPS 3 (First level customisation)	Thailand	Yousef and Suliman (2013) [73]	SOFA	Egypt
Kiatboonsri and Charoenpan (1995) [165]	APACHE II	Thailand	ZHAO Xiao-xia et al (2013) [74]	GCS (initial] GCS (24h) GCS (48h) GCS (72h)	China

				SAPS II (initial) SAPS II (TM 48 hours) SAPS II (24h) SAPS II (TM 72 hours) Simplified SAPS II (VM)	

VM = Variable Modification; TM = Temporal Modification; MTM = Modelling Technique Modification

[a] *New scoring system development*

Table 4.1.2 Model modifications

Study	Original scoring system (New model name)	Changes made
First level customisation		
Khwannimit and Bhurayanontachai (2011) [158]	APACHE II	Customized APACHE II logit=-7.7206+ (APACHE II score×0.2013)+new diagnostic category weight (Appendix I of Khwannimit et al 2011)
Khwannimit and Bhurayanontachai (2011) [158]	SAPS II	Customised SAPS II logit =-10.1779+ 0.0719 (SAPS II score)+1.4891 ln×(SAPS II score+1)
Khwannimit and Bhurayanontachai (2011) [50]	SAPS 3	Customised SAPS 3 logit=-33.4249+ln (SAPS 3 score +1)×7.8699
Variable Modifications		
Eapen et al (1997) [143]	APACHE II	GCS excluded
Eapen et al (1997) [143]	OSF	Neurological component excluded
Namendys-Silva et al (2013) [125]	SOFA (MexSOFA initial)	1. The respiratory component was assessed by SF (SpO2/FiO2) ratios instead of PaO2/FiO2 (PF)

		2. Neurological function component was excluded8 3. Data recorded in the initial 24hours after admission
Namendys-Silva et al (2013) [125]	SOFA (MexSOFA 48)	1. The respiratory component was assessed by SF (SpO2/FiO2) ratios instead of PaO2/FiO2 (PF) 2. Neurological function component was excluded8 3. Data collected between 24 - 48 hours after admission
Zhao et al (2013) [177]	SAPS II	1. Underlying disease variables excluded 2. Admission type variables excluded
Temporal Modification		
Ahluwalia et al (1999) [135]	APACHE II	Score calculated after 48 hours
Khan et al (2015) [149]	APACHE II	Score calculated after 48 hours
Khan et al (2015) [149]	SAPS II	Score calculated after 48 hours
Naved et al (2011) [146]	APACHE II	Worst values at 48 hours
Sekulic et al (2015) [156]	MPM II	Worst values at 7 days
Zhao et al (2013) [177]	SAPS II	Worst values at 48 hours
Modelling technique modification		
Hashmi et al (2016) [175]	APACHE II	APACHE II calculated automatically by software which use manually entered values using the logit equation= -4.063 + (APACHE II) x 0.181
Nimgaonkar et al (2004) [147]	APACHE II	Artificial Neural Network (ANN 22) model trained on an Indian patient dataset using the 22 APACHEII variables
Nimgaonkar et al (2004) [147]	APACHE II	Artificial Neural Network (ANN 15) model trained on an Indian patient dataset using the 15 APACHEII variables

Table 4.1.3 Missing value handling

Study	Scoring system/s	Missing value handling
		Exclusion
Acharya et al (2006) [167]	SOFA initial SOFA mean SOFA delta SOFA maximum	Where investigations were not carried out or lost or patients lost to follow up. (Numbers not reported)
Celik et al (2014) [139]	SAPSII	One hundred and seventy-eight patients (21.1%) were excluded due to lack of data, and 46 (5.55%) patients were excluded due to archival documentation problems. No information on admission source, attached devices, PaO2/FiO2, and Glasgow Coma Score was available for the excluded group in the computerised medical records. The included group survey did not differ from the excluded group regarding age, gender, admission time, and admission day. The prevalence of trauma and intoxication was higher among the excluded group than the included group (trauma 15%, intoxication 30%).
Chiavone et al (2005) [169]	APACHEII	One patient excluded
Godinjak et al (2017) [148]	APACHE II SAPS II	15 patients (7.9%) who died in the first 24 hours after admission into the MICU.
Haidri et al (2011) [173]	APACHEII	All patients with incomplete records and missing variables including laboratory investigations or who were not followed up due to any reason were excluded.
Hernandez et al (2014) [140]	SAPS 3	159 (6.6%) were excluded for incomplete SAPS 3 data.
Jain et al (2016) [144]	SOFA initial SOFA mean SOFA maximum	Three subjects (6.8%) were excluded as some of the investigation reports were not available
Naqvi et al (2016) [145]	APACHE II SAPS SOFA	29 patients (23.6%) with incomplete information of scoring system in case records
Naved et al (2011) [146]	APACHEII	Patients with incomplete records not included (numbers not reported.

Willairatna et al (1995) [178]	APACHEII APACHEIII SAPS II TISS	When scores could not be derived due to an incomplete set of physiological data patients were excluded.
		Normal values imputation
Faruq et al (2013) [170]	APACHEII SAPSII	GCS attributed as normal
Khwannimit and Geater (2007) [150]	APACHEII SAPSII	GCS attributed as normal Missing physiological variables were found in only 6% for APACHEII (excluding bilirubin, which was missing in 76.5% of the presented data records) and 6.3% for SAPSII variables (excluding bilirubin, which was missing in 76.5% of the presented data records)
Soares et al (2004) [151]	APACHE II APACHE III MPM II (0) MPM II (24) SAPS II	Zero points or normal values were inserted where data were missing [19]. There were no missing variables for physiological data. Among laboratory variables, normal values were inserted for albumin in 623 (49.6%), prothrombin time in 274 (21.8%) and bilirubin in 676 (53.8%) patients. No patient with jaundice on physical examination lacked serum bilirubin measurements.
Soares and Salluh (2006) [153]	SAPSII SAPS 3 SAPS 3 (CSA)	Zero points or normal values were assigned for missing variables [1, 12]. There were no missing data for demo-graphic, clinical and physiologic data. Among laboratory variables, normal values were attributed only for bilirubin in 535 patients (56%). No patient with jaundice lacked bilirubin level measurements.
Soares et al (2010) [152]	MPM III (24) SAPS II SAPS 3 SAPS 3 (CSA)	Zero points or normal values were attributed for missing variables. There were no missing data for demographic, clinical and physiologic data. Missing laboratory variables are depicted in Table 1 of Electronic Supplementary Material (ESM). No patient with jaundice lacked bilirubin levels measurements.
		Exclusion and normal values imputation
Nassar Jr et al (2012) [154]	APACHE IV SAPS 3 MPM III	3.02% patients with incomplete data which prevented an adequate calculation of one or more of the scores were excluded; these missing data could be pre-ICU length of stay, reason for ICU admission, chronic health variables and mechanical ventilation on first day. Missing physiologic variables, namely bilirubin, acid-base abnormalities, PaO2 or PaO2/FiO2 ratio, were considered as normal for purpose of calculations.

Riviello et al (2016) [137]	MPM (0) III	Exclusion of 2 patients (0.5%) due to lack of discharge vital status. Normal values attribution details provided in supplementary table 3 of the original paper. Highest proportions of missing values were for GCS (36.30%) followed by chronic renal compromise/ insufficiency (7.96%).

Table 4.1.4 Area Under the Receiver Operating Characteristic curve performance

Discrimination	O.9 - 0.99 (Excellent)	0.80 - 0.89 (Very good)	0.70 - 0.79 (Good)	0.6 – 0.69 (Moderate)	< 0.60 (Poor)	Total
APACHE II	3	12	7	4	0	26
APACHE II (First level customisation)	1	0	0	0	0	1
APACHE II (VM)	0	0	0	1	0	1
APACHE II (TM)	1	0	1	0	0	2
APACHE II (MTM)	0	3	0	0	0	3
APACHE III	2	1	1	1	0	5
APACHE IV	1	3	0	0	0	4
GCS	0	1	3	1	0	5
MPM I (initial)	0	1	0	0	0	1
MPM I (24h)	0	1	0	0	0	1
MPM II (initial)	1	2	0	2	0	5
MPM II (24h)	2	0	1	0	0	3
MPM II (48h and 72h)	0	2	0	0	0	2
MPM II (TM 7days)	1*	0	0	0	0	1

MPM III (initial)	1	1	1	0	0	3
MPM III (24hours)	0	0	1	0	0	1
OSF (VM)	0	0	1	0	0	1
SAPS I	0	0	2	0	0	2
SAPS II	2	11	7	1	1	22
SAPS II (First level customisation)	1	0	0	0	0	1
SAPS II (TM)		3	0	0	0	3
SAPS 3	3	5	0	0	0	8
SAPS 3 (AUS)	1	0	0	0	0	1
SAPS 3 (First level customisation)	1	0	0	0	0	1
SAPS 3 (CSA)	0	2	0	0	0	2
SOFA (Initial)	0	2	5	2	0	9
SOFA (Mean)	4	1	0	1	0	6
SOFA (Maximum)	1	1	0	0	0	2
SOFA (Delta)	0	0	0	1		1
ModifiedSOFA (Initial)	0	0	1	0	0	1
ModifiedSOFA (Maximum)	1	0	0	0	0	1
ModifiedSOFA (Mean)	1	0	0	0	0	1
SOFA (MexSOFA)	0	0	2	0	0	2
TISS	0	0	1	0	0	1
Total	28	52	34	14	1	129
Percentage	21.7%	40.3%	26.4%	10.8%	0.8%	100%

VM = Variable Modification; TM = Temporal Modification; MTM = Modelling Technique Modification

4.2 Applicability of the APACHE II model to a lower and-middle income country

4.2.1 Background

Sri Lanka is a low and middle income country (LMIC) in South Asia with state healthcare provided free of charge at the point of delivery. The country's healthcare system is extensive, with the best basic health indicators in the South Asian region [179]. State Intensive Care Units (ICUs) account for the majority of critical care health services in the island. Previous research by our group indicates that over 500 adult intensive care unit (ICU) beds (2.2 beds per 100,000 population) are available in nearly 100 units with over 38,000 admissions annually, while the overall crude mortality rate was observed to be about 17%. Most (70%) of the ICUs are medical, surgical or mixed units while 11 were paediatric ICUs. Eighty-four of the ICUs had a nurse: patient ratio of at least 1:1 [37, 58].

While critical care in Sri Lanka has been widespread, it lacked a system for benchmarking ICU services. This deficit is in common with most low income countries (LICs) and low-and-middle income countries (LMICs). In contrast, high income countries (HICs) employ medical registries to continuously audit patient care in critical care settings [180-182]. We define a medical registry as a systematic collection of a clearly defined set of health and demographic data for patients with specific health characteristics, held in a central database for a predefined purpose. Within these registries, prognostic models are used to adjust performance for case-mix differences between institutions to enable fair

comparisons. [183]. The registry led evaluation of interventions aimed at improved service delivery and patient care relies on both accurate information regarding current performance and the ability to measure impact following interventions. Thus the lack of a medical registry which enables the development and utilisation of appropriate case-mix adjustment models is a significant barrier to improving critical care services in LICs and LMICs [130, 184].

Current critical care prognostic models described in the literature have been largely developed in HICs [185]. The case-mix of ICU patients changes over time, and critical care outcomes improve. For this reason, it is common for medical registries and networks to customise prognostic models to avoid overestimating predicted mortality and to ensure continuing relevance.

The validation of such models to local settings and an assessment of their feasibility is necessary prior to advocating their use in benchmarking critical care outcomes. Moreover, it is questionable whether models developed in HIC are directly transferable to LIC/LMICs. For instance, diagnostic categories do not cater to common diagnoses in these countries, such as dengue, malaria, snakebite and organophosphate poisoning, and treatment options may vary [37, 58, 130]. These factors will affect the performance of the models, which need recalibration to compensate [131, 132, 186]. Only a few LMIC studies address these challenges, mainly single-center studies or those focusing on the predictive validity of a prognostic model for a single disease [173, 187-189].

An often under-reported but major obstacle to the use of prognostic models in LMICs is missing data. An incomplete dataset can be due to a combination of, a lack of resources (e.g. blood gas analysis), and failure to perform observations (e.g. peripheral oxygen saturation measurement), a failure to record the measurement, and are often exacerbated by the absence of electronic health

information systems. Common guidance is to assume normality for a variable when not measured or unavailable, scoring “0” in weighted scoring system [173]. Such an approach is likely to be inappropriate for resource-restricted settings such as LICs and LMICs and can adversely impact model performance by underestimating severity scores. Acute Physiology and Chronic Health Evaluation II (APACHE II), is a second generation prognostic scoring system for critically ill patients, based on the original APACHE scoring system. It represents a simplification of the original system with only 12 physiological variables used to calculate an Acute Physiology Score (APS) instead of the original 34. [185]. In addition to its role in benchmarking ICUs and comparing their performance, it is also an important stratification tool in the conduct and analysis of clinical trials.

4.2.2 Study aim

The objective of the current paper is to investigate the utility of APACHE II as a prognostic model in an LMIC setting and to explore the implications of an incomplete dataset.

4.2.3 Study design

This study of patients admitted to ICUs was conducted in Sri Lanka with the participation of 18 state ICUs; they consist of eight mixed/general (medical and surgical) ICUs, five medical ICUs and five surgical ICUs. We have previously described infrastructure, equipment and staffing in ICUs in Sri Lanka [58]. The study was conducted during three consecutive months in 2012 prior to the initiation of a medical registry in Sri Lanka. As per APACHE II exclusion criteria, patients who were transferred from other ICUs, those less than 16 years of age, patients discharged within 24 hours of admission and those who died within six hours of admission were excluded. In the case of patients with multiple admissions during the study period, only the first admission was included in the

analysis [185]. Patients presenting with burn injuries or following coronary artery bypass graft, those with pacemaker implants and those who were pregnant or in the postpartum period were also excluded from the analysis, also as per APACHE II eligibility criteria [185].

Data were extracted by trained nursing officers from case records onto paper case record forms (CRF). All data required for APACHE II probability calculation at admission and within the first 24 hours of ICU stay were extracted. Discharge information collected included ICU mortality, length of ICU stay, duration of mechanical ventilation and treatment with vasoactive drugs or antibiotics. The Glasgow Coma Score (GCS) of sedated patients were recorded as the value before sedation commenced. The study did not collect hospital or 28-day outcome data due to logistical difficulties in conducting follow-up beyond the ICU stay.

Daily telephone reminders from the investigators to the ICUs were made to encourage nursing staff to extract data from the patient records. The availability of the measurements required for APACHE II calculation (including 5 bedside measurements and 7 laboratory measurements for the Acute Physiology Score, APS) for each patient was noted in the CRF. The filled CRFs were gathered in batches, transported to a central location (Colombo) and entered into a database. There were no further measures for validation or assessment of data quality.

APACHE II APS scores were calculated using the worst physiological values during the first 24 hours of ICU admission [185]. Missing values of APS variables were imputed by two methods; by normal values to generate “0” weighting on APS; and by multiple imputation using chained equations (MICE). It was assumed that the missingness of a variable is It was assumed that the missingness of a variable depends on other observed variables, Missing At

Random (MAR). [186, 190, 191]. Multiple Imputation (MI) generates several values reflecting the uncertainty in the estimation of the imputed value. MICE was performed using Predictive Mean Matching (PMM) of the "mi impute chained" command in Stata (version 14, Stata Corp, College Station, TX, USA). The number of imputations (M) was set at 30 and "k-nearest neighbours" [41] was 10 [192]. The APACHE II mortality probabilities for normal value imputation and MICE were then calculated [185]. In addition, mortality probabilities for MICE were calculated by sequentially removing APS variables, one at a time, commencing with the least available measure and ending with the most prevalent. Model performance was assessed using discrimination, calibration and accuracy as described under Section 2.4.

4.2.4 Results

The study captured 995 admissions to the 18 units during the three-month study period. Of the 995 total admissions, 178 were excluded from APACHE II score calculations as per the exclusion criteria stated in the methods section. A further 81 patients were excluded from the probability calculations because the APACHE II reason for admission was not coded.

Table 4.2.1 summarises the characteristics of the study population and Fig. 4.2.1 summarises the ICU mortality of the commonest APACHE II diagnostic categories. The majority (over 70%) of admissions were "medical", with just over 10% being "emergency surgical" admissions. At least a quarter of the patients were known to have chronic cardiovascular and respiratory diseases co-existing at the time of ICU admission. A similar proportion had diabetes mellitus.

Table 4.2.1 describes the availability of the demographic and diagnostic information required for APACHE II probability calculation, and Table 4.2.2 similarly details the availability of the physiologic and laboratory measurements

required for APS calculation.

Complete case records for APACHE II score calculation was only available in 13 patients (1.6%). Each bedside clinical measurements needed for APS were available in at least 70.6 % of patients but the availability of serial measurements used for APS calculation over the first 24 hours of ICU stay was more variable. Availability of APACHE II laboratory measurements also varied widely, with electrolyte values (sodium and potassium) being present in over 60% but pH and serum creatinine only being available in approximately 20% of patients (Table 4.2.2). The distribution of missing data between alive and dead patients and the significance of the difference for each variable is summarised in Table 4.2.4.

APACHE II score distributions for normal imputation and MICE, for alive and dead patients, are displayed in Figure 4.2.4. The performance of the APACHE II model when missing values are imputed with normal values and by MICE is detailed in Table 4.2.3. The performance of the APACHE II model when missing values are imputed by MICE and the sequential removal of the least available APS variable is shown in Table 4.2.3 and in Figure 4.2.2. Discrimination for both imputation methods, as measured by AUROC, was between 0.70 and 0.80. However, SMR was 1.27 (95% CI 1.17, 1.40) for normal value imputation and 0.46 (95% CI 0.44, 0.49) for MICE when all APS values were included.. Both imputation methods led to poor APACHE II model calibration ($p<0.001$) with Hosmer-Lemeshow C-statistic of 68.8 for normal value imputation and 165.6 for MICE.

4.2.5 Discussion

This evaluation of the utility of the APACHE II model in Sri Lankan state ICUs highlights important challenges in the use of prognostic models in a LMIC. Structural, resource and staffing limitations result in an incomplete dataset (likely to be in common with other LMIC clinical settings) with high proportions of missing

data necessitating imperfect imputation techniques, which when combined with an inability to gather post-ICU outcomes, undermines rigorous evaluation of model performance.

There is limited data on prognostic models in resource-restricted ICU settings, including information on data availability. This can be attributed to a general lack of systematic data collection overstretched staff, the absence of electronic health records and limited Information Technology (IT) resources. Subsequently, published validations of prognostic models in LMICs are often limited to retrospective single center studies or disease specific evaluations [173]. Unpublished data from a systematic review of prognostic models by our group reveals that less than a third of all validation studies of prognostic models in non-HIC report any information on missing data. Where stated, imputation by normal values and case exclusion were by far the common strategies.

This dataset from a large number of ICUs in a resource limited setting shows limited availability of laboratory and point of care measurements, and minimal serial invasive measurements during the first 24 hours of ICU stay. The relative availability of demographic, diagnostic, comorbidity information (all more than 80%) and bedside clinical observations (all more than 70%) contrasts sharply with poor availability of the relatively expensive tests for serum creatinine and pH in the first 24 hours of ICU stay. In comparison, only 10% of blood gas values and creatinine were missing (and presumed to be normal) in the original APACHE II study [185]. Invasive laboratory or point of care tests were infrequently repeated in the first 24 hours of ICU stay. Even White Blood Cell (WBC) measurement, was repeated in less than 20% of patients during this period. Since serial invasive measurements in the first 24 hours of ICU stay do not appear to be feasible in this setting, and given the difficulties in data collection, the place of repetitive

invasive measurements in prognostic scores, especially in LICs and LMICs require reevaluation. It is to be noted that gaps in the dataset were despite daily reminders to improve data extraction and are more likely to be due to missing measurements. Impractical data requirements will discourage data gathering and contribute to incompleteness in datasets, thereby diminishing their usefulness in benchmarking, research and quality improvement efforts.

The paucity of serial bedside clinical measurements however, is unlikely to be completely explained by lack of personnel, and needs further investigation with a view to remedial measures. Improvement in clinical observations, monitoring and reassessment could potentially lead to large gains in patient outcomes with relatively minimal extra resources. An understanding of the behaviour of LMIC clinical staff with regard to clinical decision making, observations and patient assessment and reassessment, are likely pre-requisites for such improvements.

The lack of hospital and post-hospital discharge patient outcomes is a major obstacle in non-HIC when attempts are made to evaluate critical care units and to perform benchmarking. Hospital outcomes are required for evaluation of APACHE II performance and contribute to an overestimation of predicted mortality when ICU outcomes are substituted for longer term outcomes (as done in this study) and lead to difficulties in interpreting prognostic model performance. It is thus necessary to devise means of routinely assessing longer term outcomes to better evaluate the impact of ICU care in the LMIC setting and guide the utilisation of scarce critical care resources.

Validation of data and rapid feedback with visualisation of relevant data are measures known to improve data returns and data quality in HIC, frequently in association with critical care registries [193-195], but were not attempted due to lack of feasibility. The implementation of setting-adapted critical care registries,

especially when implemented by incorporating affordable Information Technology in LMIC may help overcome logistical and data capture challenges.

The initial APACHE II validation study imputed missing data (for investigations) with normal values, assuming the clinician considering the measurement to be normal, for example in patients admitted for observation to the ICU [10]. In general, it cannot be assumed that missing values denote normal organ function in the LMIC ICU setting. Disconcertingly, our unpublished review suggests that normal value imputation is the commonest strategy used in LMIC critical care prognostic studies and will lead to a left-shift of the severity scores (Figure 4.2.4). The current study utilised normal value imputation and MICE demonstrating a gulf between mean APACHE II scores (11.78 and 23.9), mean APACHE II probabilities (0·16 and 0·43, Table 4.2.3), and consequently, in SMR (1.27 and 0.46, Table 4.2.3). Discrimination and accuracy were largely aligned, but calibration, assessed by the H-L c-statistic, was 68.78 (normal imputation) and 165.62 (MICE) with statistically significant p-values in both instances, signifying very poor calibration. Overall, these study findings and the lack of hospital outcome data, make the interpretation of APACHE II model performance in this setting difficult. Limited validation studies in other resource-limited settings have reported varied findings [173, 187-189].

The large proportions of unavailable measurements (for example, pH and creatinine with more than 75% missing data), diverse mechanisms underlying the missing data to the missingness and the extent of the difference between the two model variants, call into question the suitability of current imputation strategies. As an incomplete dataset is likely to be a feature of virtually all LIC and LMIC acute care data collection efforts, research and guidance (including reporting guidelines) on missing data handling are urgent requirements.

In addition, it is not clear to what extent the prognostic variables selected for the APACHE II contribute to model performance in this setting. In the MICE model (Table 4.2.3) as the least prevalent measurements were sequentially removed, AUROC does not decrease below 0.70 even with five measurements for APS. This and other limitations of existing prognostic models for LMICs discussed above, justify the need for a setting-adapted critical care prognostic model or a de-novo model with fewer measurements in order to enable a relatively more complete dataset.

4.2.6 Conclusion

An incomplete dataset complicates the interpretation of a prognostic model's performance in the Sri Lankan ICU setting, which may have implications for other LMIC in the region. The proportion of missing data is large, and imputing missing values as normal, according to common practice, is not appropriate. Although multiple imputation is the more principled approach, the extent of missing data with unknown missing data mechanisms highlights the requirement for further research in such settings. A setting-adapted critical care prognostic model, mindful of the limitations highlighted in this study, is warranted.

Figure 4.2.1 Commonest APACHE II diagnostic categories and ICU outcomes

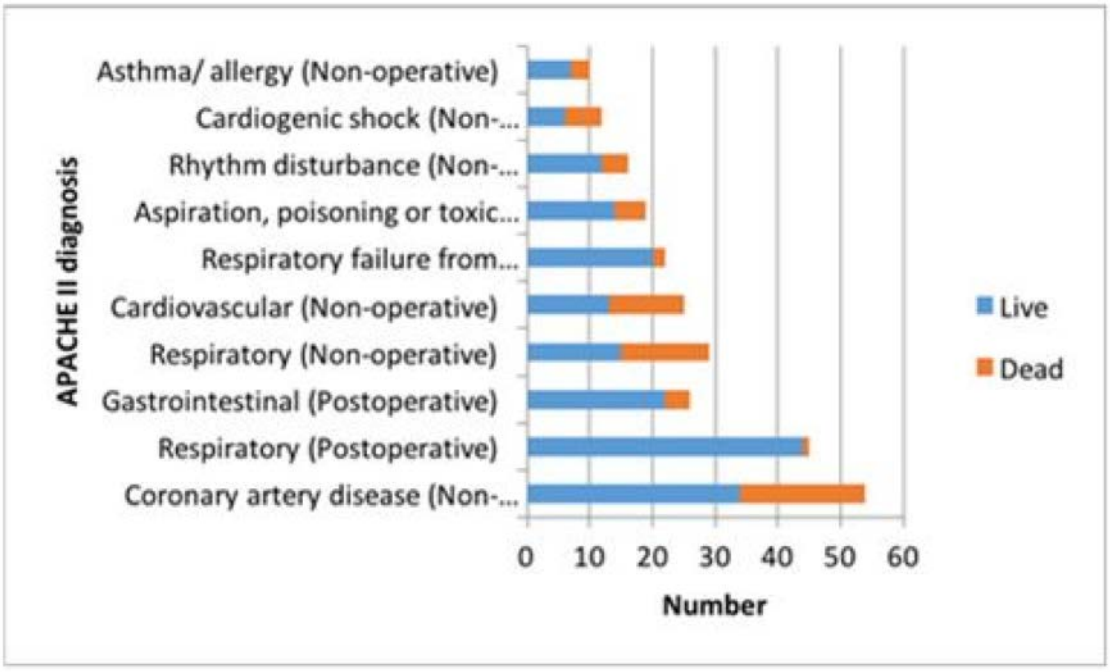


Figure 4.2.2 Performance of APACHE II model where the least prevalent APS have been removed and missing values replaced by MICE. From top to bottom; discrimination, accuracy, and calibration. In calibration '+' indicated p>0.05.

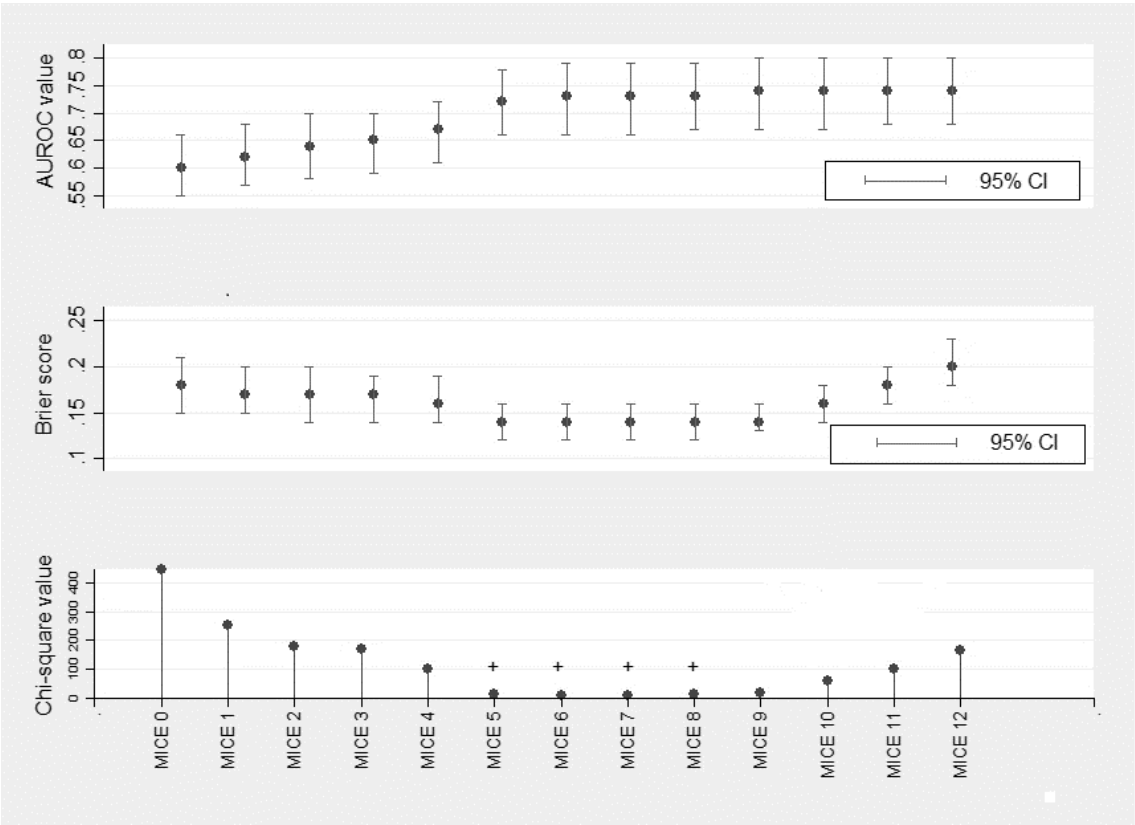


Figure 4.2.3 Proportion of missing values for variable needed to calculate the APACHE II score

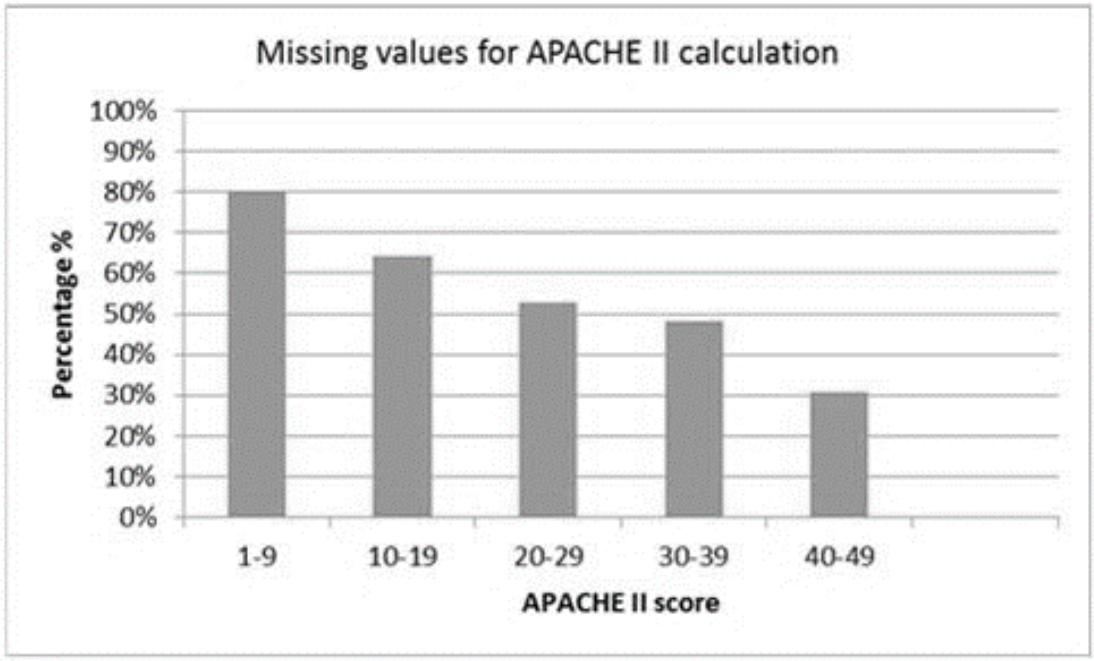


Figure 4.2.4 APACHE II scores for alive and dead patients – missing values imputed by normal values and by MICE.

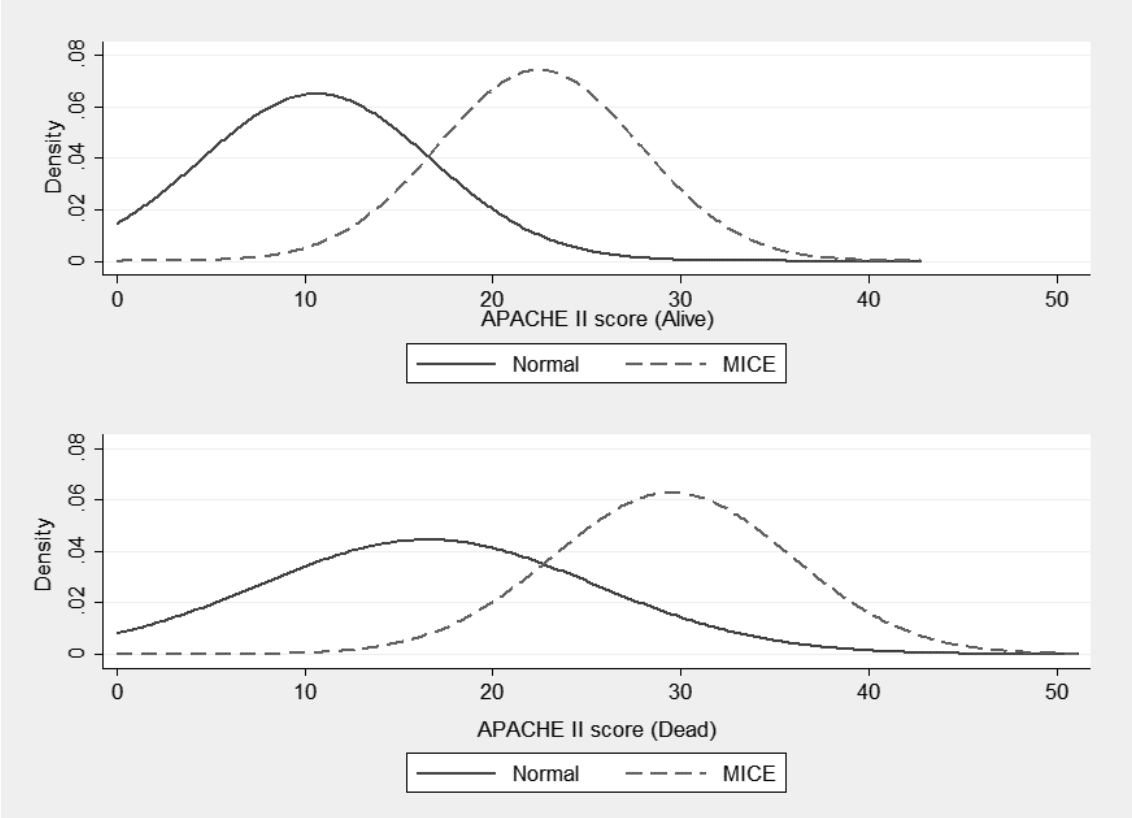


Table 4.2.1 Characteristics, case-mix and APACHE II data availability.

Characteristics and functions	**Total**	**Data availability on admission %**
Males, number (%)	461 (57.1)	98.8
Age, mean (SD)	52.4 (16.9)	81.3
Admission type	**Number (%)**	97.8
Medical	573 (70.3)	NA
Emergency surgical	91 (11.4)	NA
Elective surgical	135 (16.9)	NA
Chronic diseases	**Number (%)**	
Chronic renal failure	71 (10.5)	82.9
Chronic respiratory diseases	184 (26.5)	84.9
Chronic cardiovascular disease	185 (26.2)	86.5
Chronic liver disease	30 (4.6)	80.7
Diabetes mellitus	173 (24.4)	86.9
Tuberculosis	14 (2.0)	85.2
Primary malignancy	27 (3.9)	85.2
CPR prior to admission, number (%)	41 (5.7)	88.9

Durations	**Median [IQR]**	
Length of stay (days)	2 (1,4)	NA
Duration of mechanical ventilation (days)	3 (1,6)	NA
Duration of antibiotic therapy (days)	4 (2,10)	NA
Duration of vasoactive treatment (days)	3 (1,7)	NA

Table 4.2.2 Availability of variables needed for APACHE II score calculation – measurement at admission and at least one further measurement within the first 24 hour

Data item	Measurement at admission (%)	At least one further measurement in the first 24 hours (%)
Body temperature	78.0	58.4
Heart rate	88.5	67.6
Respiratory rate	81.0	59.9
Mean arterial pressure	70.6	62.8
Glasgow Coma Score	72.5	39.8
SpO2	80.5	31.8
PaO2	48.7	0.0
pH	20.2	6.9
WBC	38.2	16.3
PCV	58.6	12.9
Serum creatinine	18.7	7.5
K+	63.4	18.1
Na+	63.4	18.8

Table 4.2.3 Performance of the APACHE II model-normal value imputation and MICE. For MICE, APS variables are sequentially removed, commencing with the least prevalent. AP II is APACHE II and prob. indicates probability.

Model	AP II score mean (SD)	AP II prob.. mean (SD)	Expected deaths (95 % CI)	SMR (95% CI)	AUROC (95% CI)	HL C-statistic (p)	Brier score (95%CI)
Imputed (normal)	11.8 (7.2)	0.16 (0.17)	97 (88, 105)	1.27 (1.17, 1.40)	0.70 (0.65, 0.76)	68.8 (p<0.001)	0.14 (0.12, 0.16)
MICE 12 (full model)	23.9 (8.1)	0.43 (0.26)	265 (252, 277)	0.46 (0.44, 0.49)	0.74 (0.68, 0.80)	165.6 (p<0.001)	0.20 (0.18, 0.23)
MICE 11 (serum creatinine excluded from MICE 12)	21.7 (7.7)	0.37 (0.24)	230 (218, 242)	0.53 (0.51, 0.56)	0.74 (0.68, 0.80)	100.0 (p<0.001)	0.18 (0.16, 0.20)
MICE 10 (arterial pH excluded from MICE 11)	19.9 (7.3)	0.32 (0.23)	201 (190, 212)	0.61 (0.58, 0.65)	0.74 (0.67, 0.80)	60.0 (p<0.001)	0.16 (0.14, 0.18)
MICE 9 (oxygenation excluded from MICE 10)	17.1 (7.1)	0.26 (0.20)	159 (149, 169)	0.77 (0.73, 0.83)	0.74 (0.67, 0.8)	19.2 (p=0.037)	0.14 (0.13, 0.16)
MICE 8 (white blood count excluded from MICE 9)	16.4 (7.1)	0.24 (0.20)	149 (140, 159)	0.83 (0.77, 0.88)	0.73 (0.67, 0.79)	15.1 (p=0.130)	0.14 (0.12, 0.16)
MICE 7 (haematocrit excluded from MICE 8)	15.5 (6.9)	0.22 (0.18)	137 (128, 146)	0.90 (0.84, 0.96)	0.73 (0.66, 0.79)	8.0 (p=0.630)	0.14 (0.12, 0.16)
MICE 6 (serum sodium excluded from MICE 7)	14.9 (6.7)	0.21 (0.18)	129 (120, 138)	0.95 (0.89, 1.03)	0.73 (0.66, 0.79)	11.2 (p=0.342)	0.14 (0.12, 0.16)

MICE 5 (serum potassium excluded from MICE 6)	14.2(6.6)	0.19 (0.17)	121 (112, 129)	1.02 (0.95, 1.10)	0.72 (0.66, 0.78)	16.2 (p=0.094)	0.14 (0.12, 0.16)
MICE 4 (GCS excluded from MICE 5)	9.3 (3.2)	0.09 (0.06)	58 (55, 61)	2.12 (2.02, 2.24)	0.67 (0.61, 0.72)	100.0 (p<0.001)	0.16 (0.14 ,0.19)
MICE 3 (mean arterial pressure excluded from MICE 4)	7.7 (2.7)	0.07 (0.05)	46 (44, 49)	2.67 (2.51, 2.80)	0.65 (0.59, 0.70)	169.7 (p=<0.001)	0.17 (0.14, 0.19)
MICE 2 (temperature excluded from MICE 3)	7.4 (2.6)	0.07 (0.05)	45 (42, 47)	2.73 (2.62, 2.93)	0.64 (0.58, 0.7)	181.3 (p<0.001)	0.17 (0.14 0.20)
MICE 1 (respiratory rate excluded from MICE 2)	6.5 (2.4)	0.06 (0.04)	39 (37,41)	3.15 (3.00, 3.32)	0.62 (0.57, 0.68)	250.3 (p<0.001)	0.17 (0.15, 0.20)
MICE 0 (All APS variables excluded)	4.4 (2.2)	0.05 (0.03)	29 (28, 31)	4.24 (3.97, 4.39)	0.60 (0.55, 0.66)	442.5 (p<0.001	0.18 (0.15, 0.21)

Table 4.2.4 Missing APACHE II APS measurements. * signifies p<0.05 between alive and dead groups for each variable.

Measurement	Alive= 499 (80%)	Dead= 123 (20%)	Total= 622 (100%)
Heart rate	455 (91)	107 (87)	562 (87)
Respiratory rate*	423 (85)	87 (71)	510 (79)
Temperature*	411 (82)	87 (71)	498 (77)
Mean arterial pressure*	400 (80)	85 (69)	485 (75)
GCS	374 (75)	82 (67)	456 (71)
Serum potassium	340 (68)	77 (63)	417 (65)
Serum sodium	337 (68)	77 (63)	414 (64)
Haematocrit	305 (61)	77 (63)	382 (59)
White blood count*	197 (39)	32 (26)	229 (36)
Oxygenation*	154 (31)	39 (32)	193 (31)
Arterial pH*	86 (17)	41 (33)	127 (20)
Serum creatinine*	98 (20)	19 (15)	117 (18)

Figure 4.2.5 Fraction of Missing Information (FMI) and Relative Increase of Variance (RIV) for each APACHE II APS measurement

Measurement	FMI	RIV
Heart rate	32.27%	47.64%
Respiratory rate	31.66%	46.32%
Temperature	30.06%	42.97%
Mean arterial pressure	29.41%	41.66%
GCS	43.09%	75.72%
Serum potassium	43.17%	75.96%
Serum sodium	44.66%	80.71%
Haematocrit	48.01%	92.33%
White blood count	40.34%	67.61%
Oxygenation	41.17%	69.99%
Arterial pH	44.13%	78.99%
Serum creatinine	46.17%	85.77%

4.3 Traumatic Brain Injury outcomes in an LMIC tertiary care centre and performance of trauma scores

4.3.1 Background

Traumatic Brain Injury (TBI) is a major public health problem worldwide resulting in death and disability, especially of young and economically active individuals [196-198]. Neuropsychiatric consequences are common among TBI patients [199, 200]. TBI is greatest in low and middle income countries (LMIC), where 85% of the world's population live [201]. In comparison to patients in high-income countries (HIC), limited data indicates that LMIC patients have over twice the odds of dying following severe TBI [201] and have a greater disability.

Trauma scoring systems such as A Severity Characterization of Trauma (ASCOT), Trauma and Injury Severity Score (TRISS), Injury Severity Score (ISS) and Revised Trauma Score (RTS) enable benchmarking of services, quality assurance and research [202-205]. These and other similar models are usually developed for HIC settings and are infrequently validated in LMICs. Healthcare facilities, access to healthcare, varied case-mix and missing data can influence the performance of these models. Trauma or medical registries which report outcome data enable benchmarking of services (using probability of survival models such as ASCOT) and enable research are uncommon in LMICs [206]. It is thus important to validate and if necessary, adapt such models to the local setting.

Superior outcomes in HIC following TBI are most likely due to a combination of expertmultidisciplinary efforts in pre-hospital, hospital (including neurosurgical and critical care), rehabilitation, and well developed support services and quality improvement efforts [201]. In LMICs access to advanced neurosurgical and critical care services is limited and competition for these services remains high

[207]. Follow up services facilitating long-term rehabilitation require considerable equipment and manpower and are less well developed, resulting in treatment outcomes and complications being harder to ascertain and limiting improvement efforts. Similar to other critically unwell patients in LMIC settings, long-term outcomes for TBI patients, including functional status, patient independence and economic impact after TBI are not known in Sri Lanka and not widely known for other LMICs [201, 208, 209].

4.3.2 Study aim

This paper evaluates post-ICU outcomes of patients admitted with moderate and severe TBI to a tertiary neurocritical care unit in an LMIC and the performance of RTS, ASCOT, ISS and TRISS in this setting.

4.3.3 Study design

Consecutive adult patients (over 16 years of age) directly admitted to the neurosurgical intensive care units of the NHSL between 21st July 2014 and 1st October 2014 with moderate or severe TBI were recruited for this study. The selection of study duration was pragmatic. Severe TBI was defined as a GCS of <9 and moderate TBI was by a GCS of 9-12 at hospital admission [210, 211]. Patients who were transferred from other centres and any patients who had no contactable relatives in order to provide a contact telephone number and who were unable to communicate were excluded.

Patients were recruited to the study while being treated in the ICUs. Informed verbal consent was obtained from those patients who were adjudged to have capacity. Capacity was determined independently by the ICU team caring for the patient. If patients did not have capacity, assent was obtained from the Next Of Kin (NOK) and the study details were explained to them. Where assent was obtained and patient thereafter recovered to have capacity, informed written

consent was obtained from patients. Any patients who subsequently declined consent were to have their data retrospectively removed.

Data such as patient age, gender, level of education, marital status, and mechanism of injury were gathered by a data collector during ICU stay from the patient or the next of kin. ICU length of stay was collected after ICU discharge. Medical data extracted from case notes included nature and extent of injuries, CT brain findings, GCS scores, respiratory rate and systolic blood pressure on admission. RTS, ISS, TRISS and ASCOT scores were calculated [202, 212].

A telephone administered questionnaire based on the GOSE scale [213-216] was used to assess functional outcome of patients at 3 and 6 months after injury. The questionnaire could be completed independently by the patient, assisted by a adult living with the patient or completed by an adult living with the patient if patient was unable to communicate.

The GOSE scale rates the patient status into 8 categories: dead, vegetative state, lower severe disability, upper severe disability, lower moderate disability, upper moderate disability, lower good recovery, and upper good recovery. In order to aid analysis, functional outcome was divided into 3 groups based on GOSE scores; dead/vegetative (GOSE 1,2), disability (GOSE 3,4,5,6) and good recovery (GOSE 7,8).

The economic impact of the injury was assessed by the extent of economic dependence of the patient and their family, before injury, and at the time of the interviews (3 and 6 months after injury). An adapted tool from Griffiths et al was utilised with the exception of a question on specifics regarding family income which was considered too sensitive to include [217]. Patients' employment status before injury and at the time of the interviews was also assessed [6].

Data was analysed using Stata 13 [218]. Chi-Square test was used to compare

categorical variables and Ordinal Logistic Regression (OLR) was used for continuous variables. Non-parametric median test was used to analyse factors related to ICU length of stay. Discriminatory ability of RTS, ISS, ASCOT and TRISS for 30-day mortality, (and calibration) were assessed as described in Section 2.4.

4.3.4 Results

101 patients with TBI admitted to the NHSL neurosurgical unit were included in the study. 17 patients provided direct consent, 84 patients were recruited after assent from relatives and a further 16 patients were excluded due to consent or assent being declined.

83 (82%) patients were male. Ages ranged from 16 to 83 years with a mean age of 41.67 (SD 17.47) years. The dataset required for scoring system calculation was complete except for 3 (3.0%) patients who had no respiratory rate recorded and 18 (17.8%) did not have the blunt/penetrating nature of their injury recorded. Eighty-two of these patients (81.2%) had completed at least secondary education though only two patients had attended university. Just over 2/3^{rds} (68, 67.3%) of the patients were after RTAs while nearly everyone else (25 patients, 24.8%) were subsequent to falling from a height. When categorised by GCS scores on admission, 63 patients had severe TBI and 38 had moderate TBI. The mean ASCOT score was 29.2% (SD 23.7). Patient characteristics and summary values for the other three trauma scores are further summarised in Table 4.3.1.

Survival at ICU discharge, 3 and 6 months after injury was 68.3% (69 patients), 49.5% (50 patients) and 45.5% (46 patients) respectively. 7 (6.9%) patients were lost to follow-up as they were not contactable via the telephone numbers obtained. There was no significant difference between moderate and severe TBI (as per GCS) groups and survival at ICU discharge (p=0.180), survival at 3

months (p=0.308) or survival at 6 months (p=0.220). Similarly, there was no significant difference between patients after RTA and those after falls, when survival at ICU discharge (p=0.501), 3 months (p=0.502) and 6 months (p=0.847) were considered. There was no also significant association between length of ICU stay and moderate or severe TB (p= 0.411) or between RTA and fall (p=0.777).

Of the patients who were alive at 3 months after injury, 43 (86%) were living at home while the remainder were in rehabilitation centres or in hospital. Eighty percent (40 patients) could complete the study questionnaire unaided whereas 89% (41 patients) could do so 6 months after injury. Only 2 questionnaires at both 3 and 6 months after injury were jointly completed by both a patient and adult NOK. On behalf of 8 (16%) and 5 (11%) patients all information was provided by an adult NOK at 3 months and 6 months, respectively.

Further outcome data are shown in Table 4.3.2. The number of patients who had a good recovery (as defined by GOSE 7 and 8) at 3 and 6 months after injury was 19 and 20 respectively. Functional outcomes at 3 and 6 months were not significantly associated with severity of injury as characterised by GCS (9-12 and less than 9, p=0.524 and 0.294, respectively). There was no significant difference between functional outcomes at 3 and 6 months and mechanism of injury (RTA and fall, p=0.555, 0.793). Further, there was no significant association between age and functional outcome at 3 months (p= 0.782, OR =1) and 6 months (p=0.621, OR =1).

21 patients were unemployed 3 months after injury with 17 patients remaining unemployed at 6 months. One patient moved from full-time to part-time employment. There was a significant difference between moderate/severe TBI and change in employment status at 3 months (p= 0.030) but not at 6 months (p=

0.141). There was no significant difference between patients after RTA and those after falls with change in employment status due to injury at either 3 (p=0.734) or 6 months (p=0.138).

Three months after injury, 25 patients had become “economically dependent” with 14 patients remaining economically dependent at 6 months. Similarly, 17 families who were “economically independent” prior to the event became dependent and 10 families were still dependent at 6 months. There was no significant difference between patients who had a moderate or severe injury and those who became economically dependent at 3 or 6 months (p= 0.076, 0.177). There was also no significant difference between mechanism of injury (RTA/Fall) and subsequent economic dependence of patients at 3 or 6 months (p= 0.182, 0.712).

The performances of all four severity scores for predicting 30-day mortality are tabulated in Table 4.3.3.

4.3.5 Discussion

Moderate and severe TBI are catastrophic events in this LMIC setting, predominantly affecting non-university educated young men resulting in long-term adverse sequelae; 50% survival at 3-months; only 19% having a good recovery (GOSE 7 and 8) at 6 months; 50% of survivors and 34% families being economically dependent at 3 months. These findings from a premier neurosurgical unit in the country are likely to be comparable to the best care available in other LMIC countries in the region. Furthermore, all four trauma scoring systems evaluated had poordiscriminatory ability in predicting mortality.

This study demonstrates the feasibility of telephone follow-up in patients with moderate and severe TBI admitted to a tertiary neuro-critocal care unit in this

LMIC setting. There is now widespread recognition, almost exclusively from research in HIC, on the importance of patient centered post-discharge outcomes such as quality of life measures and economic impact to the individual and family, in addition to ICU or hospital survival, when evaluating critical care services [35]. There are obvious logistical difficulties in determining post-ICU outcomes in LMICs, which impair the evaluation of the effectiveness of scarce critical care services, especially in terms of a return to pre-morbid status and financial independence. The relatively minimal loss to follow-up of TBI patients in this study, albeit in a small sample, may provide insights when developing a methodology for routinely evaluating post-discharge outcomes, especially if paired with a medical registry tracking performance of critical care units [219, 220]. This study also demonstrates the feasibility of recruiting patients to an observational study in LMICs with assent from NOK where the patient is unable to consent, with the proviso of retrospective withdrawal. Missing data, another common problem in acute care settings in LMIC, was relatively minimal as data was prospectively gathered by a doctor (investigator) visiting the ICU daily and as these scores do not require often expensive and logistically difficult invasive tests. There is some evidence that non-trauma specific prognostic models such as APACHE II and III have at least comparable performance in predicting outcomes in TBI patients [221]. Our group has previously demonstrated the difficulty of missing values in such models in this setting and data for these models were not gathered in this instance [35].

In this study, all four trauma scores had unsatisfactory discriminatory ability when predicting mortality despite relatively complete datasets. The poor performance of the scoring systems cannot thus be explained by gaps in the dataset, a known problem in critical care datasets from LMICs. Of note, both ASCOT and TRISS

had acceptable (and non-statistically significant) calibration, most likely as a consequence of the test having lower power due to the small sample sizes, and not necessarily an indication of a good fit, necessitating caution when interpreting such measures[222]. Overall study findings are a reminder that tools and classifications developed for HIC settings may not be directly transferable to LMIC settings without prior validation and adaptation. Further research is required, especially if facilitated by medical registries, which will enable the development and continued adaptation of setting adapted tools and comparison with general prognostic models such as APACHE II.

The long-term sequelae of moderate to severe TBI, to the individual, families and consequently to wider society in this setting are striking. In contrast to previous reports, there were no statistically significant differences in the relatively high mortality or morbidity outcomes between moderate and severe TBI patients [198, 223, 224]. However, this study did not consider the pre-hospital care provided to these patients, the adequacy of the hospital resuscitation efforts, features of ICU care provided and features of post-ICU hospital stay. Efforts to improve hospital outcomes after TBI in this setting will need to focus on these important aspects of care with potential for improvement. Furthermore, this study did not investigate causes of death, specific complications (eg. pressure ulcers, deep vein thrombosisetc), extent of available support services or specificdifficulties (eg. travel to hospital for physiotherapy) encountered by patients and their families. Research to explore these factors, with a view to remedial measures and an evaluation of the effectiveness of such measures in this setting are an urgent requirement. The long-term consequences reinforce the importance of preventive measures, especially for RTAs and falling from a height.

This is a single centre study with a small number of patients. This study did not

gather details of ICU or post-ICU treatment received by these patients. Generalisability across other settings in Sri Lanka will become possible with on-going efforts related to an ICU registry. The economic and employment evaluations were not performed by validated tools and highlight the requirement to develop validated and practical tools for use in this setting. Possibilities of bias due to loss to follow-up (6.9%) and due to NOK assisting or completing the questionnaire for a minority of patients need to be noted.

4.3.6 Conclusion

This observational study of patients sustaining moderate or severe TBI in Sri Lanka (a LMIC) reveals only 46% of patients were alive at 6 months after ICU discharge and only 20% overall having a good (GOSE 7 or 8) recovery. The social and economic consequences of TBI were long lasting in this setting. ISS, RTS, ASCOT and TRISS all performed poorly in predicting mortality in this setting and illustrate the need for setting adapted tools.

Table 4.3.1 Patient characteristics and summary values for the trauma scores. Values are number (percentage), mean (SD) and range.

	Moderate injury (n=38)	**Severe injury (n=63)**	**Total (n=101)**	**RTA (n=68)**	**Fall (n=24)**
Gender					
Male (%)	31(82)	52(83)	83(82)	54(79)	22(92)
Female (%)	7(18)	11(17)	18(18)	14(21)	2(8)
Age					
Range	19-83	16-79	16-83	16-83	28-78

Mean (SD)	43.86 (16.85)	40.46 (17.56)	41.67 (17.47)	38.23 (17.54)	49.92 (15.47)
Marital status					
Married (%)	31(82)	39(62)	70(69)	42(62)	21(88)
Unmarried (%)	5(13)	19(30)	24(24)	21(31)	1(4)
Divorced (%)	1(2)	3(4)	4(4)	3(4)	1(4)
Widowed (%)	1(2)	2(3)	3(3)	2(3)	1(4)
Education level					
No formal education	3(8)	2(3)	5(5)	1(1)	3(13)
Primary education	5(13)	5(8)	10(10)	7(10)	2(8)
Secondary Education	28(74)	54(86)	82(81)	57(84)	18(75)
Degree	(0)	2(3)	2(2)	2(3)	0(0)
ASCOT score (%)					
ASCOT Mean(SD)	0.90(0.06)	0.61(0.22)	0.72(0.23)	0.72(0.22)	0.67(0.25)
TRISS Mean(SD)	0.97(0.02)	0.86(0.14)	0.90(0.12)	0.91(0.11)	0.86(0.16)
RTS Mean(SD)	6.81(0.24)	4.53(0.84)	5.39(1.30)	5.34(1.30)	5.30(1.37)

ISS Mean(SD)	6.87(4.41)	5.57(4.69)	6.06(4.61)	6.09(4.02)	6.00(5.08)
GCS					
<9	0(0)	63(100)	63(62)	44(65)	15(63)
9-12 score	38(100)	0(0)	38(38)	24(35)	9(38)
Mechanism of injury					
RTA	24(63)	44(70)	68(67)	68(100)	0(0)
Fall	9(24)	15(24)	24(24)	0(0)	24(100)
Other	5(13)	4(6)	9(9)	0(0)	0(0)
Length of ICU stay (days)					
Median(IQR)	6(8)	5(6)	6 (8.75)	6(8)	5.5(24)
Range	1-91	0-122	0-122	1-95	0-122

***-** ASCOT; A Severity Characterization of Trauma

Table 4.3.2 Outcome of patients: survival status, functional outcome and economic impact at ICU discharge, 3 months and 6 months after injury. Values are number (percentage)

	Moderate injury (n=38)	**Severe injury (n=63)**	**Total (n=101)**	**RTA (n=68)**	**Fall (n=24)**
Survival status at ICU discharge					
Survived	29(76)	40(63)	69(68)	46(68)	18(75)
Died	9(24)	23(37)	32(32)	22(32)	6(25)

Survival status at 3 months after discharge					
Survived	21(55)	29(46)	50(50)	32(47)	13(54)
Died	14(37)	30(48)	44(43)	31(46)	9(38)
Could not be contacted	3(10)	4(6)	7(6.9)	5(11)	2(8)
Survival status at 6 months after discharge					
Survived	20(52)	26(41)	46(46)	30(44)	11(46)
Died	15(39)	33(52)	48(48)	33(48)	11(46)
Could not be contacted	3(9)	4(6)	7(6.9)	5(11)	2(8)
Functional outcome at 3 months after discharge					
Dead/Vegetative (GOSE 1,2)	16(42)	33(52)	49(49)	36(53)	9(38)
Disability (GOSE 3,4,5,6)	10(26)	16(25)	26(26)	17(25)	7(29)
Good Recovery (GOSE 7,8)	9(24)	10(16)	19(19)	10(15)	6(25)
Functional outcome at 6 months after discharge					
Dead/Vegetative (GOSE 1,2)	16(42)	36(57)	52(51)	37(54)	11(46)
Disability (GOSE 3,4,5,6)	9(24)	13(21)	22(22)	15(22)	5(21)

Good Recovery (GOSE 7,8)	10(26)	10(16)	20(20)	11(16)	6(25)
Economic impact at 3 months after discharge					
Patients who became economically dependent after injury	7(33)	18(62)	25(50)	18(56)	6(46)
Families economically dependent after patient injury	3(14)	14(48)	17(34)	10(31)	5(38)
Patients with change in employment status due to injury	8(38)	20(69)	28(56)	19(59)	7(54)
Economic impact at 6 months after discharge					
Patients who became economically dependent after injury	4(20)	10(38)	14(30)	10(33)	3(27)
Families economically dependent after patient injury	2(10)	8(31)	10(22)	6(20)	3(27)
Patients with change in employment status due to injury	5(25)	12(46)	17(37)	13(43)	2(18)

***-** GOSE; Glasgow Outcome Scale Extended

Table 4.3.3 Performance of trauma severity scores in predicting 30-day mortality.

Values are number (upper 95% CI, lower 95% CI), C-statistic and p value.

	ROC AUC (upper 95% CI, lower 95% CI)	Hosmer Lemeshow C-statistic	HL p-value
ASCOT	0.62 (0.51,0.73)	7.49	0.4853
TRISS	0.67 (0.56,0.78)	15.83	0.0449
RTS score	0.53 (0.41,0.65)		
ISS score	0.46 (0.36,0.56)		

***-** ASCOT; A Severity Characterization of Trauma

***-** TRISS; Trauma and Injury Severity Score

***-** ISS; Injury Severity Score

***-** RTS; Revised Trauma Score

4.4 Simplified prognostic model for critically ill patients in resource limited settings in South Asia

4.4.1 Background

Critical care prognostic models such as Acute Physiology and Chronic Health Evaluation (APACHE) derived during the first 24 hours of ICU stay, and the Sequential Organ Failure Assessment (SOFA) derived from sequential data are in widespread use, especially in High Income Countries (HIC). These models are used for risk stratification of critically ill patients, benchmarking of ICUs, recruitment of patients to clinical trials and gauging the response to interventions. APACHE II, one of the simplest models, is the most widely used, especially in LMICs and is often used as a reference for the evaluation of other models.

Current critical care prognostic models have been almost entirely developed in HICs and are usually based on hospital outcomes, which may not be feasible in LMIC ICUs due to the lack of electronic records or follow-up systems. Existing

prognostic models cannot be imposed without validation in LMICs as the diseases encountered in these settings (e.g. malaria, snake bite and poisoning), treatment modalities and available resources may be different. A major shortcoming in using models such as APACHE in LMIC settings is the unavailability of required measurements. Missing measurements can be due to scarcity of equipment (e.g. blood gas machines, pulse-oximetry), or logistical difficulties in systematic data collection, especially, sequential data. Further, the absence of accessible electronic patient information systems and devices may challenge the feasibility of performing probability calculations, for example, when recruiting to research studies or for triage. Studies validating and customizing existing models in LMICs are limited and mostly from single centres using relative small datasets. [173, 187-189]. Elsewhere in this thesis, we reported on the limitations of the APACHE II model in ICUs in a LMIC, partly due to the incompleteness of data, which cannot be adequately overcome by the use of imputation techniques. This difficulty and the need for further research and development of setting adapted models have been previously highlighted [187].

4.4.2 Study aim

This study proposes a simplified critical care prognostic model for use in resource limited settings and beyond, derived from a large South Asian ICU dataset. The proposed prognostic model aims to cover all diagnostic categories admitted to ICUs, be applicable in resource-limited settings with a limited number of commonly available measurements, and be useable with the aid of a nomogram to calculate an approximate probability of survival without recourse to electronic equipment.

4.4.3 Study design

The dataset utilized in this study was derived from one ICU in India, one in Nepal, one in Bangladesh and 18 ICUs in Sri Lanka. Part of the dataset from Sri Lanka was used previously to assess the applicability of the APACHE II model and is from the period prior to the establishment of a critical care registry [204, 205]. The dataset from the other three countries was generated when evaluating the impact of a modular ICU training program [31]. The datasets from the four countries were combined to increase generalizability for the South Asian setting. Only ICU outcomes were utilized, as hospital and longer-term outcome measures were not feasible in the study settings. All patients aged 18 or over were included.

Selection of variables

Initial selection of candidate covariates for model development was based on their use in existing case-mix prediction models, perceived clinical importance and the feasibility of measurement in the settings of the participating ICUs. The initial variables included patient age, type of admission (elective surgery, emergency surgery or medical) as per APACHE II coding [185], and admission clinical assessments of temperature, heart rate, fraction of inspired oxygen (FiO2), respiratory rate, systolic blood pressure, peripheral oxygen saturation and Glasgow Coma Score (GCS). Laboratory variables included haemoglobin and blood urea available at the time of ICU admission (not creatinine as availability in LMICs is often limited [225]. Treatment measures included use of mechanical ventilation, vasopressors and antibiotics at the time of or immediately after admission. Diagnosis and co-morbidities were not included during model development as accurate, internationally translatable (eg SNOMED, ICD-10) and reproducible diagnostic information is difficult to obtain outside research settings in LMICs.

Three versions of the model were proposed based on their applicability according to available resources; model 1 included clinical, laboratory as well as treatment variables, model 2 included both clinical and laboratory variables, whereas model 3 included clinical parameters only. Treatment factors were only included in model 1 since these vary widely in relation to resource availability and local practices. Similarly, laboratory parameters were excluded from model 3 to evaluate a simpler and entirely clinical model that could be applicable to the most deprived settings, where availability of even the simplest blood tests such as haemolglobin and blood urea may be limited.

Development of the predictive model

The distributions of the continuous variables were assessed, and skewed distributions were log normalized (eg blood urea). (Figure 4.4.2). A univariate logistic regression model was fitted using the covariates listed above in order to assess their association with ICU mortality. The unadjusted estimates of the odds ratio for each variable was assessed and reported with p-values and 95% confidence intervals. All variables independently associated with ICU mortality in the univariate model were then used to develop the predictive model. A stepwise backward-elimination procedure with probability of entry set at alpha=0.05 and the probability of removal set at alpha=0.055 was used to identify contributing variables. Collinearity was considered where thought plausible, e.g. between saturation and respiratory rate and between heart rate and respiratory rate.

Model validation

The three models thus obtained were validated in order to estimate their performance in similar populations. Splitting the dataset for model development and validation was not attempted because of the limited sample size and due to

criticism in the literature [226]. A separate external dataset was not available for the purposes of validation. Consequently, an internal validation technique was employed using bootstrapping (1000 samples). The Receiver Operating Characteristic (ROC) curve was obtained together with the C-Index (Area Under receiver operating characteristic Curve, AUC) with its 95% confidence interval. The sensitivity, specificity, discrimination, calibration and accuracy were calculated as described under Section 2.4. Finally, the ability of each model to predict mortality in the most frequently occurring APACHE II diagnostic categories for the dataset was assessed.

Comparison with APACHE II model

The three models were compared against the APACHE II model [185]. APACHE II scores and probabilities were calculated for the datasets using the ICU admission parameters and the worst clinical and laboratory values from the first 24 hours [185]. Discrimination, calibration and accuracy were calculated as described under Section 2.4. The missing values were imputed as normal, according to common practice in HICs and as described in the original model publications as also described under Section 2.4 [129, 185, 227]. The APACHE II mortality prediction in the most common APACHE II diagnostic categories was also assessed.

Nomogram development for the selected model

The model with the best overall performance and clinical applicability was translated into a nomogram. The nomogram is intended as a graphical tool which can be used in a user-friendly way, even in very resource limited settings. It would have the advantage of not requiring special mathematical skills or equipment to generate a probability for mortality, increasing the applicability for use by all

health personnel.

4.4.4 Results

A total of 3,855 patient records were available for analysis. 2283 patients were from India, 430 from Bangladesh, 325 Nepal and 817 from 18 ICUs in Sri Lanka. Table 4.4.1 summarises patients' baseline characteristics on admission to ICU. Table 4.4.2 demonstrates that all the selected variables except age were significantly associated with ICU mortality in the univariate analysis.

Model 1 retained respiratory rate, systolic blood pressure, GCS, blood urea, haemoglobin, mechanical ventilation on ICU admission and vasopressor use on ICU admission. Model 2, derived by excluding the resource dependent treatment factors included emergency surgery, respiratory rate, systolic blood pressure, GCS, blood urea and haemoglobin. Model 3 was then derived by retaining only clinical measures; respiratory rate, emergency surgery and GCS were the parameters retained in the model after multivariable analysis. Systolic blood pressure was not-significant in the model and remained not-significant even when emergency surgery was excluded. The selected covariates for models 1, 2 and 3 and their coefficients are illustrated in Table 4.4.3.

Only weak collinearity was shown between respiratory rate and saturation and between respiratory rate and heart rate (Figure 4.4.3 and 4.4.4), which did not prompt modifications to the model.

Discrimination (AUC) for the 3 models were 0.818 (95% CI 0.800-0.835) for model 1, 0.767 (95% CI 0.741-0.792) for model 2 0.725 (95% CI 0.688-0.762) for model 3 (Figure 4.4.6). The H-L C-statistic had p-values of less than 0.05 for models 1 and 3, but for model 2 had a score of 11.3 and p-value equal to 0.18, indicating statistically acceptable agreement between observed ICU mortality and

ICU mortality predicted by model 2 [228]. The Brier score, denoting model accuracy in measuring prediction at an individual level, varied from 0.13 for model 1 to 0.18 for model 3, denoting acceptable performance for all three models (15). The best sensitivity and specificity was achieved with model 1. In this model at the optimal cut-off probability for poor outcome (0.26) sensitivity was 71.9% and specificity 76.9%; these numbers were slightly lower for models 2 and 3 (Table 4.4.4).

In this dataset the APACHE II model had an AUC of 0.707 (95% CI- 0.688-0.726). Calibration was very poor with the Hosmer-Lemeshow C-statistic being 124.84 ($p<0.001$). The ability of APACHE II, Models 1, 2 and 3 to predict outcomes in the commonest APACHE II categories in the dataset are shown in Figure 4.4.6. Figure 4.4.7 demonstrates the predicted versus actual mortality rates of the same models. The nomogram derived from model 2 for day-to-day clinical use is shown in Figure 4.4.1

4.4.5 Conclusion

This paper proposes TropICS, the first international critical care prognostic model developed in non-HIC settings, for use in South Asian settings with potential for application in low and middle income countries worldwide. TropICS outperformed the APACHE II model in this South Asian dataset.

Table 4.4.1 Patient characteristics at the time of ICU presentation

Covariate/Factor	Dead (n=1031)	Alive (n=2590)	Missing (%)
Age (median, range)	54 (16-102)	56 (16-103)	346 (9.0)
Heart rate (mean, SD)	109 (24)	100 (24)	436 (11.3)
GCS (median, range)	9 (2-15)	15 (2-15)	483 (12.5)

Respiratory rate (mean, SD)	24 (8)	23 (6)	1122 (29.1)
Saturation (median, range)	99 (30-100)	100 (55.8-100)	234 (6.1)
Systolic BP (mean, SD)	132 (35)	139 (29)	1027 (26.7)
Blood urea (median, range)	59 (0.6-411)	32 (0.9-672)	1919 (49.8)
Haemoglobin, g/Dl (mean, SD)	10.8 (2.8)	11.6 (2.4)	1986 (51.5)
Vasopressor use (no)n (%)	572 (64.34)	1860 (91.31)	904 (23.45)

Table 4.4.2 Univariate analysis of associations between ICU mortality and covariates

Covariate	**Odds Ratio**	**95% CI**		**P-value**	**N**
Age	0.922	0.737	1.153	0.475	3621
Emergency surgery	1.933	1.559	2.397	0.000	3585
Temperature	1.435	1.298	1.586	0.000	3192
Systolic BP (SBP)	0.989	0.985	0.993	0.000	2828
Saturation	0.931	0.914	0.948	0.000	3621
Respiratory rate	1.024	1.011	1.038	0.000	2733
Heart Rate (HR)	1.014	1.011	1.017	0.000	3419
GCS	0.844	0.829	0.858	0.000	3372
FiO2	3.212	1.759	5.863	0.000	3621
Haemoglobin	0.875	0.839	0.911	0.000	1869
Blood urea	1.007	1.005	1.008	0.000	1936
Vasoactive use	0.175	0.143	0.215	0.000	2955

Antibiotic use	0.292	0.226	0.377	0.000	2032
Mechanical ventilation	0.140	0.116	0.168	0.000	2948

Table 4.4.3 Multivariable logistic regression model of mortality on clinical and laboratory parameters, * indicates that the covariate was selected for the respective model.

	Model 1 (n=1125)		**Model 2 (n=1130)**		**Model 3 (n=2069)**	
Covariate	**#Beta-coefficient**	**95% CI**	**#Beta-coefficient**	**95% CI**	**#Beta-coefficient**	**95% CI**
Emergency surgery	0.437	-0.136, 1.010	0.547	0.025, 1.069*	0.730	0.439, 1.020*
Respiratory rate	0.060	0.018, 0.102*	0.005	0.002, 0.007*	0.064	0.041, 0.087*
Systolic blood pressure	-0.019	-0.031, -0.008*	0.002	0.001, 0.004*	0.003	-0.002, 0.008
Glasgow Coma Score	-0.099	-0.139, -0.059*	-0.150	-0.185, -0.115*	-0.128	-0.151, -0.105*
Blood Urea	0.006	0.003, 0.008*	0.006	0.004, 0.009*	NA	-
Haemoglobin	-0.093	-0.160, -0.027*	-0.098	-0.161, -0.034*	NA	-
Vasoactive use	1.057	0.5613, 1.5527*	NA	-	NA	-
Mechanical ventilation	1.429	0.9919, 1.8661*	NA	-	NA	-
Constant	6.164	4.374, 7.953	0.588	-0.358, 1.534	0.229	-0.061, 0.518

 # is the log of the odds ratio, i.e. the coefficient needed to calculate the model

Table 4.4.4 Performance of the 3 models and APACHE II

Performance item	Model 1	Model 2	Model 3	APACHE II
Score, mean (SD)				17.35 (6.16)
Probability, mean (SD)	0.20 (0.20)	0.20 (0.16)	0.28 (0.14)	0.26 (0.81)
Optimal cut-off probability	0.18	0.18	0.26	0.20
Sensitivity (at optimum cut-off)	0.72	0.70	0.63	0.67
Specificity (at optimum cut-off)	0.77	0.69	0.67	0.71
AUC (95% CI)	0.812 (0.781-0.842)	0.767 (0.734-0.800)	0.689 (0.664-0.714)	0.707 (0.688-0.727)
H/L C-statistic (p)	16.91 (p=0.03)	11.31 (p=0.19)	15.94 (p=0.01)	124.84 (P<0.01)
Brier score (95% CI)	0.13 (0.11-0.14)	0.14 (0.12-0.15)	0.18 (0.18-0.19)	0.18 (0.17-0.18)

Figure 4.4.1 Nomogram for tropics

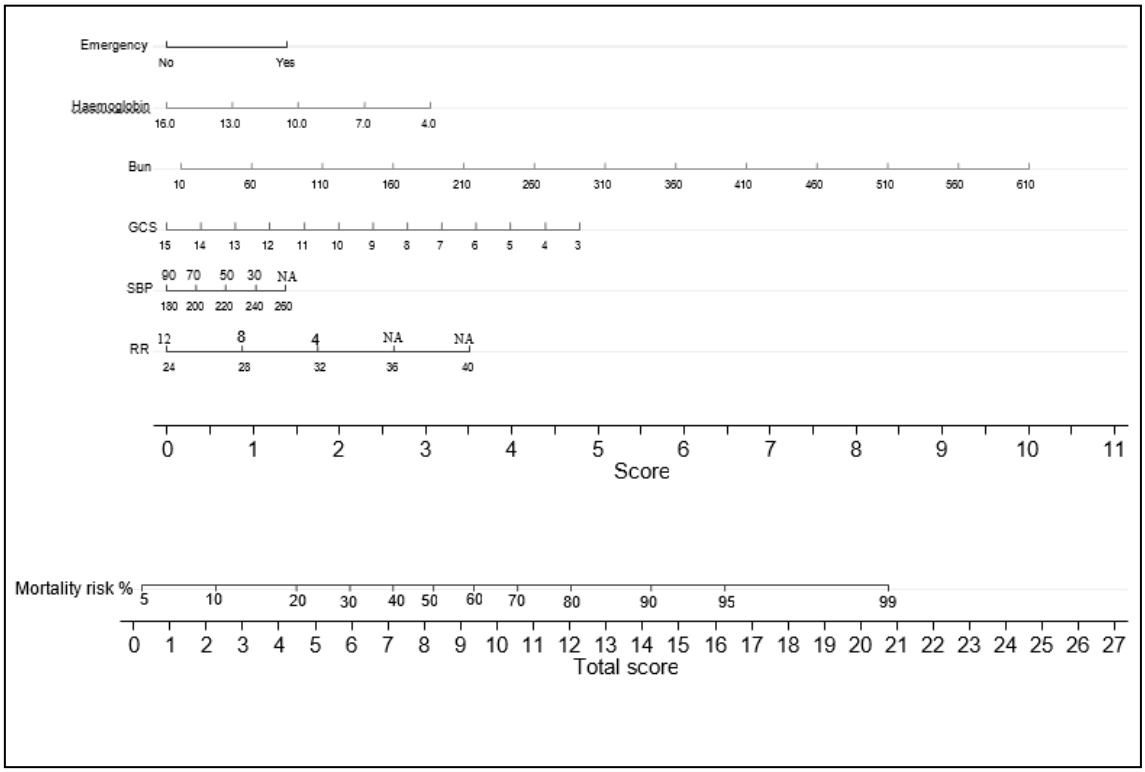


Figure 4.4.2 Distribution of systolic blood pressure, respiratory rate, heart rate, haemoglobin and blood urea

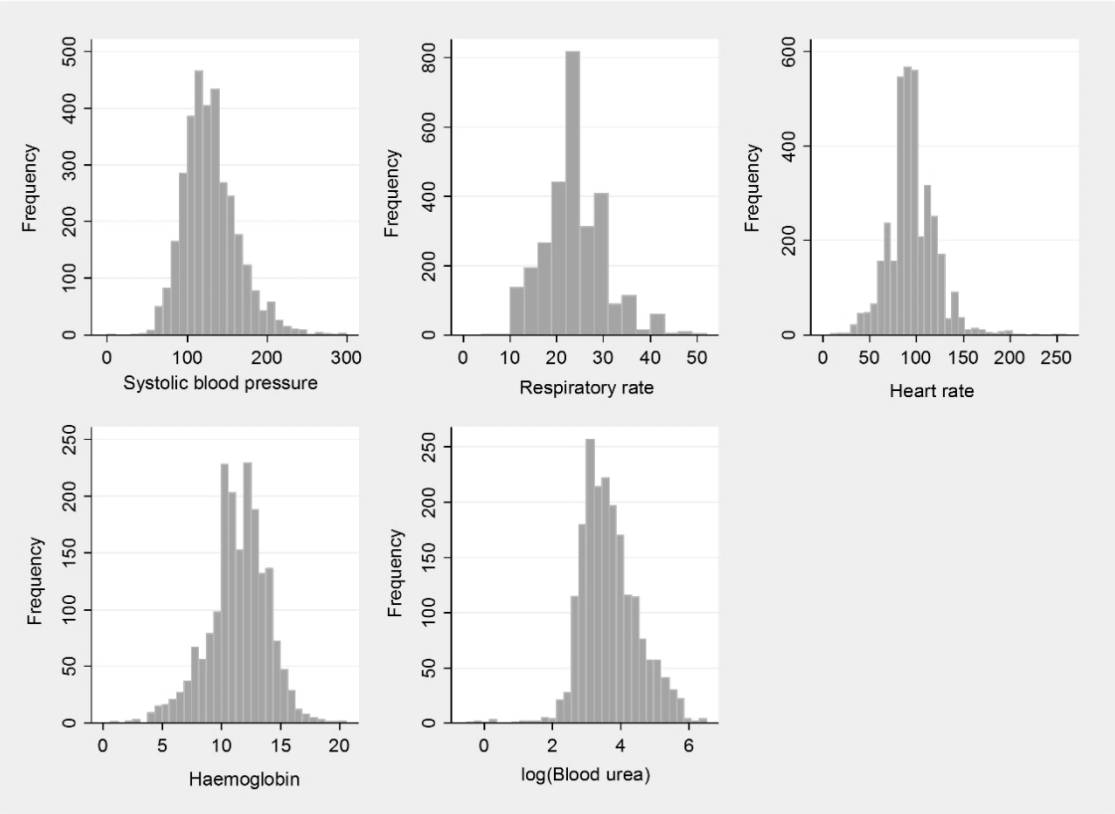


Figure 4.4.3 Collinearity between heart rate and respiratory rate

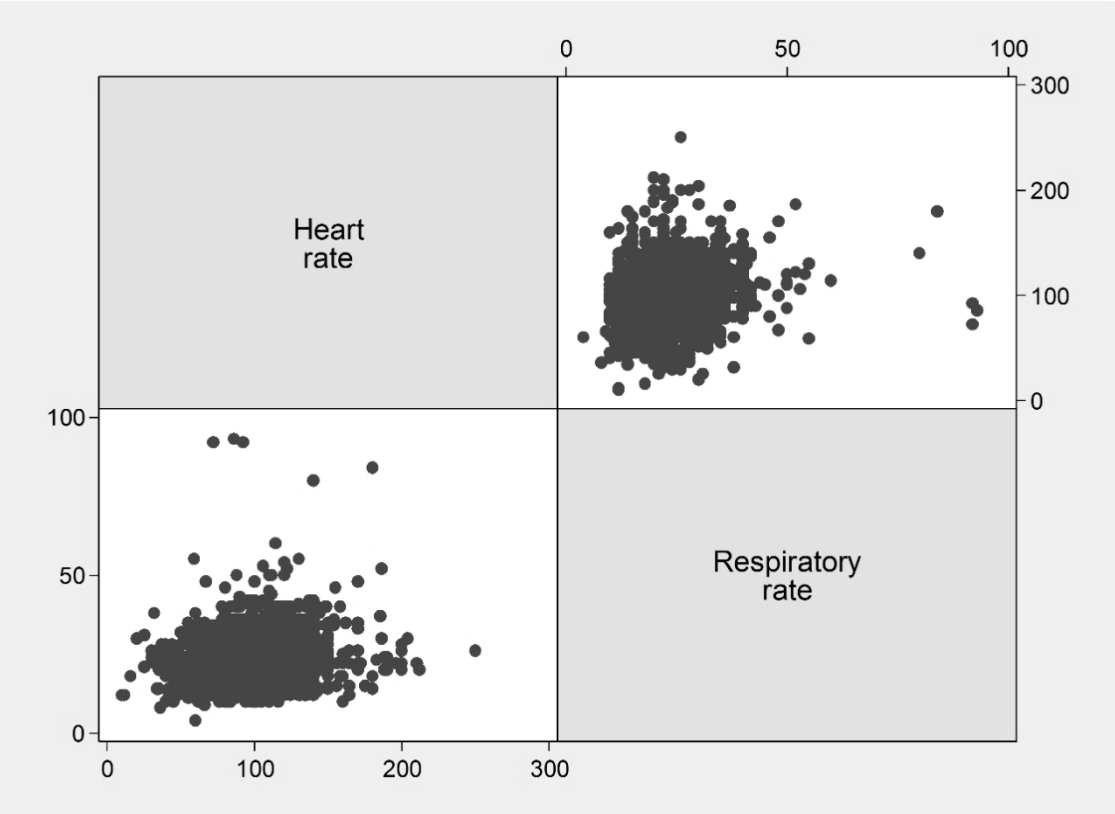


Figure 4.4.4 Collinearity between saturation and respiratory rate

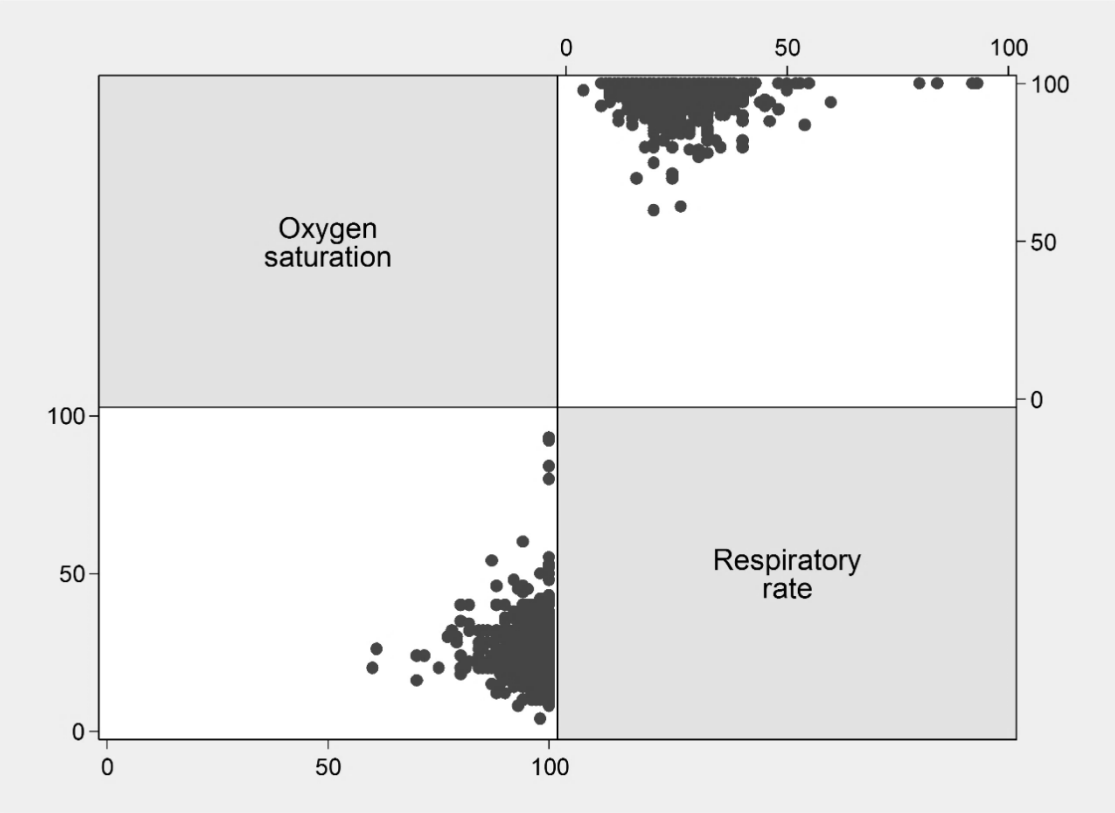


Figure 4.4.5 AUC for models 1, and 2 and 3 and for APACHE II

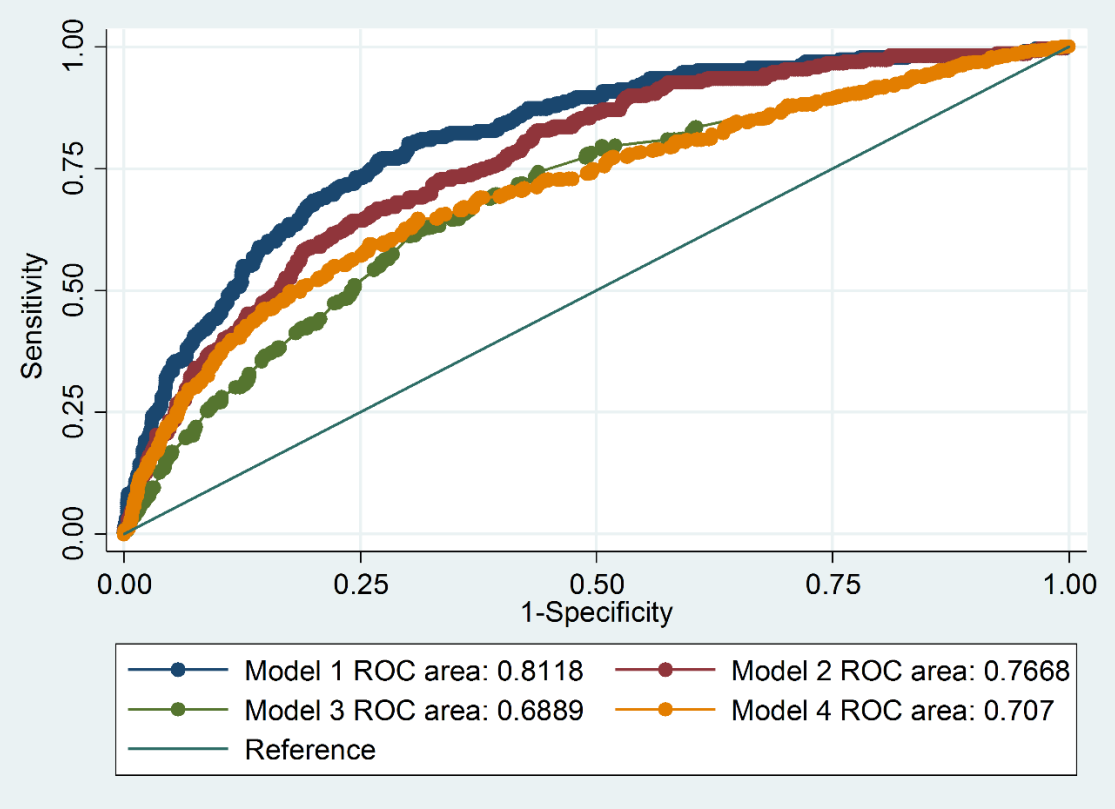


Figure 4.4.6. Model performance in common APACHE II diagnostic categories

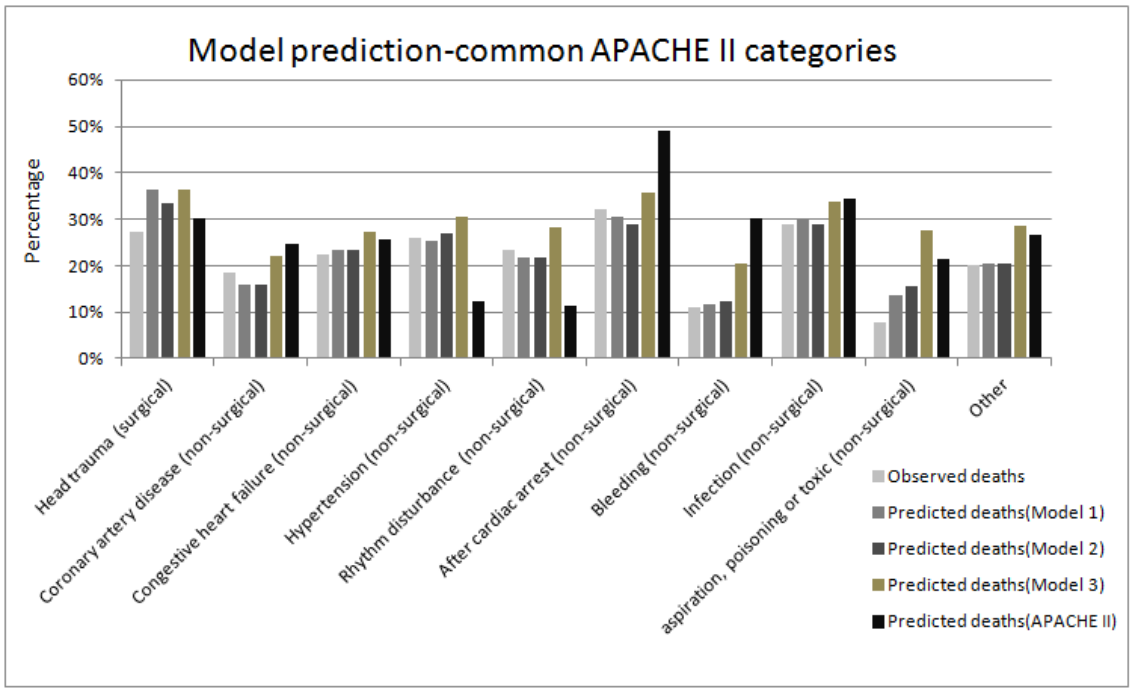
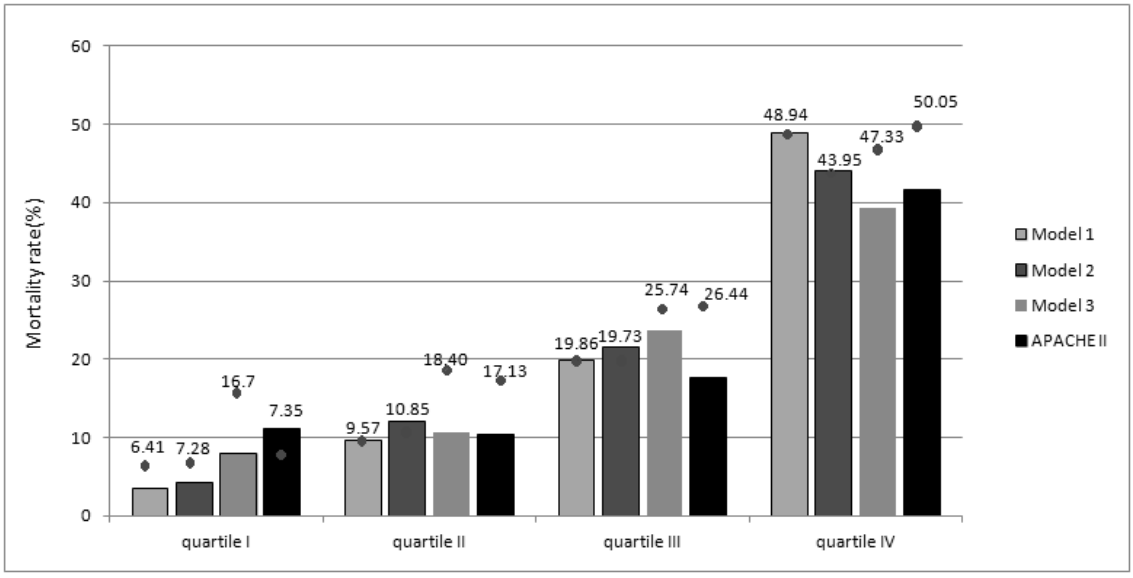


Figure 4.4.7 Expected and actual mortality rates by prediction model quartiles. Each bar represents the actual mortality rate for that quartile, with quartiles determined by the specified risk prediction model. Each circle represents the expected average mortality per quartile.



4.5 Data availability for the evaluation of critical care prognostic models in a national critical care registry.

4.5.1 Background

Prognostic models are increasingly used not only for prognostication of patients admitted to critical care, but also to evaluate individual ICU performance, benchmark services and identify disparity in equity of care. With a rising burden on critical care services and a growing international interest in improving equity of care for patients, predictive models are increasingly being applied to patients being cared for in ICU's in resource limited countries, where from the limited information available outcomes are reported to be poorer when compared to HIC's. However, prognostic models have been predominantly developed in HIC's; availability of resources, timing to presentation and diverse disease profiles are all potentially varied from LMICs and influential on patient outcomes.

Prospective validation of tools by multicentre studies in LMICs are very limited, as described in Section 4.1. Paucity of clinical information, paper based systems, and little investment in systems enabling robust surveillance limit attempts to address the inequality in availability of research. The multicentre paper-based pilot study to validate APACHE II described in Section 4.2 further illustrated the setting related challenges.

4.5.2 Study design

This study evaluates prospectively collected data from 86 ICU's recruited to NICS located in 56 hospitals; ICUs and patients were recruited to the registry incrementally from May 2012 onwards. These ICUs can be classified as (n=38, 44.19%) are general (mixed), (n=12, 13.95%) surgical, (n=14, 16.28%) medical and (n=22, 25.58%) specialty centres. Data was collected as part of routine national critical care surveillance registry input using a web-based application as

described in Section 2.2. Availability of physiological variables and laboratory measurements were calculated. The availability of data for APACHE II and IV were based upon the most deranged physiological values recorded within the first 24 h following admission to ICU.

4.5.3 Results

The study was conducted between the 1st Feb 2013 and the 1st September 2016. During this period, 22,810 patient admissions were reported to the registry from the 86 ICUs as indicated in figure 4.5.1. Patients <18 years of age (n=1887) were excluded from the study. Of the remaining 20923 patients eligible, a further 1318 patients were excluded because of missing survival status. In addition, 51 patients were excluded as they were admitted for primary burns and a further 541 patients were excluded as their ICU length of stay was less than 4 hours. A total of 19013 patients were thus included in the final analysis.

Non-survivors were significantly older and male. Mortality was significantly higher for medical versus surgical patients and emergency versus elective surgical patients.

Figure 4.5.1 The geographic distribution of hospitals recruited to the NICS registry

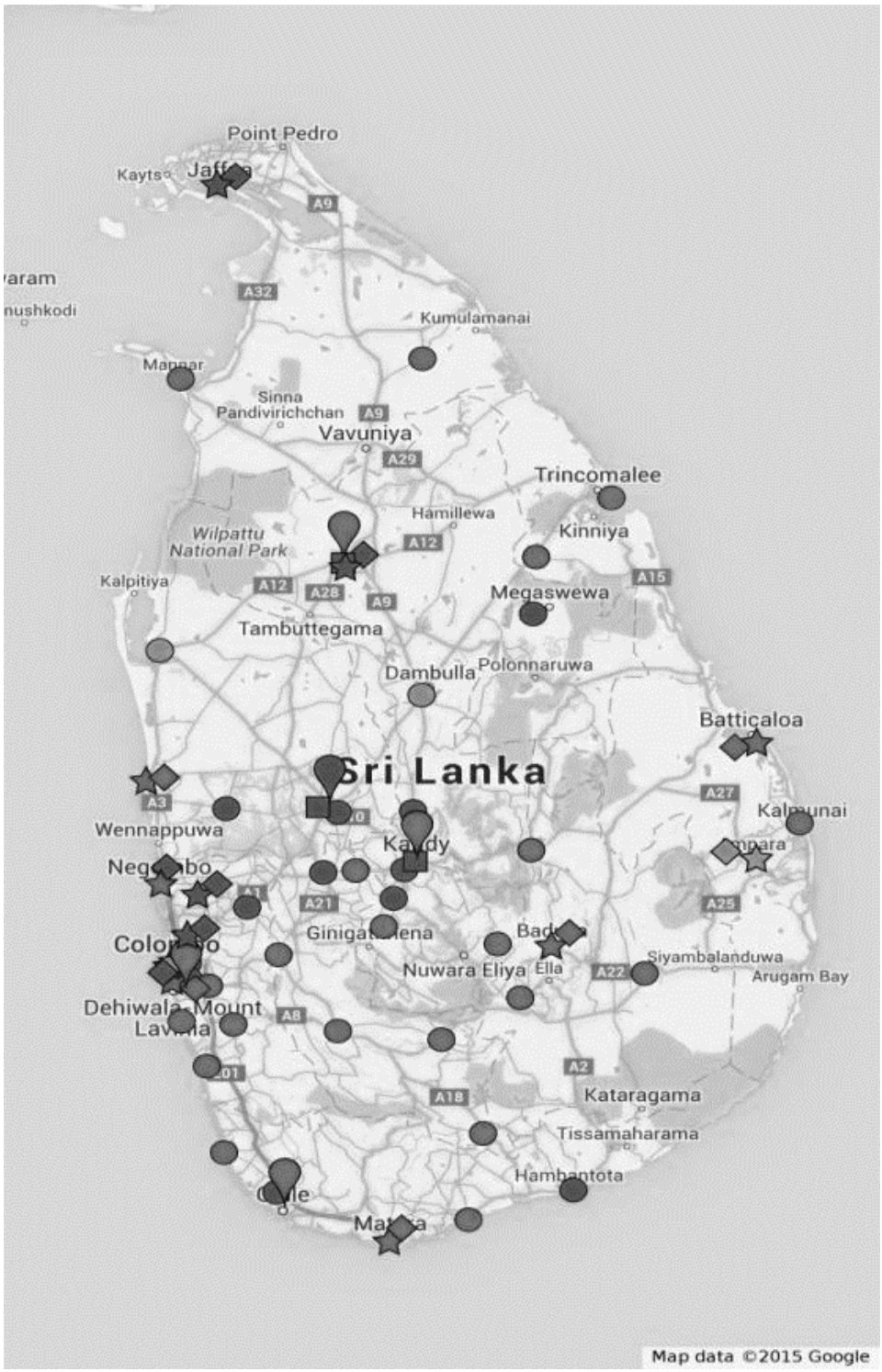


Figure 4.5.2 The timeline of the recruitment of ICUs and patients to the NICS registry

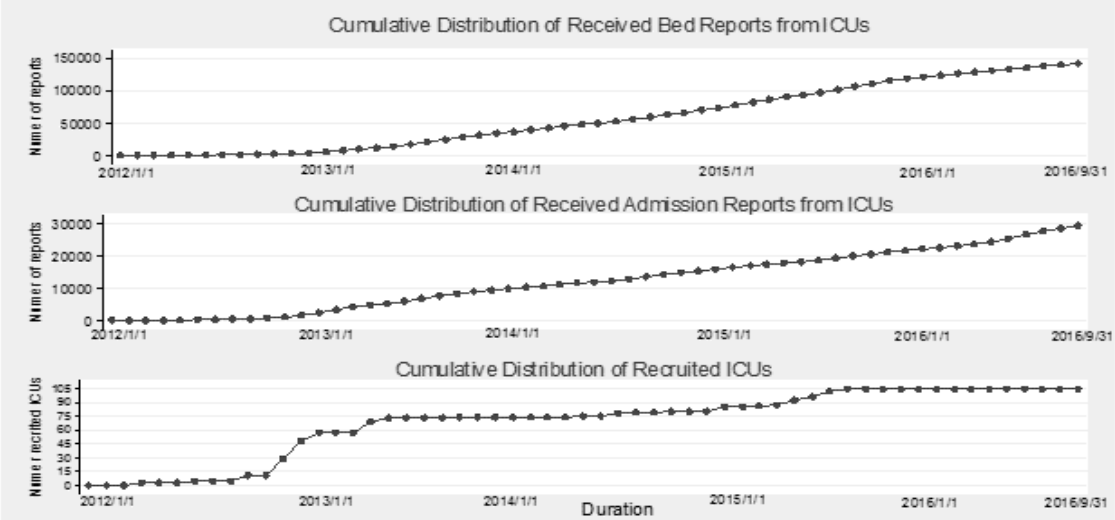


Table 4.5.1 Demographic, admission characteristics. * denotes characteristics of significance ($p < 0.05$) between survivors and non-survivors.

Patient characteristic	All	Survivors (%)	Non-survivors (%)	Total availability (%)
Number of patients		14794 (77.77)	4229 (22.23)	19023(100)
Age*	52(36,64)	50(34,63)	59(47,68)	18255(96)
Sex; Male (%)*	10452 (54.95)	7842 (53.01)	2610 (61.72)	19022 (99.99)
Admission type (%)*				17098(90)
Emergency surgical (unplanned)	3644 (19.16)	3017 (82.79)	627 (17.21)	
Medical	8405 (44.18)	5929 (70.54)	2476 (29.46)	
Elective surgical (planned)	5049 (26.54)	4383 (86.81)	666 (13.19)	
Admission characteristics (%)*				

Mechanical ventilation on admission (%)	7509 (41.32)	4909 (34.72)	2600 (64.47)	18173 (95.5)
Vasoactive medication on admission (%)	5630 (31.85)	3071 (22.31)	2559 (65.4)	17676 (92.9)
CPR before admission (%)	1899 (10.42)	911 (6.42)	988 (24.45)	18228 (95.8)
Source of admission				
Pre-ICU LOS (median and interquartile range)	1(0,3)	1(0,4)	1(0,3)	18844(99.1)

Table 4.5.2 Availability of chronic health variables within the first 24 hrs used to calculate APACHE II and APACHE IV.

Chronic health condition	**Number who had condition (%)**			**Availability (%)**
	All	**Survivors**	**Non-survivors**	
Metastatic neoplasm (%) II, IV	763(4.010)	629(4.252)	134(3.169)	17453(91.7)
Cirrhosis (%) II, IV	337(1.771)	199(1.345)	138(3.263)	17736(93.2)
Chronic renal insufficiency (%) II	1333(7.007)	853(5.766)	480(11.350)	17648(92.8)
Immunological insufficiency IV	411(2.160)	278(1.879)	133(3.145)	16958(89.1)
Haematological insufficiency (Lymphoma, myeloma) IV	328(1.724)	242(1.636)	86(2.034)	17389(91.4)
Respiratory disease II, IV	1712(8.999)	1128(7.625)	584(13.809)	17868(93.9)

Table 4.5.3 Availability and mean values of variables used to calculate APS in APACHE II and APACHE IV.

Acute physiology Variable. APACHE II and IV	Mean scores			Availability (%)
	All Mean (sd)	Survivors Mean (sd)	Non-survivors Mean (sd)	
Heart rate II, IV	99.132 (25.816)	96.639 (24.478)	107.910 (28.365)	18640(98)
Respiratory rate II, IV	21.320 (8.973)	21.010 (8.479)	22.414 (10.467)	18578(97.7)
MAP II, IV	89.366554 (21.476912)	91.8252.016 (20.082497)	80.636.816 (23.8644.400)	18609(97.8) 18615(97.9)
GCS II, IV	10.645 (5.185)	11.331 (4.945)	8.254 (5.288)	18001(94.6)
Temperature II, IV	98.253 (1.462)	98.235 (1.396)	98.314 (1.670)	18549(97.5)
Urine 24 hrs II, IV	1709.422 (1374.054)	1818.870 (1357.523)	1337.621 (1364.911)	16058(84.4)
Haematocrit IV	34.045 (6.867)	34.181 (6.7134)	33.588 (7.3421)	10668(56.1)
PaO_2 II, IV	125.00835.125 (56.36177.524)	128.152137.361 (55.765(74.528)	117.11929.553 (57.08484.283)	8516(44.8)8821(46.4)
FiO2 II, IV	55.792 (26.336)	51.855 (25.701)	68.274 (24.363)	14844(78)
PH II, IV	7.356 (0.149)	7.376 (0.131)	7.303 (0.174)	8898(46.8)
HCO_3 II, IV	22.082 (6.184)	22.744 (5.791)	20.282 (6.828)	7701(40.5)
WBC II, IV	19.284 (27.821)	18.959 (27.689)	20.390 (28.238)	14771(77.6)
Urea IV	51.580 (61.733)	44.432 (55.064)	74.598 (75.011)	12219(64.2)
Creatinine II, IV	1.948 (2.389)	1.751 (2.291)	2.534 (2.574)	10352(54.4)

Potassium II, IV	4.093 (0.723)	4.0623 (0.655)	4.197 (0.906)	14194(74.6)
Sodium II, IV	137.976 (6.801)	137.758 (6.174)	138.704 (8.536)	14182(74.6)
Bilirubin IV	29.542 (88.272)	27.608 (84.731)	34.702 (96.949)	3780(19.9)
Blood Glucose IV	142.092 (60.671)	138.040 (54.758)	155.956 (75.959)	14908(78.4)
Albumin IV	31.391 (8.794)	31.849 (8.839)	30.178 (8.560)	2628(13.8)

Table 4.5.4 Records available for complete case analysis

Scoring system	Complete records
SAPS II	2097
MPM II	13161
MPM III	13161
RMPM	16108
TropICS 1	8274
TropICS 2	8104
TropICS 3	16217
APACHE II	5465
APACHE III	586
APACHE IV	311

4.5.4 Discussion

This preliminary evaluation of the NICS dataset comprises the largest national output so from a LMIC and confirms the feasibility of gathering prospective ICU outcome data nationally in this setting with a purpose-built setting-adapted, nationally implemented software system supported by a registry methodology.

These results should be considered in relation to findings from the previous paper-based pilot described in Section 4.2 [35]. Similar to findings from that study,

bedside observations were more commonly available when compared to blood tests. Furthermore, relatively inexpensive laboratory blood tests such as FBC were more commonly available when compared to point of care testing measures such as blood gas measurements and more relatively expensive and harder to access investigations such as albumin.

Whereas complete case analysis for APACHE II system in the paper-based study yielded only 1.6% of records, this dataset had higher completeness- RMPM and TropICS 3 being most complete - and APACHE II being complete in more than 25% of all cases. Unsurprisingly, complete records for APACHE III and IV data are available in far fewer patients- as investigations such as bilirubin and albumin were infrequently recorded. The reason for improved completeness of records could be due to a multitude of factors; electronic registry system, improved awareness of the importance of observations due to critical care and data entry training, and improved availability to variables in the setting- especially the laboratory and point of care testing- as a result of overall improvement in services. The near complete availability of the clinical observations in this study when compared to previous attempts described in this thesis [35, 229, 230] is perhaps suggestive that the setting-adapted registry system has contributed to this improvement. Further exploration of the underlying reasons for incomplete recording of observations, decision-making in requesting investigations and the factors that may have led to the reported improvements in this study are likely to be important for quality improvement efforts beyond this setting.

This dataset can now be utilised for the external validation of critical care prognostic models in this setting, enable national benchmarking of critical care services [34, 231], and assess whether interventions to improve critical care services- including training, quality improvement projects and systematic

collection of data by a national registry system- has an impact on patient outcomes. This data platform provided by the registry, can now enable critical care multicentre studies[232, 233] to be effectively promoted and coordinated in this setting. In addition, the platform has enabled registry systems- for example for renal and perioperative patients- to be constructed using the same methodology and also supports the national critical care bed availability system [36].

4.6 An evaluation of the feasibility and performance of EWS in a Sri Lankan DGH

4.6.1 Background

Patients who suffer adverse events on hospital wards, such as cardiac arrest and death, often show changes in basic physiological parameters in the hours before the event. Based on this, early warning scores (EWS) have been developed and widely implemented in high-income countries (HIC) with the aim of identifying clinical deterioration early [234] .

Both Aggregate Weighted Track and Trigger (AWTTS) and Single Parameter Track and Trigger (SPTTS) together under the umbrella of EWS utilise physiological measures and other clinically significant variables (e.g. age) categorized and scored based upon their degree of abnormality [235]. AWTTS uses a range of parameters which are weighted and calculated to form a composite and often complex score. SPTTS whilst often including more than one parameter, allow for a single parameter to act as an independent trigger. Although less well evaluated, SPTTS tend to have acceptable specificities and negative predictive values, but low sensitivities and positive predictive values for death or adverse events [235]. EWS allow for stratification of patients at high risk of deterioration and for objective evaluation of the clinical status over time [75,

76, 80]. In HIC, EWS are increasingly accompanied by dedicated nurse led rapid response teams, trained in critical care and resuscitation skills to respond in the event of clinical deterioration [75, 80, 81] (3,6,7).

Despite a multitude of EWS being developed and validated predominantly in HICs - each with varying ability to predict patient deterioration- eight basic parameters consistently appear in such systems [78, 79]; age, respiratory rate, urine output, saturation of oxygen, temperature, systolic blood pressure, heart rate and a measure of mentation such as AVPU or GCS [75, 80].

In Low and Middle Income Countries (LMICs), availability of critical care remains limited and variable [34, 37, 58, 236]. Healthcare services are usually overcrowded, poorly equipped and understaffed, hindering the systematic and accurate monitoring of vital parameters required for multi-parameter EWS implementation and validation [87, 88]. Whilst availability of data is limited, studies evaluating EWS performance show wide variation [85, 237]. Thus evaluation of feasibility and performance of EWS prior to implementation in an LMIC setting is crucial.

This study at a LMIC District General Hospital (DGH) describes the availability of core parameters for EWS, and evaluates the ability of selected EWS (AWTTS and SPTTS) to identify patients at risk of death or other adverse outcomes, including cardiac arrest, ICU admission or clinical transfer. At the time of data collection, there was no EWS in use in the hospital, and no escalation policy in response to adverse observation. The decision to admit a patient to this hospital is made by attending physicians.

4.6.2 Study design

All consecutive adult (age ≥17 years) patients admitted from May to December 2015 to District General Hospital Monaragala (DGHM) were prospectively included. Measures of pulse rate, respiratory rate, blood pressure, measure of consciousness (AVPU) and temperature, were all collected on admission and then twice daily (which is the usual frequency for the recording these observations as described by the clinical team in this setting). The data was extracted daily from the patient records by trained data collectors into an electronic data capture system. All patients were followed daily until hospital discharge. Diagnoses were coded as per ICD 10 [238]. The following were considered as adverse outcomes; in-hospital death, ICU admissions, clinical transfers to tertiary hospitals or other ICUs in other hospitals, and cardiac arrest or cardiopulmonary resuscitation. Transfer to higher level facilities and CPR both carry high mortality in this setting, hence their inclusion as adverse outcomes [239].

The selection of AWTTS for evaluation in this study was based on studies reporting on the use of these systems in LMIC settings [30, 85, 237]. Age, heart rate, respiratory rate, AVPU as a measure of mentation, systolic blood pressure, and oxygen saturations were included in the evaluation. The Glasgow Coma Score (GCS) and urine output, are not part of routine observation in this setting outside of the ICU, and therefore AWTTS including these parameters were not considered. ViEWS, SEWS, MEWS, and CART score (Table 4.6.6), were included based on their superior performance for detecting cardiac arrest, mortality, ICU transfer, and composite adverse outcomes in HIC studies [235]. NEWS was included as it is the national tool recommended in the UK by NICE and is now widely adopted within the National Health Service, UK [234].

Selection of SPTTS parameters was based on the finding of a systematic review

[240]. The selected parameters were high and low pulse rate, high and low respiratory rates, high and low systolic blood pressure, high and low temperature. Oxygen saturations and a measure of mentation were not considered in single parameter scores due to their limited availability in the study setting.

The performance of both AWTTS and SPTTS was evaluated with the missing values imputed as normal as detailed in Section 2.4. Discrimination for the AWTTS was assessed for adverse outcomes and for death both at admission and at 24 hours prior to adverse event or discharge, using methods described under Section 2.4. Discriminatory power of the AWTTS was then re-assessed using complete case analysis only.

Clinically recommended cut-off values and corresponding sensitivity and specificity on admission for MEWS, SEWS and ViEWS to predict death were applied based upon those reported in the literature [241]. A NEWS score of 5 or more is used as trigger for escalation to senior review and the commencement of ward level continuous bedside monitoring. Therefore a score of 5 was taken as the clinical cut off [242] [243]. No clinical cut-off for CART was proposed in the original publication, with the premise that users should decide based upon clinical application and resource availability. However existing literature validating and comparing CART with MEWS used a cut-off of 20. This was therefore utilised in this analysis [235]. Given the relatively low mortality in this setting (approximately 250 annual deaths) when compared to studies, sensitivity and specificity was further evaluated to identify optimal cut-offs [30, 85, 237].

The ability to predict mortality and adverse outcomes, was assessed for each SPTTS class using sensitivity, specificity, positive predictive value (PPV: the proportion of patients predicted to die who die) and negative predictive value (NPV: the proportion of patients predicted to survive who survive). Given a prior

knowledge of observation reporting behaviours in the study setting, performance of best performing SPTTS to predict death when applied at admission was then evaluated when using either single, two or three parameters. All possible combinations of single, 2, and 3 of the 4 parameters are described. Sensitivities for the best performing AWTTS at the optimal cut off and SPTTS were then compared using Z test. The proportion of patients who would be triggered (thereby at risk of deterioration) at each cut-off was measured.

4.6.3 Results

There were 16386 adult in- patient episodes to DGHM over the 8 month period. The characteristics, adverse events and outcomes for the study population are described in table 4.6.1. Of the 16386 patients included, 502 (3.06%) had 1 or more adverse outcomes. A total of 102 (0.62%) cardiac arrests, 83 (0.51%) unplanned ICU admissions were reported, and 253 (1.54) patients were transferred to tertiary facilities. Total in-hospital mortality was 149 (0.91%). The availability of observations over the 8 month period is described in Figure 4.6.1. Availability of physiological parameters on admission varied widely; heart rate 90.97 % (CI 90.52,91.40), systolic blood pressure 86.80 % (CI 86.27,87.31), respiratory rate 65.24 % (CI 64.51,65.97), saturation 23.94 % (CI 23.29,24.60) and assessment of mentation 32.89 % (CI 32.17,33.61). With the exception of temperature, availability of physiological parameters is significantly diminished after admission ($p<0.05$)(Table 4.6.2).

Of the AWTTS assessed for their ability to discriminate death on admission and at 24 hours prior to death, only CART 0.781 (CI 0.744, 0.818) and SEWS 0.702(CI 0.656, 0.748) had an AUROC of >0.70 (Table 4.6.3). CART performed better ($p<0.05$) at predicting death both at admission and at 24 hours prior to death/discharge with missing values imputed as normal, when compared to the

other 4 selected AWTTS. Discriminatory power of all AWTTS diminished when evaluated for their ability to predict death at 24 hours compared with admission (Table 4.6.3).

SEWS and MEWS have an increased discriminatory ability (but AUROC <0.8) to predict death when applied on admission but not when applied at 24 hours prior to death when calculated without missing values imputed (complete case analysis). The discriminatory power of AWTTS when calculated with and without missing values, for all adverse outcomes, both on admission and at 24 hours prior to event was < .70 (Table 4.6.3). Sensitivity to predict death when applied on admission was ≤ 30% for all AWTTS when evaluated at the recommended clinical cut-offs (Figure 4.6.2).

The performance of the SPTT scores which utilised the 4 selected observations are shown in Table 4.6.1. The highest sensitivity for deaths and adverse outcomes for an SPTTS applied on admission were for the SPTTS proposed by Kenward et al (Table 4.6.5, row vii) were 59.1% and 48.4% respectively (PPV 1.72%). Five thousand and sixty two (32.46%) patients would be triggered if this SPTTS, which includes heart rate, respiratory rate, systolic blood pressure and temperature, was applied on admission (27). All other selected SPTTS had sensitivity less than 47% to predict death when applied on admission and positive predictive values were low <8.24%. Sensitivities and specificities of the best performing SPTTS (27) to predict death when applied on admission when computing only 1, 2, or 3 of the 4 parameters are reported in Table 4.6.4. Sensitivities of the best performing AWTTS (CART) at the optimal cut off and the best performing SPTTS [1](27) to predict death when applied on admission are comparable at 63.2% and 59.1% ($p>0.05$) respectively (Figure 4.6.2).

4.6.4 Discussion

Availability of observations is poor in this setting. Heart rate, respiratory rate and systolic blood pressure have the highest availability at admission; however availability of these measurements also decreases throughout the hospital stay. Low nurse to patient ratios, limited equipment for monitoring and limited understanding of the importance of observations in detecting unwell patients and preventing avoidable death are all cited as barriers in resource limited settings [88, 244]. In this study, reporting behaviours were sustained over the study period (figure 4.6.1). Observations which require no equipment for their measurement such as AVPU are also often incomplete (Figure 4.6.1). It is necessary to acknowledge that the presence of data collectors capturing data in the study setting may have had an influence on observation reporting behaviours [245]. Further exploration of this and of the underlying reasons for variations in reporting e.g. number of admissions, the influence that the healthcare culture, existing clinician decision-making structures and in particular nurses understanding of the importance of observation reporting in identify patients at risk of deterioration, is a necessary next step. Quality improvement measures including bedside clinical training [86, 246] to improve observation reporting, informed by greater understanding of existing reporting behaviours are necessary if an AWTTS is to be implemented in this setting.

Performance of the AWTTS was variable (Table 4.6.2). More complete observation reporting may improve performance; however, the practicalities of attempting to implement such a tool in this setting should be considered. Given existing observation reporting behaviours and with high patient burden and limited resources being cited as barriers to observation reporting, implementation of a system that requires sustained multi-parameter reporting without first

increasing understanding of their importance, may be viewed as impractical by frontline clinical staff. Sensitivity was low, echoing similar studies from LMIC's [85]. Lowering the cut off value at which patients would trigger to increase the sensitivity would result in large numbers of triggered patients, thereby increasing the burden of monitoring, documentation and potentially interventions. In addition, implementation of AWTTS in HIC's has highlighted challenges in accuracy of AWTTS score calculation and subsequent failure to escalate, precipitated by limited investment in training frontline users [240].

Of SPTTS tested Kenward et al's (2004) had the highest sensitivity to predict death or any adverse outcomes when applied on admission, however this sensitivity would not be high enough for implementation in clinical practice. As with the AWTTS, ability of SPTTS to predict all adverse outcomes at 24 hours prior to event was diminished. The sensitivities of the best performing AWTTS and SPTTS were comparable (Figure 4.6.2 and Table 4.6.5). Implementation of such a system may have a negative impact on staff attitudes towards EWS and understanding their value in helping detect unwell patients [245].

In addition to the challenges for users (observation reporting behaviours, staffing, resources) and in analysis (completeness of data, statistical methodology), differences in patient population (age, disease characteristics, timing of hospital presentation) also need to be considered when evaluating the accuracy and feasibility of both AWTTS and SPTTS for use in the clinical setting [247]. These confounding factors are poorly understood in resource limited settings [88].

The first step towards a pragmatic solution for improving identification of patients at risk of deterioration in this setting may be the implementation of single parameters trigger system that assists clinicians to detect at risk patients on admission based on parameters that are have good availability in current routine

practice.

This tool could be used as an alert to trigger more intensive observation monitoring needed for identification of vulnerable patients who are at risk of an adverse event, or who may benefit from simple interventions e.g supplemental Oxygen therapy in response to tachypnoea [30]. Subsequent evaluation of existing AWTTS and SPTTS scores and identification of additional variables that may have an association with adverse outcome in this setting could then be undertaken; they can be then further evaluated for safety and effectiveness.

Similar approaches have been suggested for other resource limited settings [87].

A simple electronic tool to record and visualise observations, which is increasingly feasible in LMIC settings [248-250] may assist clinicians in identifying at risk patients, improve visibility of observations and trends, assist to overcome the limitations of disparate paper systems and facilitate education in recognition and response to deterioration [245]. Such tools have been successfully implemented in other healthcare arenas to assist in both surveillance and clinician decision support by the study group [240, 249, 250]. Electronic tools have been successfully implemented to assist in both surveillance and clinician decision support, and is a part of the ongoing quality improvement effort outside of critical care in this setting [250]. A nurse led response team deployed in conjunction with a single parameter trigger system would seem a logical intervention in this setting and is now being implemented [75, 80, 81, 251].

4.6.5 Conclusion

There is limited availability of observation reporting in this setting. Further research is required to understand the behaviours and barriers to monitoring acutely unwell patients in this setting.

Existing AWTTS and SPTTS, possibly impeded by missingness, are not sufficiently able to discriminate patients at risk of death or adverse event so as to be deployed in this clinical setting. Further exploration of the influence that confounding factors, observation behaviours, and patient population may have on evaluation of EWS may be beneficial. Efforts to improve availability of observations in this setting are necessary in order to enable robust evaluation of EWS's.

Table 4.6.1. Summary of study population

	Patient characteristics (n=16386)
	Gender (%)
6640 (40.52%)	Male
9710 (59.26%)	Female
16386	Total
Mean age in years (sd)	
48.40 (17.52)	Male
38.88(16.42)	Female
42.70(17.50)	Mean age
Number of events (%)	
502 (3.06)	Patients with 1 or more event
149 (0.91)	Death
102 (0.62)	Cardiac arrest
83 (0.51)	ICU Admission
253 (1.54)	Transfers

Figure 4.6.1 Availability of observations during the 8-month study period. Unit of measure= weeks.

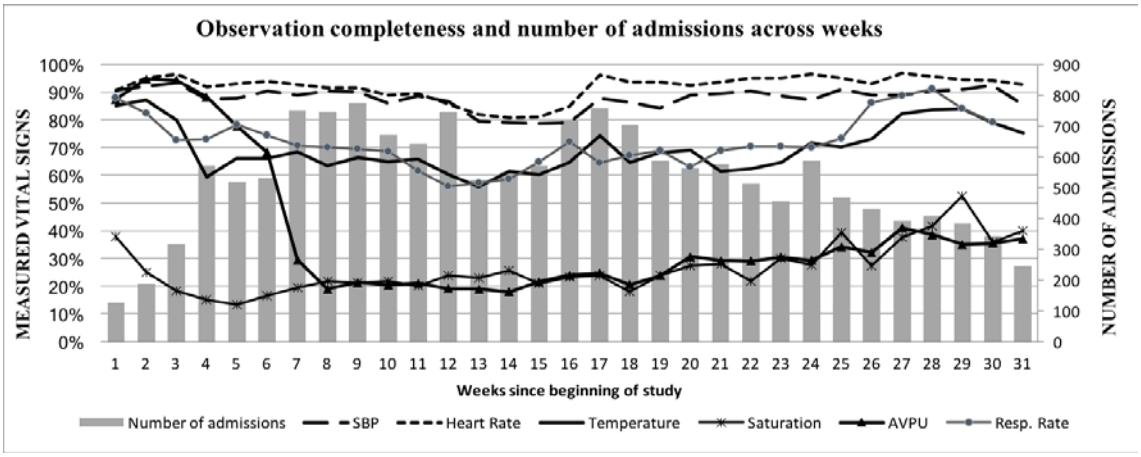


Table 4.6.2 Availability of observation reporting at admission and 24 hrs before event. * indicates a significant difference (p< 0.05) between availability at admission and 24 hours before the event.

Mean (sd) 24 hours prior to event	Availability % (CI) 24 hours prior to event	Mean (sd) on admission	Availability % (CI) on admission	Observation
121.91(22.73)	45.17 (44.36,45.98)*	122.07(23.35)	86.80 (86.27,87.31)	Systolic BP
78.92(9.58)	66.98 (66.21,67.74)*	80.69(11.38)	90.97 (90.52,91.40)	Heart Rate
19.49(2.33)	61.63 (60.84,62.42)*	19.85(2.56)	65.24 (64.51,65.97)	Respiratory Rate
98.45(0.30)	67.61 (66.85,68.37)*	98.58(0.71)	63.60 (62.85,64.33)	Temperature
97.70(3.75)	16.67 (16.07,17.28)*	97.49(3.83)	23.94 (23.29,24.60)	Saturation
4184(99.88) score of A (%)	28.67 (27.93,29.41)*	5371(99.67) score of A (%)	32.89 (32.17,33.61)	AVPU
42.70(17.50)	99.38 (99.24,99.49)	42.70(17.50)	99.38 (99.24,99.49)	Age

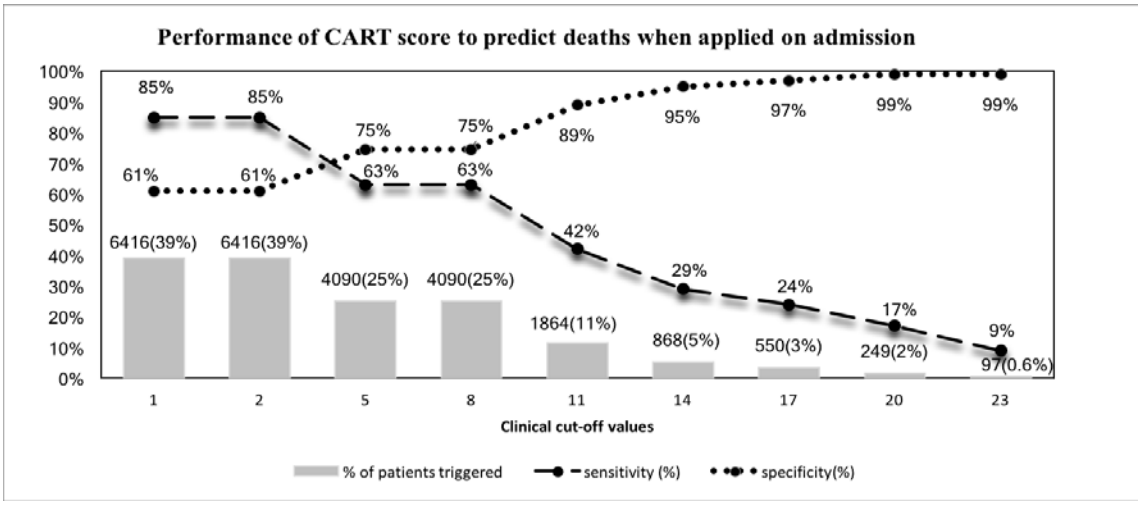
Table 4.6.3 Discrimination of selected AWTTS for deaths and events. Sample size of non-imputed scores are in brackets []. * indicate a significant difference between discrimination at admission and discrimination at 24 hours before for imputed scores.

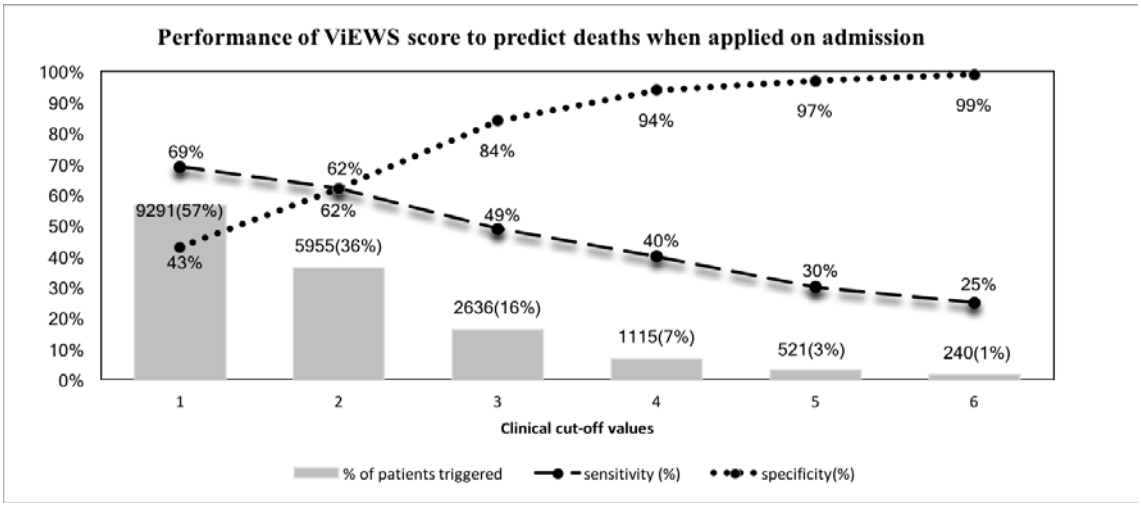
AWTTS	Death		Events	
	AUROC (CI) admission	AUROC (CI) 24 hours	AUROC (CI) admission	AUROC (CI) 24 hours
MEWS score	0.706 (0.64,0.78) [4232]	0.623 (0.49,0.75) [2160]	0.609 (0.57,0.65)	0.564 (0.49,0.64)
MEWS score with missing values imputed	0.667 (0.62, 0.72)	0.490* (0.42, 0.56)	0.617 (0.59, 0.64)	0.386* (0.36,0.42)
NEWS score	0.792 (0.68,0.90) [1857]	0.657 (0.49,0.83) [1293]	0.616 (0.54,0.69)	0.555 (0.45,0.66)
NEWS score with missing values imputed	0.677 (0.62,0.73)	0.583 (0.525, 0.641)	0.602 (0.57,0.63)	0.475* (0.45,0.50)
SEWS score	0.793 (0.71,0.88) [1862]	0.676 (0.49,0.85) [1294]	0.621 (0.55,0.69)	0.562 (0.46,0.66)
SEWS score missing values imputed	0.702 (0.66, 0.75)	0.599* (0.55,0.65)	0.609 (0.58,0.63)	0.510* (0.49,0.53)
CART score	0.764 (0.72,0.81) [9737]	0.787 (0.71,0.87) [5735]	0.604 (0.58,0.64)	0.665 (0.61,0.72)
CART score missing values imputed	0.781 (0.75, 0.82)	0.744 (0.69,0.74)	0.636 (0.61,0.63)	0.569* (0.54,0.59)
ViEWS score	0.778 (0.67,0.89) [1862]	0.679 (0.52,0.85) [1299]	0.602 (0.53,0.68)	0.565 (0.45,0.68)
ViEWS score missing values imputed.	0.677 (0.62, 0.73)	0.585 (0.53,0.65)	0.601 (0.58,0.63)	0.476* (0.45,0.50)

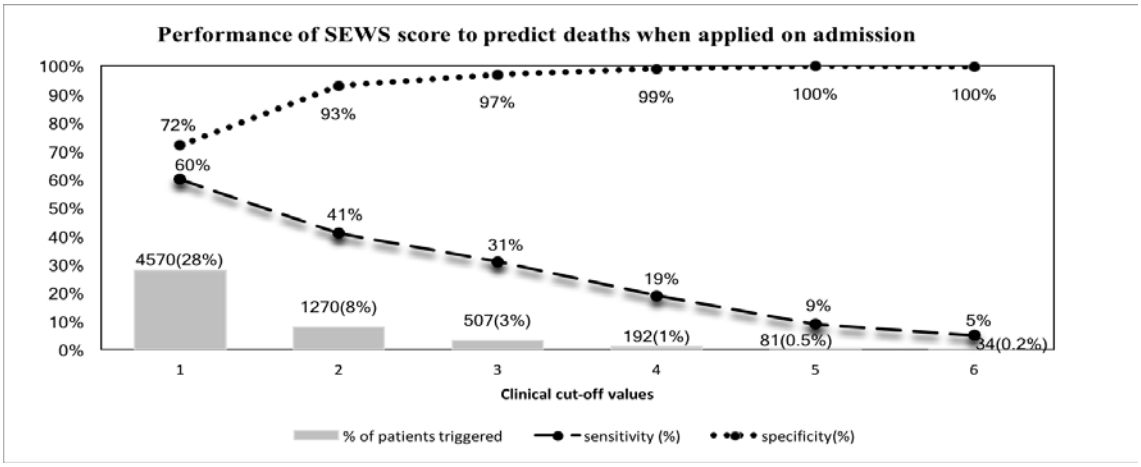
Table 4.6.4 Performance of best performing SPTTS [1] to predict death when applied at admission, using single, 2 and 3 parameters. All possible combinations of single, 2, and 3 of the 4 parameters are described.

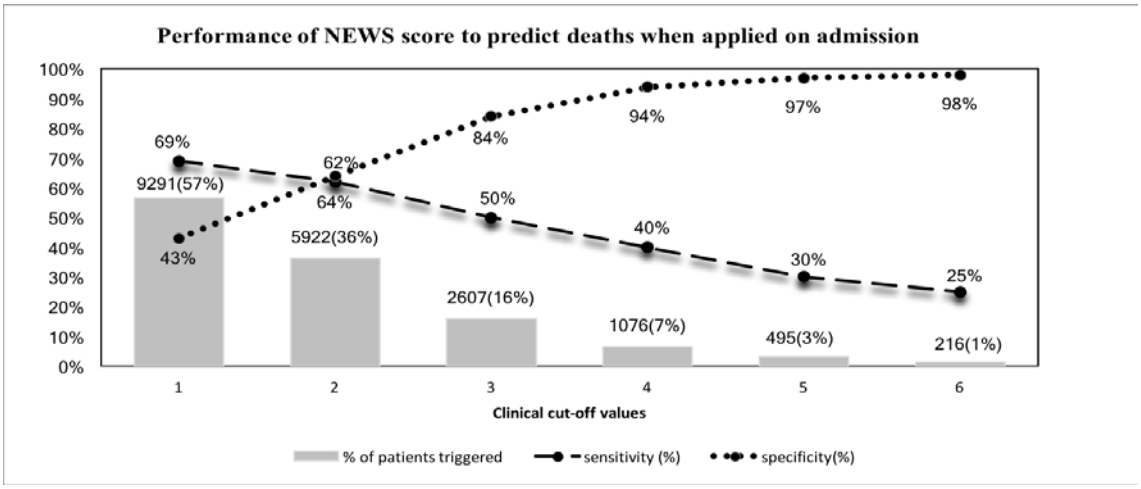
Parameter combinations			Sensitivity %	Specificity %	PPV %	NPV %
Heart rate	Resp rate	Systolic BP	59.1	69.7	1.75	99.5
Heart rate	Resp rate	Temp	54.4	72.6	1.79	99.4
Heart rate	Temp	Systolic BP	47.7	81.9	2.36	99.4
Resp rate	Systolic BP	Temp	45.6	77.0	1.79	99.4
Heart rate	Resp rate	-	57.6	72.15	1.64	99.52
Heart rate	Systolic BP	-	49.6	81.98	2.17	99.50
Heart rate	Temp	-	43.2	85.54	2.36	99.46
Resp rate	Systolic BP	-	48	76.99	1.66	99.45
Systolic BP	Temp	-	19.2	92.81	2.11	99.30
Resp rate	Temp	-	40	80.69	1.65	99.40
Heat rate	-	-	41.6	86.41	2.41	99.46
Resp rate	-	-	39.2	81.77	1.71	99.40
Systolic BP	-	-	16	94.16	2.16	99.28
Temp	-	-	3.2	98.42	1.61	99.21

Figure 4.6.2 Performance of AWTTS at clinical cut-offs. Missing values have been imputed as normal.








Performance of NEWS score to predict deaths when applied on admission
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
69%
62%
64%
50%
40%
30%
25%
43%
84%
94%
97%
98%
9291(57%)
5922(36%)
2607(16%)
1076(7%)
495(3%)
216(1%)
1
2
3
4
5
6
Clinical cut-off values
% of patients triggered
sensitivity (%)
specificity(%)

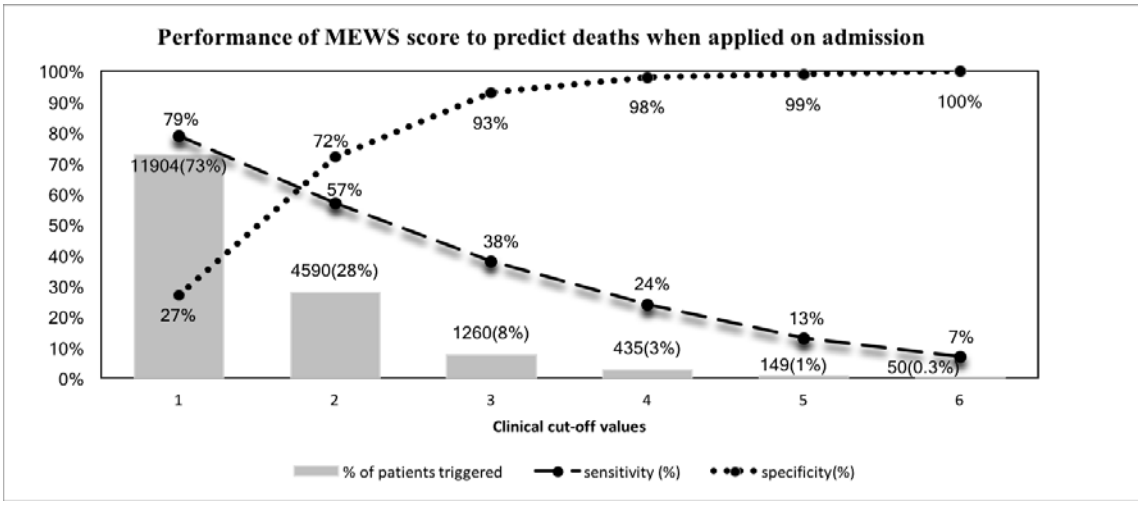

Performance of MEWS score to predict deaths when applied on admission
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
79%
72%
57%
38%
24%
13%
7%
27%
93%
98%
99%
100%
11904(73%)
4590(28%)
1260(8%)
435(3%)
149(1%)
50(0.3%)
1
2
3
4
5
6
Clinical cut-off values
% of patients triggered
sensitivity (%)
specificity(%)

Table 4.6.5. Performance of all SPTTS with 4 parameters to predict both death and events at admission and 24 hours before the event. SPTTS' i-vii parameters are described in Table 4.4.8

SPTTS	Outcome	Admission				24 hours before			
		Sensitivity %	Specificity %	PPV	NPV	Sensitivity %	Specificity %	PPV	NPV
i	Death	27.52	94.33	4.27	99.30	2.99	97.93	5	96.52
	Event	16.14	94.46	8.43	97.27	5.21	97.92	6.33	97.45
ii	Death	46.31	86.34	3.02	99.43	4.01	94.07	2.86	96.38
	Event	28.89	86.92	6.37	96.47	10.14	94.05	4.40	97.48
iii	Death	28.19	92.87	3.5	99.30	3.76	96.73	4.05	96.48
	Event	15.74	92.94	6.58	97.21	7.12	96.72	5.54	97.47
iv	Death	14.77	97.87	5.98	99.21	1.62	98.91	5.06	96.55
	Event	7.37	97.92	10.05	97.10	2.74	98.90	6.32	97.41

v	Death	32.89	89.61	2.82	99.32	4.33	95.11	3.16	96.42
	Event	20.72	89.73	5.99	97.28	9.04	95.09	4.74	97.48
vi	Death	22.15	97.93	8.94	99.28	2.21	99.35	10.89	96.57
	Event	11.35	98.04	15.45	97.22	3.56	99.35	12.87	97.44
vii	Death	59.06	69.07	1.72	99.46	6.18	79.96	1.15	95.77
	Event	48.41	69.36	4.76	97.70	19.45	79.85	2.54	97.35

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iii. Buist M.D., Jarmolowski E., Burton P.R., Bernard S.A., Waxman B.P., and Anderson J.: Recognising clinical instability in hospital patients before cardiac arrest or unplanned admission to intensive care. A pilot study in a tertiary-care hospital. Med J Aust 1999; 171: pp. 22-25.

iv. Lee A., Bishop G., Hillman K.M., and Daffurn K.: The Medical Emergency Team. Anaesth Intensive Care 1995; 23: pp. 183-186.

v. McGloin H, Adam SK, Singer M. Unexpected deaths and referrals to intensive care of patients on general wards. Are some cases potentially avoidable? J R Coll Physicians Lond. 1999;33(3):255–9.

vi. de Pennington J, Laurenson J, Lebus C, Sihota S, Smith P. Evaluation of Early Warning Systems on a Medical Admissions Unit. 2005;6(2):19–21.

vii.. Kenward G., Castle N., Hodgetts T., and Shaikh L.: Evaluation of a medical emergency team one year after implementation. Resuscitation 2004; 61: pp. 257-2

Table 4.6.6 AWTTs, parameters for AWTTs and clinical threshold

AWTTS	Parameters	Clinical threshold for escalation.
CART	HR, RR, Dias BP, Age	20
MEWS	SBP, HR, RR, Temp, AVPU	5
SEWS	RR, saturation, temp, SBP, HR, AVPU	5
NEWS	SBP, HR, RR, Temp, AVPU, saturation, supplemental oxygen (yes or no),	5
ViEWS	HR, Temp, SBP, RR, AVPU, saturation, spp O_2(yes or no)	5

Table 4.6.7 Reason for admissions

Reasons for admission (based upon ICD 10 diagnostic coding)	Frequency (%)
Pregnancy, childbirth and the puerperium	3316(20.24)
Observation and investigation	1745(10.65)
Diseases of the genitourinary system	1608(9.81)
Injury, poisoning and certain other consequences of external causes	1598(9.75)
Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified	1592(9.72)
Cardiovascular Disease	1245(7.60)
Respiratory Disease	977(5.96)
Certain infectious and parasitic diseases	898(5.48)
Diseases of the digestive system	667(4.07)
Endocrine, nutritional and metabolic diseases	484(2.95)
Trauma	80(0.488)
Other	2176(13.27)

Missing	409(2.49)

Table 4.6.8 SPTTS parameters i-vii

SPTTS	Pulse rate (beats m $^{-1}$)		Respiratory rate (breaths m $^{-1}$)		Systolic BP (mmHg)		Temperature (°C)	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
i	<50	>125	<8	>25	<90	>200		>38.0
ii		≥100		≥25	≤95	≥200	≤35.0	≥38.0
iii	<50	>130		>30	<90	>200	<35.0	>40.0
iv	<40	>120	<10	>30	<100	>200	<35.5	>39.5
v	<60	>120	<10	>25	<100	>200	<35.5	>38.5
vi		>120		>30	<90			>39.0
vii	<60	>90	<12	>20	<100		<35.0	>38.4

4.7 Experiences of ICU survivors in a low middle income country - a multicentre study

4.7.1 Background

The availability of ICUs in LMICs is increasing, however information on ICU performance and service user experience remains limited [29]. Admission to the ICU is often preceded by traumatic events leading to limited patient recall of their admission and ICU stay [252].

Patients who experience critical illness are at their most physically, mentally and emotionally vulnerable during their ICU stay, when they regularly experience Loss of control, including the ability to communicate and complete physical dependence on others for even the most basic daily needs [252, 253]. Both

disease process and the day-to-day procedures related to ICU care such as tracheal suctioning, and invasive line placement are associated with acute pain and discomfort. ICU stay can thus leave patients anxious, with sensory hypersensitivity and increasingly chronic neurological pain. Similarly, the ICU environment, including daily structure of ward rounds, complex clinical discussion about both themselves and other patients and the relentless nature of 24-hour activity often results in loss of day-night differentiation, sleep disturbance and disorientation, and add external stressors to patients who are already both physically and emotionally burdened [252-254]. Studies from HIC show that this complex combination of experiences and stressors can lead to cognitive impairment, chronic pain, and post-traumatic stress disorder (PTSD) that affect the recovery of patients both in the short and long term [252, 255, 256]. These repercussions impact on not only the patient but also their families [252, 257-262].

Stressful patient experiences during the ICU stay is associated with reduced satisfaction with the critical care experience [263]. Increasingly clinicians and patients are attempting to evaluate the quality of critical care in terms of the quality of care, the experience of survivors and their emotional recovery as opposed to the traditional mortality outcomes alone [264, 265]. Being satisfied with health care is important for patient wellbeing and public acceptance and is an important measure of the adequacy of healthcare services [266, 267]. Patients and the public are rightfully regarded as key stakeholders in quality improvement, research and service development for instance within the UK ICU setting [268].

Despite growing expansion of critical care services in developing countries research on patient experiences comes almost exclusively from HIC settings. This paucity in LMICs is partly due to the lack of ICU follow-up services and the

absence of medical registries that enable global service evaluation. As ICU survivors' experiences, satisfaction, recovery requirements and stress are likely to be influenced by the case-mix, social and economic factors such as education, wealth and pre-existing support structures, it cannot be assumed they will be identical to findings from HIC.

4.7.2 Study aim

This study, utilizing a critical care network established in a lower middle income country, describes the recall of ICU survivors' experiences, stressors and their satisfaction with ICU services. The study also sought to determine whether ICU patient's experiences are associated with satisfaction with their care, and reports survivors' suggestions for service improvement.

4.7.3 Study design

All consecutive adult patients between July and December 2015 (18 years and older) who were admitted to any of the 32 state participating ICUs (19 mixed general, 6 medical and 7 surgical ICU's) and were discharged alive from the ICU were included [269].

Name, age, gender, telephone number, length of ICU stay, discharge status, severity of illness (APACHE II score) and primary reason for ICU admission (APACHE II) were obtained from the critical care registry where data is input by clinical staff on the ICU. Eligible patients were contacted by the first author one month after ICU discharge in order to obtain informed verbal consent. As the study used a telephone administered data instrument, patients who were unable to communicate over the telephone at first contact were again contacted one week later. If the patient was still unable to communicate at this time, they were excluded from the study.

ICU experiences, stress and satisfaction were gathered using a telephone questionnaire (Supplementary Table 4.7.1) adapted from two previous studies [269, 270]. The tool from Granja et al has been previously successfully used in an Asian higher-middle income country setting [271]. Questions related to satisfaction with ICU care, stressful experiences, memories retained by the patient, the ICU environment, interaction with healthcare professionals, dreams, nightmares, sleep disturbances and difficulties in concentrating were included. As this was a study focused on patient's experience of their ICU stay, questions directed to quality of life and patients' families were not included.. The questions involving procedures and other experiences were measured on a five-point Likert scale where 0 ='I don't remember', 1 = 'It was not hard', 2 = 'It was indifferent', 3 = 'It was hard', 4 = 'It was very hard' and 5 = 'It was awful' [269]. The additional option of 'not relevant' was included to denote both when the procedure or experience was not applicable (eg NG tube use not recalled) and when the patient felt unable to comment (eg music played in the ICU). Satisfaction with the different aspects of care were also measured on a Likert scale where 1 = Excellent, 2 = Very good, 3 = Good, 4 =Fair, 5 = Poor and 6 = Not Applicable [270].

Following completion of the pre-specified questions, all patients were requested to provide comments including suggestions on how care in the ICU they were treated in, could be improved. All free text responses were coded and frequencies calculated with infrequent responses (<5) being listed under "other".

Conforming to previous studies [269]. Likert scale points 1 and 2 were grouped denoting "not stressful" and 3, 4 and 5 as "stressful". Patient characteristics were compared between those who recalled ICU admission and those who did not.

4.7.4 Results

Between July and December 2014 there were 1665 ICU survivors from the 32 ICUs eligible for the study. Of these 818 (49.1%) patients were not contactable and 389 (23.3%) patients died before 30 days after discharge from the ICU (Figure 4.7.1). Of the 458 (27.5%) survivors contacted, 20 (4.4%) patients were excluded due to inability to communicate [261] or denying consent [257]. Thus, a total of 438 (26.3%) patients were included in the study.

Summary ICU data of surveyed patients is presented in Table 4.7.1. The mean age was 45.0 (SD 29.1) years and 48.0% were males. A total of 159 (36.3%) patients were admitted to the ICU for medical reasons, 124(28.3%) for elective surgery and 95 (21.7%) for emergency surgery. The median (IQR) length of ICU stay was 2.0 (3.4) days and the mean (SD) APACHE II score was 13.0 (7.2). Mechanical ventilation had been instituted at admission in 107(24.0%) patients and 69(16.4%) were on vasoactive (vasopressor/inotrope) medication. The most common APACHE II diagnostic categories of those surveyed are shown in Table 4.7.2. For 386 (86.4%) patients the evaluated episode was their first admission to ICU.

Patients' recollection of the ICU experiences is presented in Table 4.7.3. Whilst 349 (78.1 %) - of patients were able to remember their admission to the hospital, only 189 (42.3%) could recall their admission into the ICU. The characteristics of the ICU episode for patients who were able to recall their ICU admission are compared with those who were not able to in Table 4.7.4. Significant characteristics impacting on patients' ability to recall ICU admission included, sedation at admission, mechanical ventilation at admission, administration of vasoactive medications at admission, lower conscious level (GCS) and a higher severity of illness (APACHE II score) (Table 4.7.4).

Three hundred and ninety-six (88.5%) patients surveyed did not object to recalling their ICU experiences (n=396, 88.5%) whereas 3 patients (0.7%) were unable to recall their entire ICU stay and another 3 patients did not wish to do so.

Patients' recollections of their stressful experiences in the ICU are shown in Figure 4.7.2. Of the 107 (23.9%) patients who were ventilated at admission, only 53 remembered the experience. Twenty-nine (54.7%) of those who remembered being ventilated found "dependency" on the ventilator to be stressful, and 13(24.5%) - feared being disconnected from it. Being bedridden, pain and general discomfort, daily needle punctures, family worries, fear of dying or uncertainty in the future were associated with the greatest amount of stress. (Figure 4.7.2). The majority of patients (376, 84.12 %,) found the atmosphere of the ICU to be friendly and calm. Just over half -227(50.78%) said that their sleep was sufficient and restoring, 112(25.06%) stated that their sleep was excessive and 108 (24.16%) said that it was insufficient. Fifty-nine (13.2%) of the patients recalled dreams during their stay in the ICU and in 25 cases (5.59%) they felt these dreams occurred on a daily basis. A similar number of patients (n=54,2.8%) stated that they had nightmares with 11 (2.46%) of them suffering from this on a daily basis.

Details of patient satisfaction pertaining to their ICU care are shown in Figure 3. None of the patients who felt able to comment (91.06%) considered the skills and competence of the doctors and nurses to be poor. Overall, the patients found the level of health care received in the ICU to be "very satisfactory" (n=409, 91.5%) with none stating they were either "dissatisfied" or "very dissatisfied". Few (n=15) patients made suggestions for improvement; increasing the number of beds in the ICU (n=3), increasing the facilities available to the staff (3), reducing noise in the ICU (n=2), staff (specified by patients as health care assistants) being kinder to patients (n=2), having curtains between patients (n=1), separate cubicles for

patients (n=1), increasing the space between beds (n=1), improving technology available in the ICU (n=1) and allowing more visitors in order to reduce stress (n=1) were included in the suggestions. In addition to these suggestions, 398 patients made additional comments. These included: ICU staff were excellent / very good (n=160), I appreciate the service of ICU staff (n=92), the ICU staff saved my life (n=49), I want to thank them (n=18), the staff were hardworking (n=17), kind (n=15), dedicated to service (n=13) and “God like” (n=9).

4.7.5 Discussion

This multicenter study of a large cohort of ICU survivors from an LMIC critical care network, demonstrated the feasibility of telephone follow-up in this setting, but with a 49.12% loss to follow up. However, this level of attrition is not limited to LMICs [269]. In addition, 30-day post-ICU mortality was 23.3% of ICU survivors (causes and other details of death were not available), which emphasized the importance of determining post-ICU outcomes when evaluating the effectiveness of scarce critical care services in LMICs. Innovative electronic techniques including registries [250], investment in dedicated patient liaison officers (not available in LMICs presently and who do not necessarily have to be clinically trained) and enlisting the assistance of the well-developed community public health services, especially in Sri Lanka, are potential strategies for the routine evaluation of post-discharge outcomes [272].

In this study cohort, nearly all patients (91.5%) expressed satisfaction with the ICU care they received and none of the patients surveyed considered ICU nurses or doctors to be lacking in their provision of care. However, the potential bias of the nurse interviewer, the use of a tool which had not been validated to this setting and the default high standing held by healthcare professionals in Sri Lanka (a cultural norm in many LMIC setting) need to be considered [273]. Patient

expectations regarding ICU care in LMIC settings such as Sri Lanka may be different to those of high income countries due to a multitude of factors, including; the fierce competition for scarce critical care services [43, 274] the relatively low-staffing, overcrowding and low resources in non-critical care wards to which patients are discharged to, and originate from [274, 275] ; and conversely the relatively well staffed ICU environment [37, 276]; cultural beliefs regarding critical illness [277]; and the minimal access to family and friends during ICU stay with very limited visiting hours [278]. In addition, patient satisfaction when evaluated in isolation has been known to be a poor measure of evaluating critical care services in HIC settings [279, 280] and this difficulty may be more pronounced in LMIC settings as suggested by the non-critical patient comments recorded in this study.

Inability to recall admission to ICU was relatively common and is in keeping with other studies from LMIC settings, however rate of total amnesia for the duration of the ICU stay was much lower (0.67%) than reported previously [269]. Unsurprisingly, the use of sedation, greater severity of illness and critical care therapies were more prevalent in the group who had limited recall. Details of organ support instituted during the remainder of the ICU stay and details of sedation, analgesia and incidence of delirium were not available preventing further exploration of possible contributors to amnesia.

Stressful experiences were only experienced by a minority of patients, but the commonest stressful experiences were similar to other settings [269, 281]. Whether the low levels of stressful experiences are due to sample or interviewer bias, lower patient expectations, or cultural, religious or fatalistic views, require further qualitative exploration.

4.7.6 Limitations

As no patients expressed dissatisfaction with their ICU care it was not possible to evaluate associations between satisfaction and ICU stressors. A mixed methods evaluation, including quality of life measures, ongoing patient and family experiences, and assessment of PTSD may provide better discriminators when evaluating ICU performance regarding patient centred outcomes and for exploring the impact of critical care stay on economic and social recovery. A follow- up study in this setting is currently being undertaken by our group.

4.7.7 Conclusions

This follow-up study of ICU survivors in Sri Lanka highlights loss to follow up and post-ICU discharge mortality as important considerations in LMICs. In common with HIC, survivors were very satisfied with their ICU care. In contrast to HIC settings, specific ICU experiences were frequently not being recalled, but those remembered were reported as relatively stress free. Stressful experiences, in common with HIC, were most frequently related to uncertainty about the future, dependency, family, and economic concerns. The study highlights two important areas central to the delivery and evaluation of critical care services in LMIC settings: the feasibility and importance of determining outcomes beyond ICU endpoints and the necessity of engaging with ICU survivors in order to identify issues important for quality improvement efforts.

Figure 4.7.1 Flow chart of patients recruited

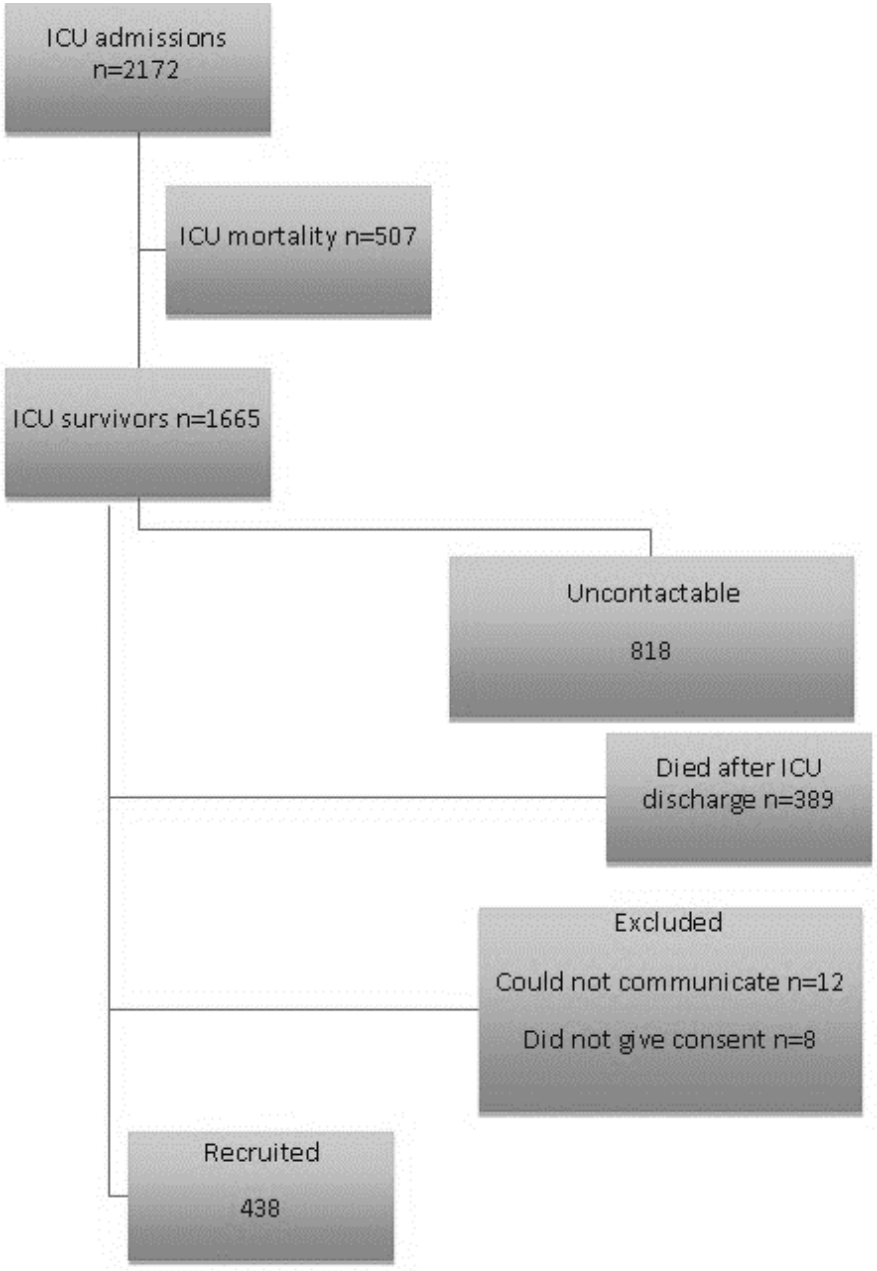


Table 4.7.1 Summary ICU details of survivors**.** Numbers in [] indicate the 25th and 75th percentile of the mean/median/percentage value of each ICU. For example, Q1 for the percentage of males in each ICU is 42.9.

	No (%), mean(SD) or median (IQR)
Male	207 (47.3) [42.9,52.8]
Median ICU LOS (IQR)	2.0 (3.5) [2,3]
Mean ICU LOS (SD)	3.84 (5.6) [2.4,4.6]
Mechanical ventilation on admission	104 (24.8) [14.3,29.1]
Vasoactive medication on admission	69 (16.4) [9.0, 25.0]
APACHE II Score, Mean(SD)	12.96 (7.2) [12.6,15.6]
APACHE II probability, Mean(SD)	0.22 (0.2) [0.19,0.29]

Table 4.7.2 Common diagnoses of respondents**.** Numbers in [] indicate the 25th and 75th percentile of the mean/median/percentage value of each ICU

APACHE II diagnosis	**Number(n=438)**	**Percentage %**
Gastrointestinal (surgical)	60	13.7 [11.1, 25.7]
Bleeding (surgical)	47	10.8[5.6, 16.7]
Cardiovascular (non-surgical)	36	8.2[4.5, 12.5]
Neoplasm (surgical)	28	6.4[0, 19.6]
Respiratory (non-surgical)	22	5.0[0, 9.5]

Table 4.7.3 Consciousness and recollection of ICU admission and stay**.** Numbers in [] indicate the 25th and 75th percentile of the mean/median/percentage value of each ICU

Question	Number	(% of responses)
Consciousness		
Do you remember your admission to hospital? Yes	349	78.08% [71.4, 86.7]
Do you remember your admission to the Intensive Care Unit (ICU)? Yes	189	42.28%[40, 46.7]
What do you think regarding the memory of your ICU stay?		
I prefer not to remember	3	0.67%[0, 1.8]
I don't remember anything	3	0.67%[0, 1.8]
I don't mind to remember	396	88.59% [85.2, 93.3]
I want to remember everything	34	7.61%[0, 11.1]
None of them	11	2.46%[0, 2.9]
Experiences		
How do you classify your sleep during ICU stay?		
Excessive	112	25.06%[19.0, 31.3]
Sufficient and restoring	227	50.78%[47.3, 63.6]
Insufficient	108	24.16%[14.8, 31.3]
Have you had any dreams during ICU stay?		
Yes	59	13.20%[9.8, 18.8]

No		
If yes, how frequently did they occur?		
Daily	25	5.59%[0, 8.3]
Twice a week	2	0.45%[0,0]
Once	3	0.67%[0,0]
Have you had any nightmares during ICU stay? Yes	54	12.08%[8.3,17.1]
If yes, how frequently did they occur?		
Daily	11	2.46%[0, 2.8]
Twice a week	6	1.34%[0, 0]
Once	5	1.12%[0, 0]
3 days	1	0.22%[0, 0]

Table 4.7.4 Characteristics of patients who recall ICU admission and those who do not

	When admitting to ICU		p-value
	Recall (186)	**Do not recall (252)**	
Mechanical ventilation on admission (%)	25(14.2)	79(32.5)	0.000
Sedated on admission (%)	37(21.9)	114(51.4)	0.000
Vasoactive medication on admission (%)	20(11.2)	49(20.1)	0.015
APACHE II Score mean (SD)	11(6.45)	14.4(7.38)	0.000
GCS mean (SD)	13.6(3.6)	11.7(4.87)	0.000
Gender; Male (%)	94(50.5)	113(44.8)	0.238
Admission Type (%)			
Emergency surgery	40(26)	53(25)	
Medical	66(42.9)	85(40.1)	
Planned surgery	48(31.2)	74(34.9)	0.751

Figure 4.7.2 Patients' recollecton of stressful experiences

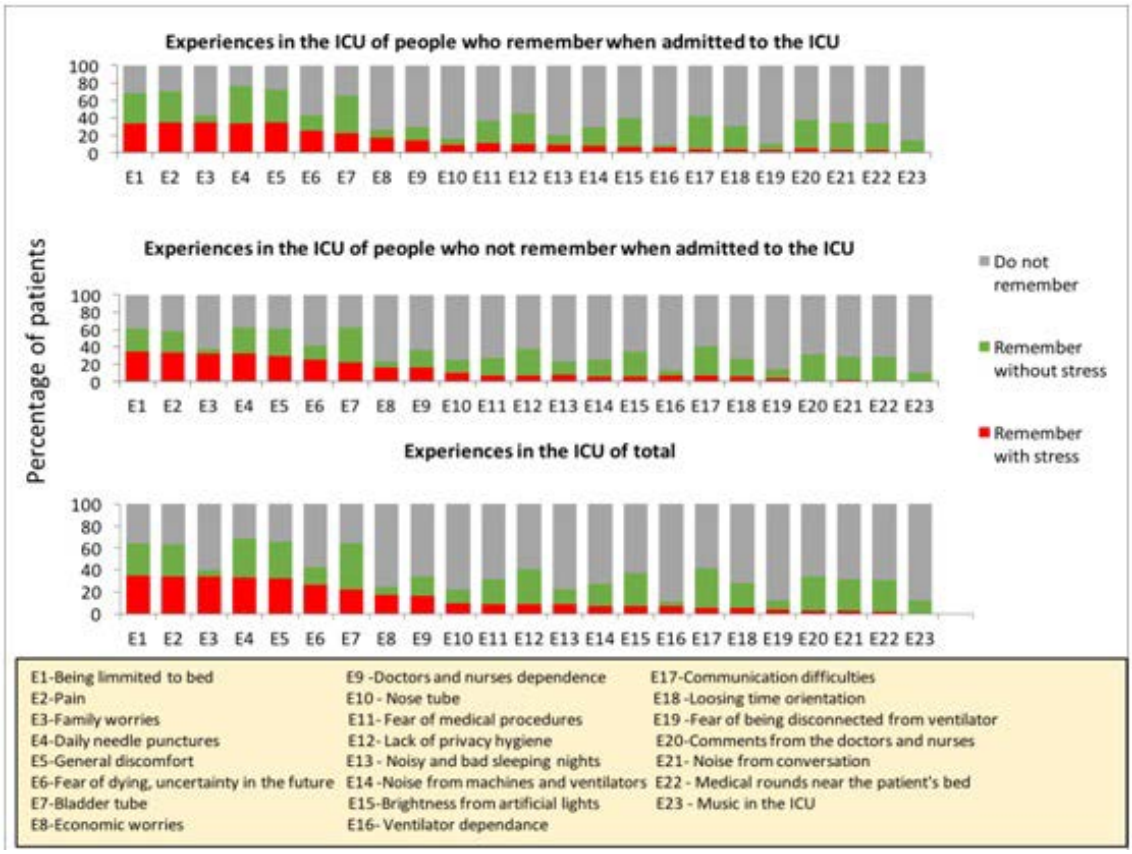
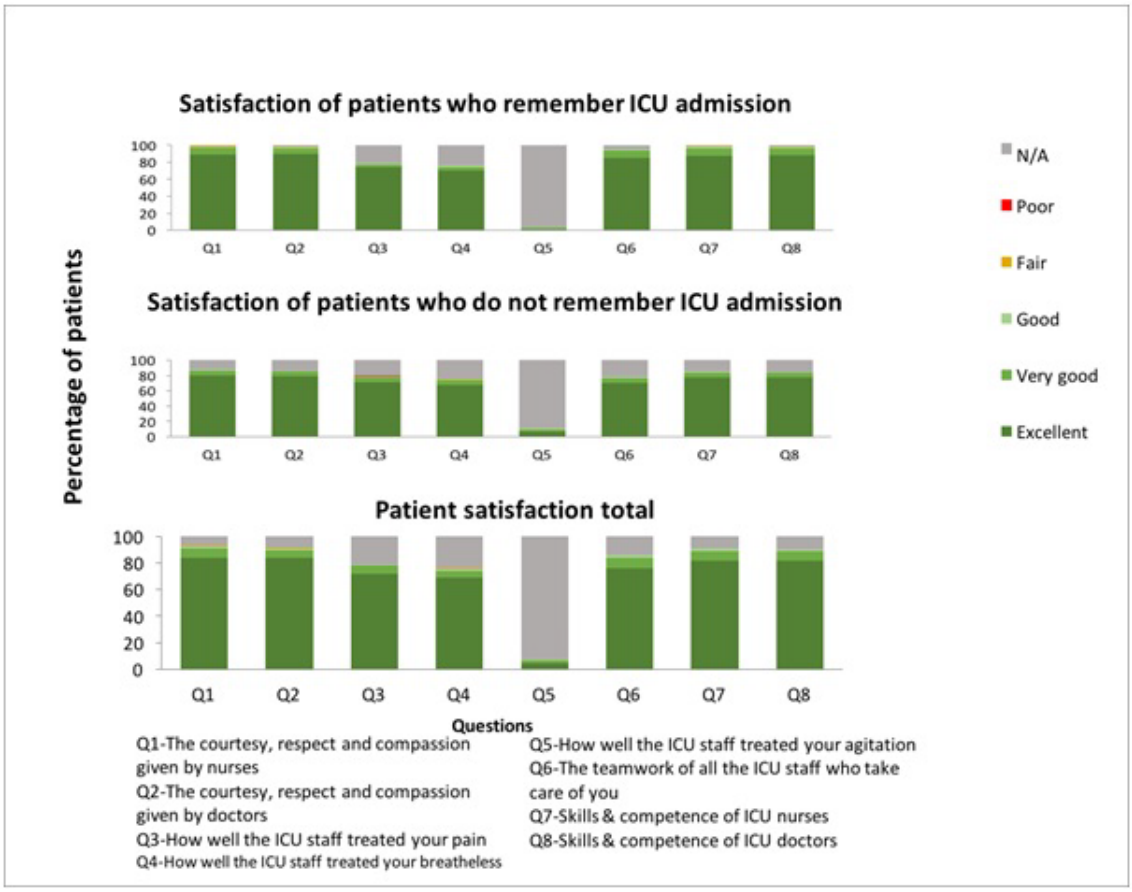


Figure 4.7.3 Satisfaction level of ICU patients


Satisfaction of patients who remember ICU admission
Satisfaction of patients who do not remember ICU admission
Patient satisfaction total
Percentage of patients
100
80
60
40
20
0
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
N/A
Poor
Fair
Good
Very good
Excellent
Questions
Q1-The courtesy, respect and compassion given by nurses
Q2-The courtesy, respect and compassion given by doctors
Q3-How well the ICU staff treated your pain
Q4-How well the ICU staff treated your breatheless
Q5-How well the ICU staff treated your agitation
Q6-The teamwork of all the ICU staff who take care of you
Q7-Skills & competence of ICU nurses
Q8-Skills & competence of ICU doctors

5.0 Acute and critical training model in LMIC settings

5.1 Critical care junior doctors training profile in a LMIC

5.1.1 Background

Critical Care Medicine is an established, and especially in high-income countries (HICs), an increasingly independent specialty. Universally, junior doctors and Intensive Care Unit (ICU) nurses are at the forefront of providing ICU care. The distribution of doctors, their training and skills plays a role in determining ICU outcomes [282]. In HIC countries such as Australia and the United Kingdom critical care specialists are trained through a comprehensive program similar to any other clinical discipline. Sri Lanka, in contrast to many Low-Middle Income Countries (LMICs) where such programs are non-existent, has a fledgling programme for specialist adult critical care training [283].

Doctors working in ICUs require specialist skills and invariably work in a stressful environment. For example, junior doctors face difficulties in managing airway emergencies especially if they have not had previous exposure to anaesthesia/ICU [284]. Doctors when allocated to ICUs experience stress, which is likely to be greater in non-HIC countries, and is compounded by staff shortages, high turnover and increased caseloads. [285, 286]. Perhaps consequently, retention of junior doctors (and nurses) in specialties such as critical care is difficult, especially in resource limited settings [19, 107]. Frontline staff in LMIC ICUs, in addition, face difficulties related to resource limitations and organizational aspects of critical care. For instance, in low income countries (LICs) of the African continent ICU patients are cared for by the doctors in base specialties [287]. Junior doctors will thus be very aware of the strengths and

limitations of services they provide and are likely to be central to improvement strategies. There are however limited studies from LMIC settings focusing on ICU staff [19, 288].

In Sri Lanka, state critical care is spread over 500 beds in approximately 100 ICUs with an average doctor: ICU bed ratio of 1.16 : 1 [37]. All junior doctors, not training to be consultants (specialists) and not in a formal postgraduate training programme, are allocated 4-year rotational postings by a centralized transfer system which is administered by the Ministry of Health. This system has been designed to ensure that less popular settings and specialties are adequately staffed by means of an easy to administer system. The allocations depend on vacancies, seniority, doctors' preference and previous hospital of employment. Qualifications, specialty courses, special skills or relevant training are not priority considerations. In parallel, doctors enrolled in formal postgraduate training to be consultants (specialists) are allocated posts via an alternative allocation system, tailored to their training needs.

The aim of this national cross sectional survey was to determine the profiles and training needs of junior doctors working in state ICUs in Sri Lanka in order to inform strategies to improve retention, training and service delivery.

5.1.2 Study aim

The aim of this national cross sectional survey was to determine the profiles and training needs of junior doctors working in state ICUs in Sri Lanka in order to inform strategies to improve retention, training and service delivery.

5.1.3 Study design

This was a cross sectional survey aimed at all state sector adult intensive care unit (ICU) doctors. Private sector ICUs in Sri Lanka were excluded as they are

predominantly staffed by junior doctors from state hospitals doing extra shifts. Paediatric and neonatal ICUs were also excluded. All state sector adult ICUs were contacted to ascertain contact details of junior doctors. The ICUs that declined to provide contact details of doctors following a second attempt by a senior investigator were not pursued any further. The doctors, whose contact details were thus obtained, were contacted by telephone by an investigator and invited to participate in the survey.

A self-administered anonymous electronic questionnaire was utilized for the study. The survey instrument underwent pre and pilot-testing including by selected junior doctors with regard to its flow, salience, acceptability and administrative ease. Inter-rater reliability was also assessed. Based on the results of the pilot-testing, the questionnaire was modified. Finally, clinical sensitivity testing as well as testing for internal validity was conducted. Free text responses were minimized by the using drop down menus and radio buttons (for Likert scales) to facilitate user entry and statistical analysis. The questionnaire covered the following; ICU training needs and career aspirations; ICU competencies and stress; and junior doctors' views on how LMIC ICUs can improve services. Questions deemed central to the study were made mandatory to minimize incomplete responses. The survey tool was made available on a dedicated website and automated field validation used to minimize erroneous entries. Frequently Asked Questions were made available on the website alongside contact details for any clarifications. The survey tool was only available in English.

The junior doctors' whose contact details were obtained from the ICUs, were contacted over the telephone. Any doctor who declined consent was not contacted again. The survey form was then emailed to these doctors followed by

a short message service (SMS) alert. Two weeks after the link was shared, reminders were sent by email and SMS. The doctors were requested to convey contact details of other eligible colleagues directly to the investigators, in order to ensure that as many as possible were contacted. The survey was also offered over the telephone as an interviewer-administered instrument or by post. At the end of the study period, questionnaire accessibility through the study homepage was blocked and raw data manually checked independently for plausibility and quality control. Duplicates were removed and exclusion criteria (doctors predominantly working in paediatric or neonatal ICUs) enforced.

All Likert scales ranged from 0-10 and were mapped into five groups after the survey for analysis; 0, 1-3, 4-6, 7-9 and 10. Overall competency was a mean score calculated from 8 ICU skills scored from 0 to 10.

5.1.4 Results

93 adult ICUs were contacted with 5 ICUs declining to participate. A total of 539 doctors from the agreeable ICUs were contacted (figure 5.5.1). The total number of responses received, after removing duplicates, was 207. Nine were discarded as they were doctors primarily employed at paediatric or neonatal ICUs. All doctors preferred the online questionnaire and administration via the telephone/post was not necessary.

Table 5.5.1 summarizes the profile of the respondents. The mean age of the doctors was 35 years (SD= 5) with 86 (43.4%) doctors in the 31-35 year category. For over two thirds of the doctors (134, 67.7%) this was their first ICU job. 155 (78.28%) of the doctors had a formal induction (orientation) at the commencement of their ICU posting.

Overall, 68 (34.3%) respondents identified themselves as anaesthetic junior

doctors, 66 doctors (33.3%) categorized themselves as critical care junior doctors. The remaining doctors ascribed themselves to other specialties or none. Just under half of the respondents (93, 47%) work exclusively in ICUs with no allocated duties outside these units. Overall, 57 doctors (28.8%) worked in more than one ICU. It is notable that 150 doctors (75.8%) had no previous exposure to anaesthesia prior to this ICU appointment and only 4 respondents (2.1%) had any ICU training overseas. Twelve (6.3%) doctors had already completed a critical care diploma course conducted by the national postgraduate institute of medicine. One hundred and sixteen (60.7%) ICU doctors expressed a wish to specialize in critical care as a postgraduate specialty. In addition, 99 doctors (50.5%) were able to recommend critical care, to the highest possible recommendation (10 on a likert scale of 0 to 10), as a specialty in Sri Lanka to a colleague. Only two doctors marked “zero” for this specialty recommendation. Similarly, in response to how likely they were to choose this ICU posting again, 72 (36.92%) doctors indicated complete certainty with a score of 10 (on a likert scale of 0 to 10) with 130 (66.67%) doctors scoring between 7 to 10 on a 0-10 likert scale. A majority (133, 67.2%) of doctors also felt well supervised and 102 (51.52%) respondents had a named educational supervisor for their current ICU posting.

Table 5.1.2 further summarizes the training needs related to relevant short courses. Figure 5.1.2 illustrates junior doctors’ self-assessed competence in 8 common ICU skills. The median self-assessed competency for junior doctors who have been in a previous ICU post is 8.9 (IQR 1.6) when compared with the median value of 8 (IQR 2.25) for those who have not held a previous ICU post. This difference is statistically significant ($p<0.05$). The overall median competency progressively improves with the length of ICU experience; <12

months experience median of 6.88 and IQR 2.75; 1-4 years experience median 8.69 and IQR 1.62; >4 years median of 9 and IQR 1.25. These differences are also statistically significant. ($p<0.05$). Overall, there was also a statistically significant difference ($p<0.05$) between the median self-assessed confidence of anaesthetic junior doctors (median 8.9, IQR 1.75), and non-anaesthetic junior doctors (median 8.1, IQR 2.38). Figure 5.1.3 illustrates the distribution of ICU doctors' self-perceived happiness and stress. There was a statistically significant difference in stress and happiness levels when ICU postings and the last non-ICU posting ($p < 0.05$) were compared, with the ICU posting being perceived to be more stressful and feeling less happy.

The vast majority 173 (88.2%) of doctors felt the care provided for patients in their ICUs was good, very good or excellent. 71 doctors (36.2 %) would be happy to recommend the ICU where they work to a relative with the highest possible score of 10 (on a 0-10 likert scale) with 139 doctors (70.9%) scoring this recommendation between 7 and 10. The challenges experienced by these ICU junior doctors are shown in the figures below. The barriers faced by their ICUs and strategies for improvements as perceived by the doctors are shown in figures 5.1.5 and 5.1.6.

5.1.5 Discussion

This national survey of adult critical care junior doctors is a first for a LMIC. Most (67.7%) respondents are in their first ICU posting and are not currently part of a formal critical care training programme. However, unlike similar settings, the doctors did not predominantly originate from an anaesthestic background [285, 286]. These critical care junior doctors are both significantly more stressed and significantly less happy in comparison to their last non-ICU posting, even though this did not deter them from aspiring to critical care as a career for themselves or

when recommending to a colleague. In addition, the junior doctors overwhelmingly perceived ICU care provided by their unit as good and had no hesitation in recommending the ICU as part of a friends and family test [289].

The survey response rate was 40.1% amongst those who consented to participate. This figure necessitates caution when interpreting the study findings. The low response rate is in contrast to the 100% response rate in the national survey of physiotherapists [276] and the survey of ICU services [37] by the same group of investigators. The low response rate is despite measures to improve participation; contacting the doctors through their ICU, reminding those who consented by text messages and email, ensuring and reassuring anonymity, study being conducted by a multi-disciplinary group, obtaining ethical review, securing MOH approval for the study, obtaining the endorsement of the doctors' union, approaching the relevant academic professional colleges and making the survey available in multiple (online and non-online) formats. The sensitive nature of the questions, the length of the survey, online (primary) format of the survey and the unfamiliarity of these doctors towards surveys in this setting may have contributed to a low response rate. These possibilities need further exploration, especially to inform the conduct of future surveys of doctors in this setting, bearing in mind the difficulties in ensuring adequate doctors participation in non-mandatory surveys are not limited to ICUs or LMICs [290]. In order to enhance participation, the use of more innovative techniques such as social media or very short survey tools or alternative modes such as a telephone interview, which has been previously successful in this setting, merit further consideration.

The staffing and retention of doctors in specialties such as emergency and critical care medicine is a universal problem, and perhaps worse in LMICs [19, 107]. The importance of appropriate specialist medical staffing of ICUs has been

internationally recognized. The College of Intensive Care Medicine of Australia and New Zealand (CICM) recommends that only ‘a registered medical practitioner with an appropriate level of experience’ should be ‘exclusively rostered and predominantly present in the ICU at all times [285]. However, especially at night, many hospitals including those of high-income countries, lack resident doctors with adequate competencies to manage ICU airway emergencies [285, 286]. In Australia and New Zealand, only 15% of units had a dedicated resident doctor to manage complex/emergency airway issues at night time. Similar difficulties were observed in limited studies in non-HIC, compounded by severe staffing limitations and increased caseloads [287].

This study confirms previous reports that Sri Lankan adult critical care units are relatively well staffed, with junior doctors staffing ratios being comparable to countries with better resources [68, 70, 291]. However, this survey reveals that more than half the junior doctors have clinical commitments outside critical care and that most junior doctors currently working in Sri Lankan ICUs had no previous critical care experience. This is due to junior doctors who previously held such ICU posts moving to non-critical care postings or leaving the state sector. The underlying reasons for this worrying pattern needs to be explored and remedial measures instituted. The lack of retention is perhaps surprising given that the junior doctors surveyed would choose their current ICU posting, if allowed to re-visit their choice, despite the significantly lower levels of self-reported happiness and higher levels of stress, when compared to previous non-ICU postings.

However, they were not explicitly asked as to whether they would take up another ICU posting as their next job. This study is unable to delineate the relative contributions of the Sri Lankan doctors’ allocation system, overseas migration (known to be a problem in this setting), stress, lifestyle preferences or other

factors. This transitional junior doctor population with a high annual turn-over, can make service provision very challenging, especially in areas such as critical care, where specialist technical skills are acquired over the years (as evidenced by this study) and where multidisciplinary care plays an increasingly important role. Therefore, in Sri Lanka, skills acquired by critical care junior doctors are not being retained within the specialty, necessitating the re-training of a high proportion of junior doctors posted to ICUs every year. In addition, given the junior doctors allocation system, such challenges are unlikely to be limited to critical care medicine, and justify further investigation and implementation of remedial measures with the involvement of the different stakeholders.

Doctors previously employed in an ICU were significantly more competent in ICU technical skills. Their perceived competency in these skills also improved with increasing ICU experience. These findings, corroborated by studies in HIC settings, support the need for retaining expertise within the specialty by minimizing turnover. In parallel, new doctors starting out in critical care will require training in order to gain the necessary skills without compromising patient safety. These novice doctors will require robust supervision, mentoring and orientation as they acquire these skills on the ICU in order to support them and ensure patient safety. It is reassuring to note that more than three quarters of the doctors had some form of formal orientation at the start of their posting and just over half had a named educational supervisor.

Given that a majority of technical skills are common to critical care and anaesthesia, junior doctors from an anaesthetic background were significantly more competent in ICU technical skills when compared to those who had no anaesthetic experience. This supports the preferential deployment of junior doctors with anaesthetic/critical care skills in ICUs. Such allocated junior doctors

could also mentor and support their colleagues with no exposure to anaesthesia/critical care in a formal but peer-led capacity, until the latter gain the requisite competencies.

A majority of the respondents from this survey expressed a desire to specialize in critical care, if given the opportunity. There is recognition that training opportunities in critical care in Sri Lanka need to be widened to keep pace with the service needs and aspirations of junior doctors. It is beyond the remit of this paper to determine how this challenge is best addressed, though it is important for the stakeholders and administrators to consider the extent to which difficulties in career progression as a critical care specialist may be hindering the retention of junior doctors in this specialty. Simultaneously, it is also important to note other recent pleas for acute and critical care training, reported by our group, from diverse healthcare professionals in Sri Lanka; critical care nurses[37, 39, 84]; nurses and doctors working in general wards providing acute care[86, 100]; physiotherapists working in CCU[25, 276]; medical graduates prior to their residency or foundation training[115, 292].

The doctors felt the greatest impact on improving the functioning of the ICU would arise from better training of doctors, followed by training of nurses and a formal admissions/discharge policy for the ICU. The last suggestion probably reflects variations in admission and discharge thresholds of the ICU, though ICUs in Sri Lanka are predominantly “closed” in nature with a consultant in charge of the ICU [37]. Continuing the training theme, the doctors felt those who are outside the system (such as foreigners etc) could best benefit the ICU by helping with developing protocols and training materials for the unit, followed by incorporating doctors in research and training events such as conferences. This emphasis on training combined with usage of checklists and simple protocols is consistent with

previous recommendations for ICUs in resource limited settings [19]. The perception that the ICUs could most benefit by better training of doctors, including by utilizing external resources in such training, when considered alongside the aspirations of the doctors to specialize in critical care should be seen as a call to widen opportunities in training for these doctors. Further, it should reinforce the need to explore how to better retain trained staff. In contrast, the doctors did not feel the involvement of outsiders in training ICU nurses in any form would have a good impact. Potential reasons for such a view, including the English language difficulties of the nurses, need further exploration. Possibly the doctors feel that they would be better placed to facilitate the training of nurses in their ICUs, though the survey did not explore this.

5.1.6 Limitations

The low response rate of the survey makes generalization difficult. Selection bias due to online nature of the survey has to be considered. The concerns of HCWs in non-HI to express opinions that they perceive to be critical regarding the system they are part of and the possibility of social desirability bias leading to over-response to questions may have also affected the survey responses. Unfortunately, the survey did not seek to determine what would influence doctors to continue in critical care or leave for other postings.

5.1.7 Conclusion

Critical care junior doctors in Sri Lankan ICUs, unlike other LMICs, are predominantly from a non-anaesthetic background and have a high turnover despite wishing to specialize in critical care. Doctors with an anaesthetic background feel more competent in performing ICU skills. ICU junior doctors are more stressed and less happy in comparison to previous non-ICU jobs. In common with recommendations from other settings they perceive that better

training opportunities for junior doctors would be important for their careers and contribute to improving critical care services. Measures to improve training opportunities for these doctors and strategies to improve their retention in ICUs need to be addressed.

Table 5.1.1 Profile of junior ICU doctors

Characteristic	Number (Percentage%)
Age	
26-30	35(17.68)
31-35	86(43.43)
36-40	41(20.71)
41-45	32(16.16)
46-50	2(1.01)
>50	2(1.01)
Gender	
Male	104(53.33)
Female	91(46.67)
ICU	
General	89(44.95)
Medical	35(17.68)
Surgical	25(12.63)
Special	49 (24.7)
Duties	
Only ICU	93(46.97)
More in ICU and less in theater	27(13.64)
More in theaters less in ICU	52(26.26)
More in ICU less wards	6(3.03)
More wards less ICU	14(7.07)

More in ICU less in OPD and other	4(2.02)
More in OPD and other less in ICU	2(1.01)
Proportion of time in ICU Shifts	
< 20%	13(6.88)
21-40%	40(21.16)
41-60%	25(13.23)
61-80%	10(5.29)
81-99%	6(3.17)
100%	95(50.26)

Table 5.1.2 ICU junior doctors' views on short courses

Relevant courses	View	Number	Percentage %
ALS	Willing to do	112	57.1
	Already done	71	36.2
	Not interested	13	6.6
Practical medical emergencies course	Willing to do	183	92.9
	Already done	4	2.0
	Not interested	10	5.1
Simulation training for ICU/emergencies	Willing to do	180	91.4
	Already done	3	1.5
	Not interested	14	7.1
BASICS	Willing to do	169	85.8
	Already done	12	6.1
	Not interested	16	8.1

ALS: Advanced life support

BASICS: Basic Assessment and Support in Intensive Care

Figure 5.1.1 Summary of the study population.

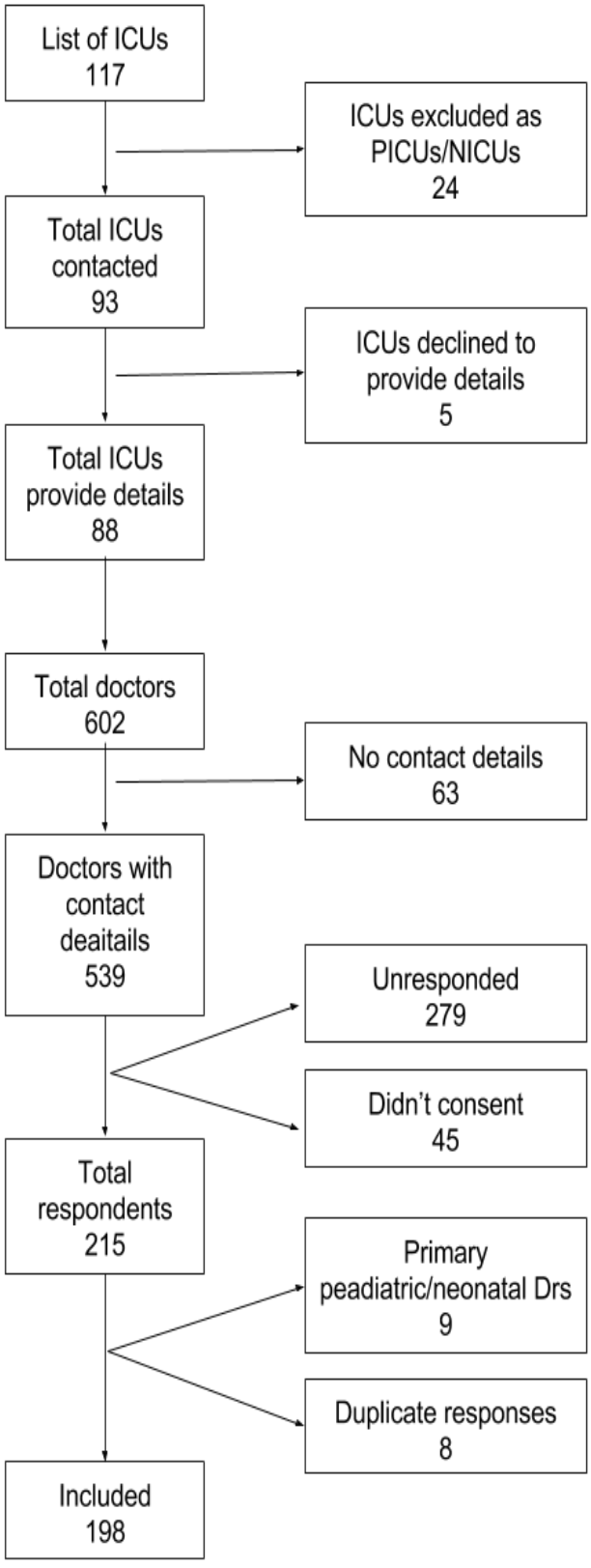


Figure 5.1.2 Self-assessed competency in 8 common ICU skills.

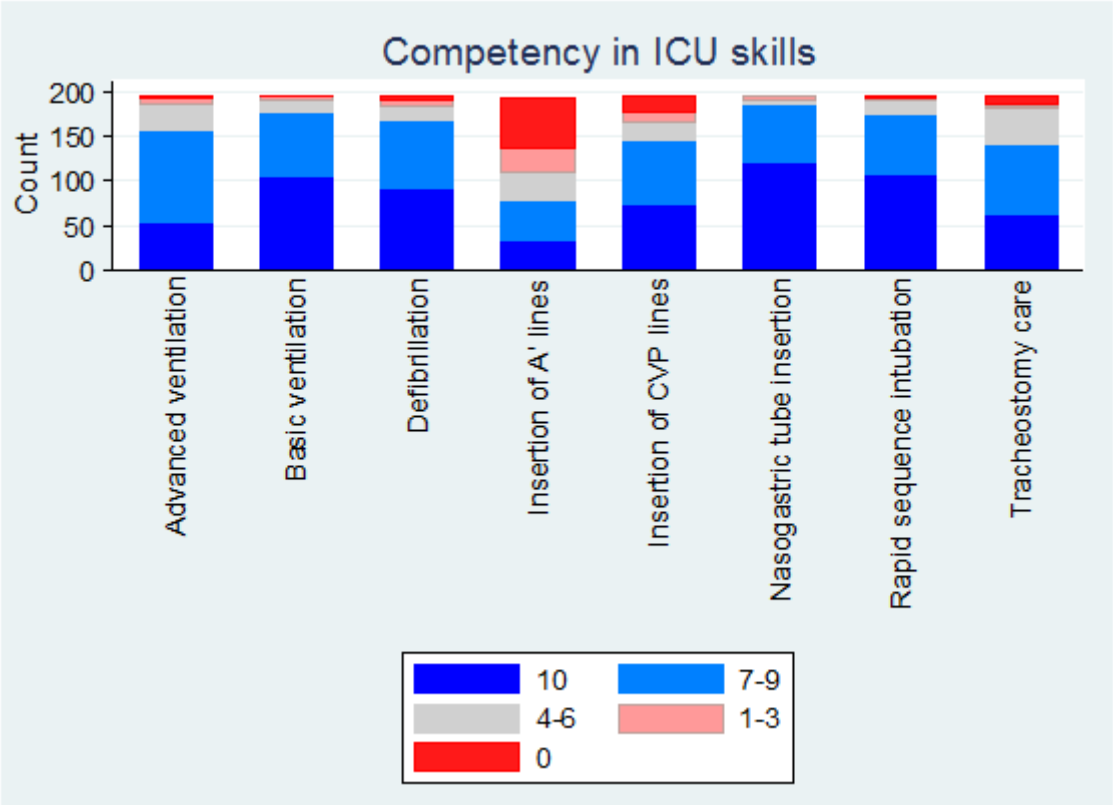
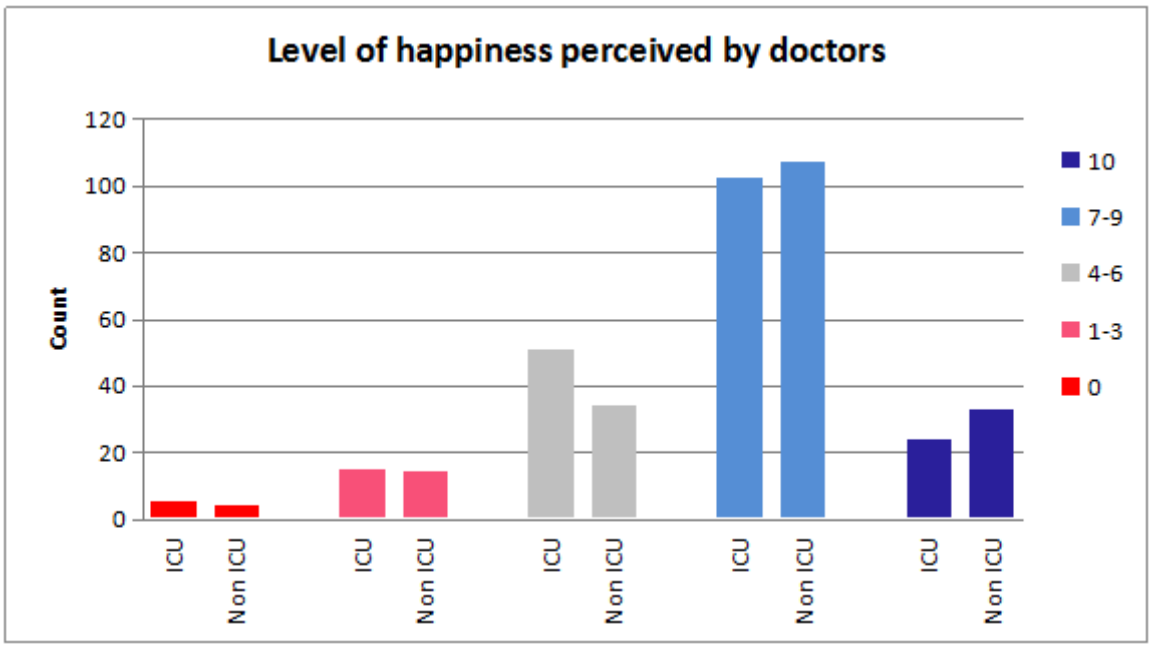


Figure 5.1.3 The comparison of level of stress and happiness of doctors working in ICUs and in their last non- ICU posting.



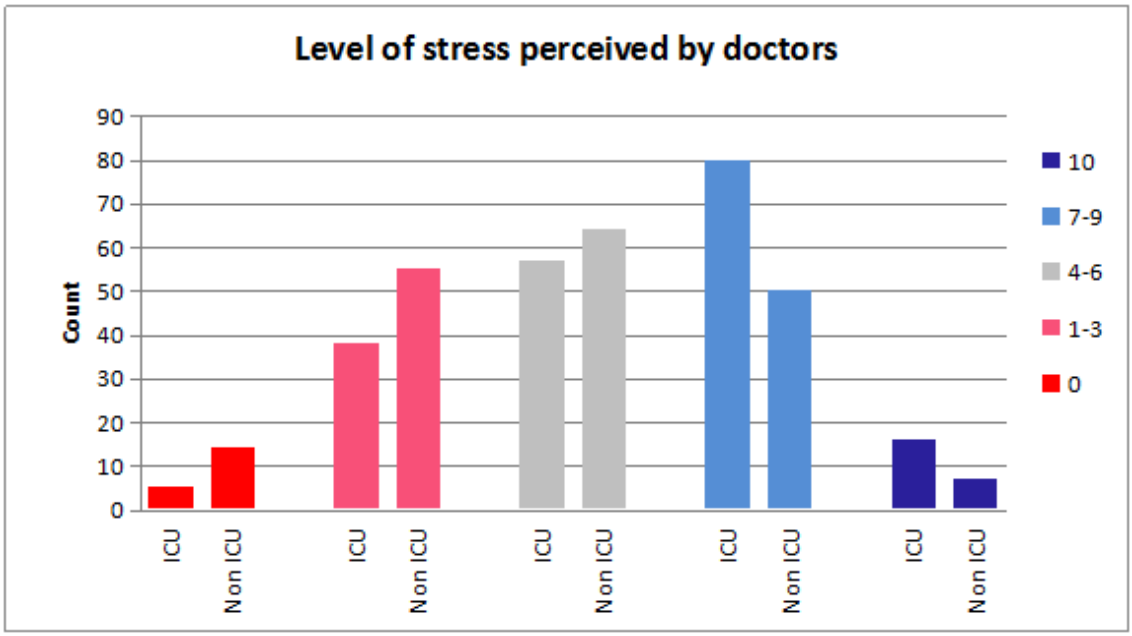


Figure 5.1.4 The challenges experienced by ICU junior doctors

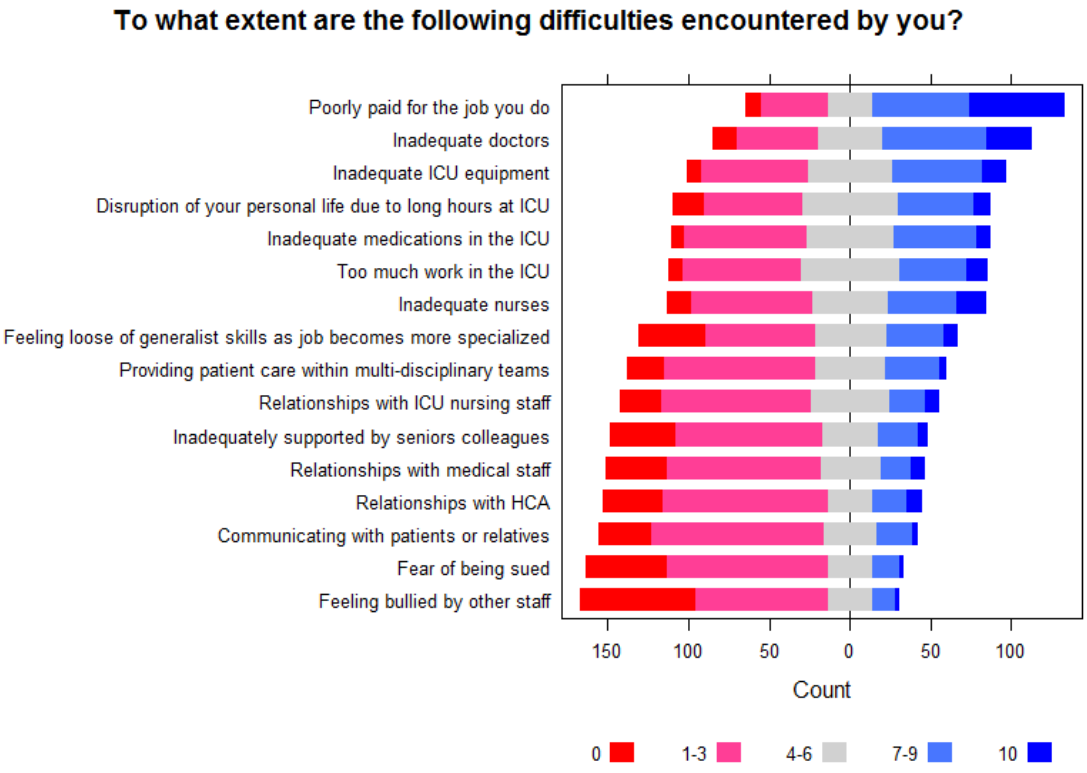


Figure 5.1.5 The barriers faced by Junior doctors in ICUs

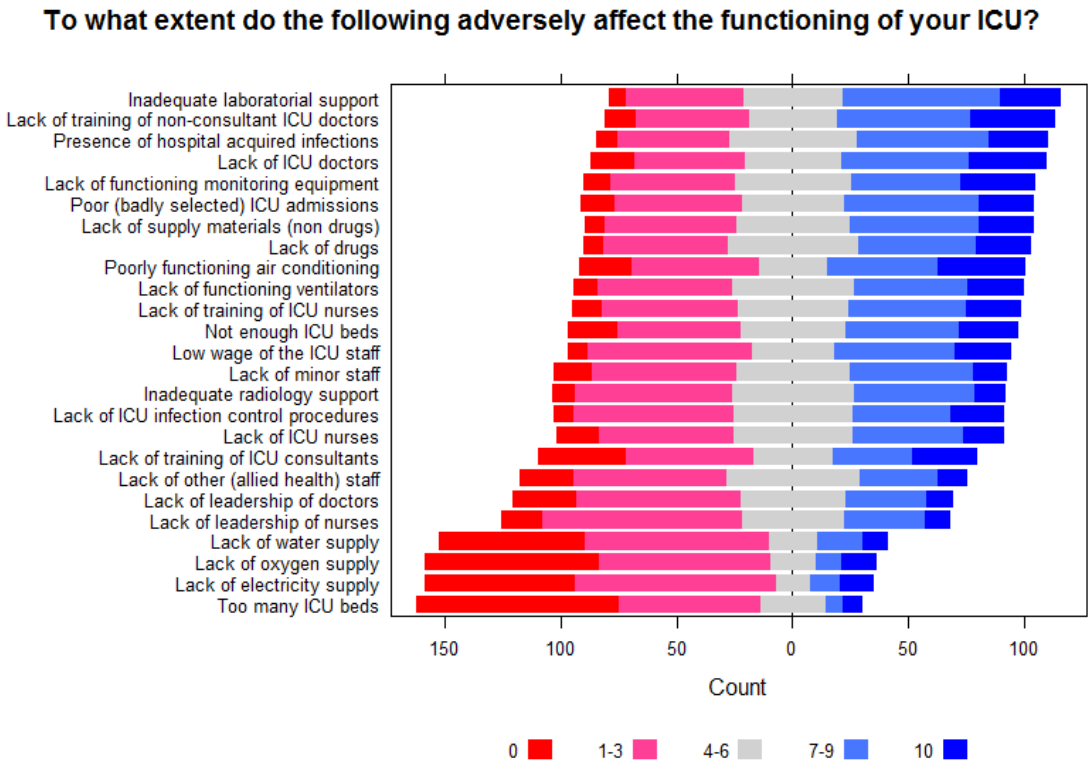
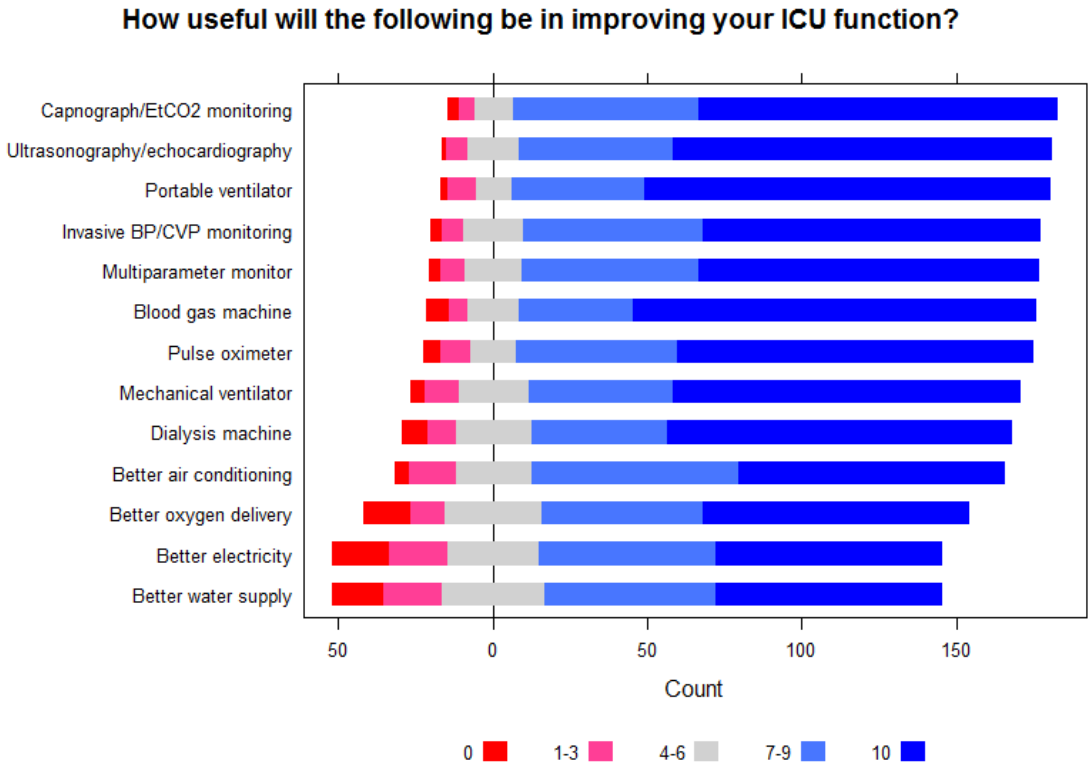


Figure 5.1.6 Strategies for improving ICU functionality as perceived by junior doctors



5.2 Impact of a structured ICU training programme in resource-limited settings in Asia.

5.2.1 Background

Although access remains limited, intensive care (ICU) facilities are increasingly available in many low and middle income countries [18, 37, 43, 46, 64, 293]. Nonetheless, from the limited data available, case fatality rates in these ICUs remain high [28, 294]. A lack of both material resources and trained staff is likely to be an important contributor[26]. But within these limits better use of available ICU resources and adherence to basic principles of critical care have the potential to reduce mortality without increasing cost of treatment. These principles, however, will have to be translated into setting-specific strategies, adapted to the local infrastructure and disease case mix [295]. Quality training in critical care medicine is a prerequisite for good care of the ICU patient, but formal training programs are either absent or minimal in low-income and sometimes also in middle income countries [37, 46, 293]. The importance of training for medical and nursing staff is being increasingly emphasized by those seeking to improve ICU performance and increase capacity in these settings [19, 26].

An international critical care training collaboration with the aim to improve patient outcomes within the constraints inherent to the resource-limited setting was convened. It was hypothesised that the introduction of a modular training program would lead to improvement in ICU performance indicators: with a reduction in the disease severity–adjusted mortality, length of ICU stay, duration of mechanical ventilation, duration of vasoactive drug use and in the duration of antibiotic therapy.

5.2.2 Study design

The modular training programme, with a focus on practical bedside teaching, aimed at critical care physicians and nurses in three ICUs in, Rourkela, India (11–bed ICU at Ispat General Hospital), Chittagong, Bangladesh (9–bed ICU at Chittagong Medical College Hospital) and Patan, Nepal (6–bed ICU at Patan Hospital) was instituted.-Trainers consisted of ICU doctors and nurses trained in Europe or the U.S.A. This multifaceted training programme evaluated using a two-phase interrupted times series design at three sites. ICU routine performance indicators were collected over a period of three years: from 8 to 15 months before the start of the intervention (pre-intervention period) until 18-24 months after (post-intervention period) for evaluation of the programme. The training was focused on the basic tenets of intensive care and was analogous to the continuing professional training for doctors and nurses carried out in most ICUs in high income countries. No direct patient interventions were performed and no additional tests or new data collection implemented. The participating ICUs are further described under Section 2.1.

The intervention consisted of a six-module training programme on basic intensive care practices over a period of 20 months evaluated by performance indicators before, during and after the training programme. Each module consisted of two to three weeks of short classroom lectures in the morning complemented by extensive bedside teaching for both doctors and nurses during the rest of the day. A brief needs-analysis was performed by the training team at the commencement of the training model; this was then used to guide the delivery of the training module. Each of the 18 training teams consisted of an experienced intensivist and an ICU nurse (see Supplementary File 5.2.1 for list of trainers) and trained approximately all 100 doctors and nurses across the three sites (30 each in Patan

and Chittagong and 40 in Rourkela). The modules covered the following themes: i) Basic care for the critically ill patient; ii) Care on admission and in emergency situations; iii) Shock and its treatment; iv) Feeding, glucose control and monitoring; v) Care beyond the initial phase; vi) Remaining issues, which depended on local demand and remaining observed deficiencies. When appropriate, local staff in collaboration with the trainers were encouraged to produce locally adapted treatment guidelines, for instance on severe sepsis management (see Supplementary File 5.2.1 for further details of the training program). The training was conducted in English, with on–site translation for nurses in Bangladesh.

To assess the training impact we collected (from routine patient records) a range of demographic, clinical and resource utilization data on patients admitted to the ICUs before, during and after the implementation of the training modules. The intervention was non-randomized and the analysis focused on describing the change in pre-defined indicators prior to and after the commencement of the training program. These data were extracted from routine patient records of patients admitted to the ICU during the following periods: for Rourkela – every second patient (due to high case load and limited availability of human resources) admitted between August 2009 to June 2012; for Chittagong all patients admitted between June 2009 to June 2012; and for Patan between February 2009 and December 2011 (limited by logistics of data extraction). Clinical data included diagnosis at time of ICU admission, comorbidities, physiology at time of admission and organ support initiated on arrival to ICU. Physiology and laboratory parameters during the first 24 hours needed to calculate APACHE II scores (the simplest of the commonly used critical care prognostic scoring systems) were also extracted. Discharge information consisted of ICU survival,

durations of mechanical ventilation, vasoactive drugs and antibiotic treatment. The study did not attempt to collect hospital or 28-day outcomes due to infeasibility of such follow-up in these settings. The study did not capture information regarding readmissions due to the lack of unique identifiers during repeat admissions in the three hospitals.

All data extracted were stored in the ICUs, entered into a password protected electronic database and then securely disposed of. Data extraction was performed by trained nurses in Rourkela while in Chittagong and Patan it was performed by trained medical officers working in the hospitals.

We assessed the effect of the intervention on three process outcomes and three patient outcomes. Process outcomes were time on mechanical ventilation, time to discontinue vasoactive drugs or to stopping antibiotics (amongst those ventilated, taking vasoactive drugs or antibiotics within 24 hours of ICU admission respectively). Patient outcomes were cumulative incidence of ICU mortality, ICU mortality rate, and the rate at which patients were discharged alive from the ICU. Analyses were performed separately for each of the three centres. ICU mortality and discharge from the ICU alive were considered competing events. To account for this the effect of the intervention on the cumulative incidence of ICU mortality was assessed with a Fine and Gray model [296]. This accounts for the possibility that the intervention may change both the mortality rate and patient discharge rate; both will affect the cumulative incidence of ICU mortality [297]. In this case the association between the intervention and outcome is reported with the adjusted sub-distribution hazard ratio (aSHR). An aSHR less (greater) than one indicates an association with a reduced (increased) *risk* of the outcome. For other outcomes we estimated cause-specific hazards using a Cox proportional hazards model, with censoring at the time of the competing events (death or discharge).

In this case the association between the intervention and outcome is reported with the adjusted hazard ratio (aHR), An aHR less (greater) than one indicates an association with a reduced (increased) *rate* of the outcome, where the rate is the risk (i.e. probability) of the event per unit time. Models also allowed for pre-training trends. In all models we allowed for both an immediate step change due to the start of the intervention and a change in trend following the intervention to account for a possible learning curve associated with the intervention. Trends were assumed to be linear on the log hazard scale. Models adjusted for sex, age, season (rainy season or otherwise), type of admission (medical or otherwise), and APACHE II probability, unless there was evidence to reject the proportional hazards assumption in which case stratification was used. This was the case for ICU mortality rate in Chittagong (stratified by whether or not admission was classified as “medical”) and antibiotic stopping rate at Rourkela (stratified by medical and sex)

Outcomes from the Fine and Gray model are expressed through the sub-distribution hazard ratio while results of the Cox models were expressed through the hazard ratio (values greater than one indicate an association with, respectively, an increased risk or rate of the outcome).

5.2.3 Results

A total of 3,868 patients were included in the dataset, with over two–thirds of these admitted to the Rourkela ICU. The median age was 52 years in Rourkela, 32 in Chittagong and 54 in Patan. Further demographic, clinical and severity of illness information along with ICU discharge status pre and post-intervention are summarised in Table 5.2.1.

Table 5.2.1 Demography, clinical profile, severity of illness and ICU discharge status of patients in the three ICUs admitted during the before and after commencement of training period.

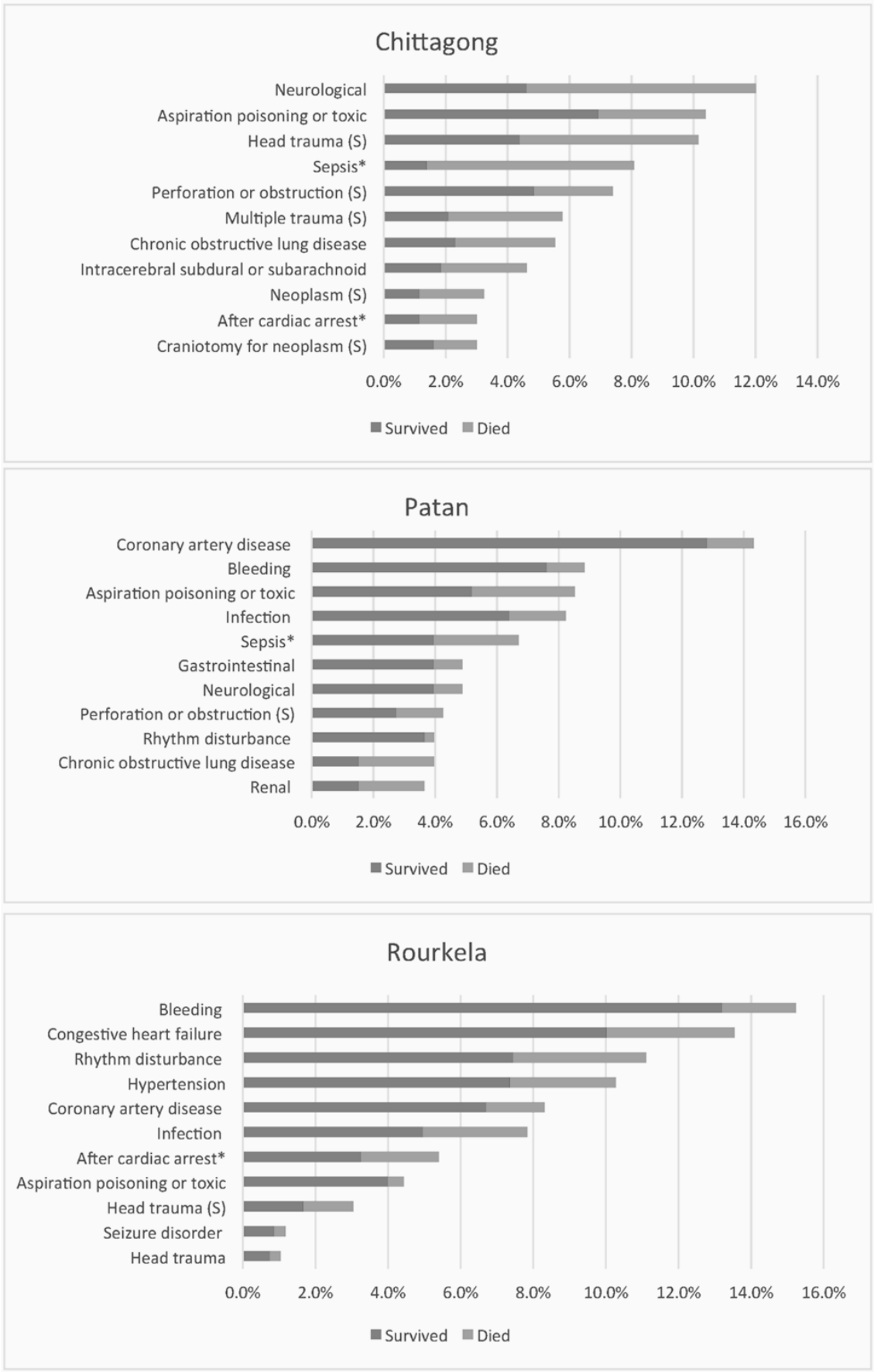
	Pre-intervention			Post-intervention		
Site	**Rourkela**	**Chittagong**	**Patan**	**Rourkela**	**Chittagong**	**Patan**
Patients (n)	822	103	122	1777	616	293
Age, y (mean, range)	49.7(0 .5–95)	39.7(7–96)	54.3(9–95)	49.6(1.5–95)	36.6(10days-98)	49.8(12–90)
% Male	69.80%	65.40%	50%	68.90%	49.50%	44.40%
APACHE II(mean, SD)	24.7(7.5)	13.8(6.4)	9.2(5.9)	24.5(7.9)	12.7(5.9)	9(5.7)
APACHE II pr*(mean, SD)	0.125(0.13)	0.162(0.146)	0.121(0.102)	0.124(0.125)	0.182(0.152)	0.123 (0.112)
Dead at ICU discharge (%)	228(28%)	64(62%)	50(41%)	525(30%)	313(51%)	53(18%)

* probability

https://doi.org/10.1371/journal.pone.0173483.t001

The frequency of the most common diagnoses and their associated mortality for each site are shown in Fig 5.2.1 ICU mortality in the pre and post intervention periods respectively were as follows Rourkela 28% and 30%, Chittagong 62% and 51% and Patan 41% and 18%.

Figure 5.2.1 Common admission diagnoses (APACHE II diagnostic category) and mortality by site during study period



The cumulative incidence of ICU mortality between pre-training and post-periods was associated with a substantial stepwise reduction at Chittagong and Patan as indicated by a Phase 2 step change aSHR of less than one (Fig 5.2.2, Table 5.2.2). There was no evidence at Rourkela that the intervention resulted in reduced ICU mortality. At Chittagong, the Phase 1 trend aSHR was above one 1 (95% confidence interval [1.00, 1.04]), providing evidence of a tendency for cumulative incidence of ICU mortality to increase over calendar time during the pre-intervention period; the intervention was associated with a reversal of this trend reflecting a post-intervention reduction in the ICU mortality rate and increase in the ICU discharge rate (Table 5.2.2). The steep increase in the cumulative incidence of ICU mortality in the first few weeks following admission at all three centers and subsequent levelling off reflects the short length of ICU stays (Fig 5.2.3). Since very few patients remain in ICU for more than 50 days, the cumulative incidence of ICU mortality changes little after this time period.

Figure 5.2.2 Cumulative incidence function for ICU mortality in the three study sites. P-values refer to the evidence for stepwise changes in adjusted subdistribution hazard ratio from the Fine-Gray model for the cumulative incidence of ICU mortality.

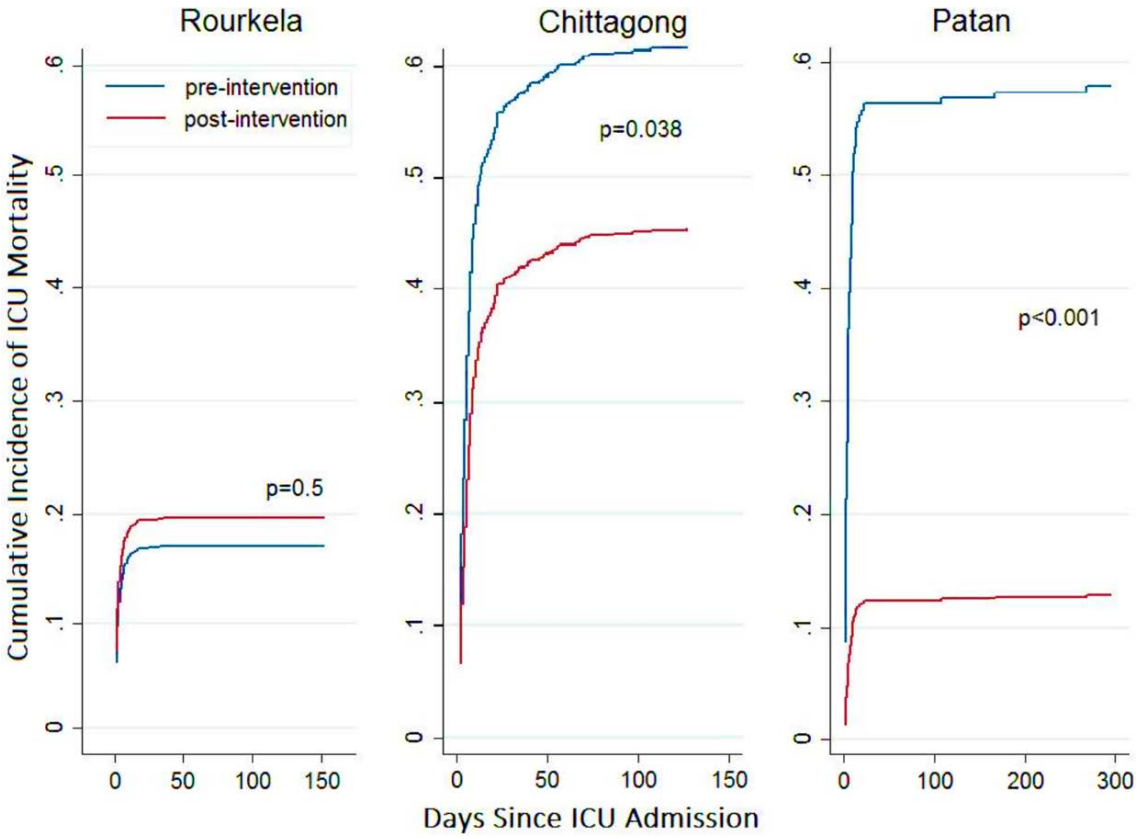


Figure 5.2.3 Median duration of ICU stay, mechanical ventilation, vasoactive drug use and antibiotic use in the three study sites by four-week period. The trend line is a non-parametric locally weighted scatterplot smoother. The vertical line indicates the time that the training intervention started.

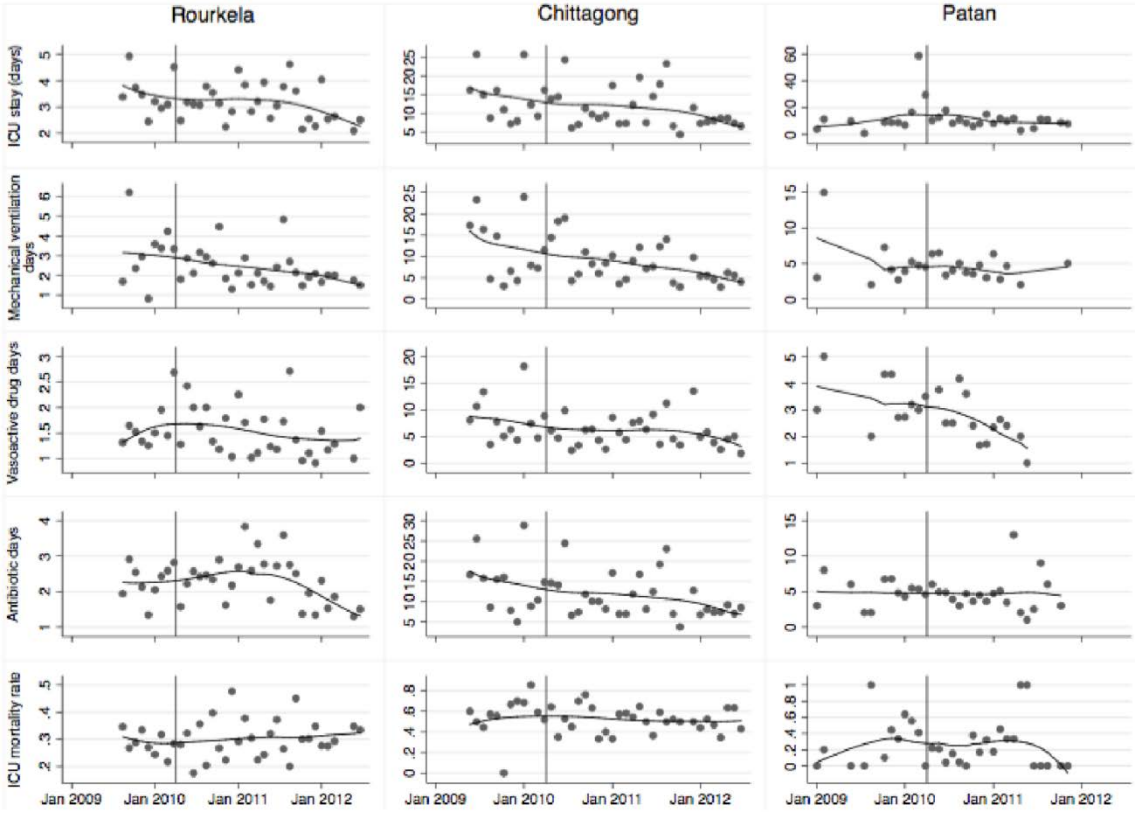


Table 5.2.2 Trends for outcomes in the three study sites

Rourkela	Outcome					
Variable	Cumulative incidence of ICU mortality aSHR (95% CI)[1]	ICU mortality rate aHR (95% CI)[2]	ICU discharge alive rate aHR (95% CI)[2]	Rate of stopping mechanical ventilation aHR (95% CI)[2]	Rate of stopping vasoactive drugs aHR (95% CI)[2]	Rate of stopping antibiotics aHR (95% CI)[2]
Phase 1 trend[3]	0.99(0.98–1.01), p = 0.55	1.01(0.99–1.03), p = 0.55	1.01(1.00–1.02), p = 0.07	1(0.97–1.04),p = 1.00	0.93(0.880.98), p = 0.01	0.99(0.96–1.01), p = 0.30
Phase 2 step change	1.17(0.75–1.82), p = 0.49	0.96(0.61,1.51), p = 0.87	0.9(0.70–1.15), p = 0.40	0.94(0.45–1.93), p = 0.86	2.45(0.76–7.88), p = 0.13	0.56(0.32–1.00), p = 0.05
Phase 2 change in trend[3]	1.01(0.99–1.03), p = 0.50	1(0.98–1.02), p = 0.68	0.99(0.98–1.00), p = 0.06	1.01(0.97–1.04), p = 0.69	1.08(1.03–1.14), p = 0.002	0.99(0.98–1.01), p = 0.55
Chittagong	**Outcome**					
Variable	Cumulative incidence of ICU mortality aSHR (95% CI)[1]	ICU mortality rate aHR (95% CI)[2]	ICU discharge alive rate aHR (95% CI)[2]	Rate of stopping mechanical ventilation aHR (95% CI)[2]	Rate of stopping vasoactive drugs aHR (95% CI)[2]	Rate of stopping antibiotics aHR (95% CI)[2]
Phase 1 trend[3]	1.02(1.00–1.04), p = 0.03	1.01(0.99–1.03), p = 0.51	0.99(0.97–1.02), p = 0.47	0.96(0.93–1.00), p = 0.03	0.99(0.95–1.04), p = 0.77	0.98(0.92–1.04), p = 0.49
Phase 2 step change	0.62(0.40–0.97), p = 0.04	0.9(0.54–1.49), p = 0.69	1.6(0.85–3.02), p = 0.15	2.97(1.24–7.14), p = 0.02	1.2(0.43–3.35), p = 0.72	1.26(0.27–5.91), p = 0.77
Phase 2 change in trend[3]	0.98(0.96–1.00), p = 0.03	0.99(0.97–1.01), p = 0.55	1.01(0.99–1.04), p = 0.34	1.04(1.01–1.08), p = 0.01	1.01(0.97–1.06), p = 0.59	1.04(0.98–1.10), p = 0.23
Patan	**Outcome**					
Variable	Cumulative incidence of ICU mortality aSHR (95% CI)[1]	ICU mortality rate aHR (95% CI)[2]	ICU discharge alive rate aHR (95% CI)[2]	Rate of stopping mechanical ventilation aHR (95% CI)[2]	Rate of stopping vasoactive drugs aHR (95% CI)[2]	Rate of stopping antibiotics aHR (95% CI)[2]
Phase 1 trend[3]	1.02(1.00–1.05), p = 0.08	1.01(0.99–1.04), p = 0.38	0.99(0.97–1.00), p = 0.11	1(0.97–1.02),p = 0.90	1.01(0.97–1.06), p = 0.60	1.01(0.98–1.04), p = 0.42
Phase 2 step change	0.16(0.06–0.41), p<0.001	0.22(0.08–0.62), p = 0.004	1.87(1.02–3.43), p = 0.04	1.95(0.51–7.4),p = 0.33	2.04(0.45–9.16), p = 0.36	1.85(0.82–4.18) p = 0.14
Phase 2 change in trend[3]	1(0.96–1.03),p = 0.82	1.01(0.97–1.04), p = 0.69	1.01(0.99–1.03), p = 0.23	0.99(0.95–1.03), p = 0.70	0.98(0.93–1.04), p = 0.57	0.98(0.95–1.01), p = 0.24

aHR, adjusted hazard ratio; aSHR, adjusted sub-distribution hazard ratio

[1] Results are based on the competing risks regression, which accounts for the effect of the intervention. aSHR is the adjusted sub-distribution hazard ratio, adjusting for sex, age, reason, APACHE II probability, and whether the patient is a medical admission.

[2] Results are based on a Cox regression model

[3] Time units are expressed in weeks, so reported aSHR and aHR represent proportional change in outcome each week

https://doi.org/10.1371/journal.pone.0173483.t002

Length of ICU stay, duration of mechanical ventilation, vasoactive drug days and antibiotic days all demonstrated reductions in the post-intervention period at Rourkela and Chittagong and vasoactive drug days decreased at Patan (Fig 5.3.2). Accounting for possible confounding factors (continuation of pre-intervention trends, changes in mortality and ICU stay, changes in patient mix, changes in bed occupancy, and changes in the number of patients starting mechanical ventilation, vasoactive agents or antibiotics) in the survival analysis indicated that the training was associated with earlier discontinuation of vasoactive drugs at Rourkela, shorter time on mechanical ventilation at Chittagong, and faster discharge from ICU at Patan (Table 5.2.2). There was, however, no evidence that the intervention was associated with an increase in

the rate of stopping antibiotics at any site, and some evidence of the converse effect at Rourkela.

5.2.4 Discussion

The structured critical care training programme was associated with a reduction in ICU mortality in two of the three study sites with a positive effect on at least one of the predefined process outcome indicators at each site, including duration of mechanical ventilation or vasoactive drug use and the time to ICU discharge (Table 5.2.2). There was no significant impact on the duration of antibiotic use. Study sites differed considerably in case-mix, staffing and staff workload, resources, management and treatment practices. The positive effects on case fatality and other impact indicators were independent of the differences in severity of disease and other variables between sites and over time.

The larger reductions in mortality and lengths of stay in Chittagong could be related to more successful implementation of the training (for example by the institution of a twice daily inter-professional ICU ward round [298]) but can also be explained by high baseline case fatality compared to the other two sites. The absence of any effects on mortality in Rourkela could be due to the short ICU stay and high turnover of patients. The relatively small patient numbers in the pre-intervention phase should be noted when interpreting the relatively high baseline mortality during that phase in Patan and Chittagong. The reduction in duration of mechanical ventilation was accompanied by a larger proportion of patients being mechanically ventilated; this relationship was most noticeable in Rourkela (Figure 5.2.4).

There is increasing awareness of the importance of identifying strategies capable of improving intensive care in resource limited settings [19, 130]. Our study

highlights the importance of training aiming at both doctors and nurses for improving ICU performance. The potentially vast gains achievable by focusing on improving the knowledge, skills and attitudes of ICU staff in resource limited environments is remarkable and should stimulate the implementation of similar local capacity building measures. It further demonstrates the applicability and benefit of basic intensive care good clinical practice across these three sites even when resources and workload are obvious challenges. The gradual improvement, and the persistence of the changes after the last module, suggests a sustained change in outcomes related to staff knowledge and skills, stimulated by the trainers and the training program. Longer-term sustainability of these changes is worthy of future investigation.

In high-income countries, implementation of so–called ‘care bundles’ for the treatment of severe sepsis have been shown to improve outcome in ICUs. The effects of training programs in resource-limited settings are rarely evaluated in terms of results or outcome improvements (Kirkpatrick model - level 4,[299]) and the limited reports available focus on protocol implementation related to sepsis management [300], infection prevention [301], or the teaching of specific clinical skills [302]. In contrast, our training program addressed a wide spectrum related to the basic aspects of critical care practices and demonstrated improvement across diverse predefined performance indicators in ICUs in three countries.

It became apparent during our program that in addition to specific ICU technical aspects of care, organisational and basic nursing care aspects were equally important to address. This included the need for patient-centred nursing, empowerment of nurses on treatment decisions in acute situations, the need to improve attitudes with regard to teamwork, monitoring of vital signs with proper alarm limits settings prompting appropriate action, use of both short- and long-

term treatment plans, and accurate patient documentation with systematic hand-overs for the new shift. Enforceable admission and discharge policies, consistent and structured staffing rotas for doctors and nurses with adequate supervision, development of governance and audit policies, guidelines on accepting and transferring patients to and from other institutions were additional areas for improvement. The training program was deliberately not rigorously controlled for content or format and the training teams were encouraged to address these additional aspects and prioritise content as per local need and learning capability.

The structure of short classroom-type presentations for theoretical knowledge, but with an emphasis on bedside training in core critical care skills proved an appropriate teaching model and can be a template for future training programs. The combined teaching model enabled training to be conducted in each three-week period catering to the highest possible number of staff whilst minimising disruption to patient care in these ICUs. The training program can also contribute to the development of a portfolio of critical care training material. However, high travel costs and the limited number of units and personnel who can be reached at any one time are barriers for scaling up the presented model. A more sustainable and scalable program should focus on creating a critical mass of local trainers within these countries and across the region to initiate a “train the trainer” model [39]. Mentoring trainees by utilising the increasing local critical care specialists, for example in India, can facilitate such programs. A shortage of trainers might be addressed temporarily by using other training methods including a manual, online training, audio-visual material reinforced with limited face-to-face teaching. This more regimented model which requires less time of face-to-face teaching is more often used internationally [303]. However, its effectiveness in resource-poor settings will need to be assessed. Another option is visits from

selected staff to ICUs in high-income countries, providing exposure to state of the art intensive care practices that can serve as a reference standard. However, in our experience the benefits of such visits are generally limited because of the vast disparities in the organisational, governance, equipment, patient case-mix and language elements between the two settings.

The training program was highly appreciated and an important learning experience for both the trainers and recipients. A focus of the training course was on implementation of evidence based interventions in a setting-relevant manner. One of the early outputs was a setting-adjusted guideline for the treatment of severe sepsis designed by the local teams in consultation with the training teams (Figure 5.2.5). This exercise emphasized the need for re-evaluation of many aspects of the 'surviving sepsis' guidelines in resource poor settings. Not only are many of the recommendations not fully implementable because of the material limitations, but also the different local patient case-mix can prompt additional adaptation of the guidelines. An example is modified fluid management guidelines required in severe sepsis syndromes caused by dengue or malaria.

In our project, we encountered difficulties in data extraction from paper records (especially in Patan), even when attempted during the patient's stay in the ICU. We suspect that this will be a common theme in similar settings where electronic records and continuous surveillance or registry processes are absent. Implementation of setting adjusted electronic ICU registries will be an important way forward to address this issue. This will also greatly facilitate future evaluation of training interventions, in which evaluation of impact on outcomes is essential.

A limitation of our study is that the quasi-experimental nature of the design precludes a strong causal interpretation; post-intervention changes in outcomes

may reflect changes in patient characteristics or other aspects of care unrelated to the intervention. While adjustment for patient-level covariates (including APACHE II probabilities) goes some way to reducing this risk, the study remains vulnerable to presence of important unmeasured confounders. It is also possible that incomplete sampling of patients in Patan led to bias. Nevertheless, results are encouraging enough to suggest a larger cluster randomized study able to provide more definitive evidence could be warranted. Ideally such a study should be designed to detect changes in an endpoint of unambiguous clinical relevance such as 28-day mortality which due to resource constraints was not possible here and which are not routinely available in such settings.

A further shortcoming of our project was that we did not evaluate the knowledge and skills of staff pre and post training and subsequent changes in level of implementation of these skills. We also did not control for the impact of staff turnover and did not explore barriers to implementation of already existing knowledge and skills. Furthermore, we did not monitor the extent to which the training was adhered to and whether the levels achieved post-intervention were maintained subsequent to the departure of the trainers. Our study was not designed for the evaluation of individual modules therefore conclusions with regard to the impact of specific areas of the training could not be made. Data availability posed additional limitations, especially in Patan. APACHE II may not be predictive of mortality in a low-middle income setting, given differences in patient characteristics. Further we did not record hospital, 30 or 90-day survival data.

5.2.5 Conclusion

This broad, pragmatic multidisciplinary training program, performed in three diverse resource limited ICUs was associated with a decrease in ICU mortality

and improvement of other performance indicators. Providing setting-adapted training is important to improve ICU performance in resource-limited settings.

Figure 5.2.4 Adapted sepsis guidelines prepared by Rourkela ICU team based on training module on sepsis

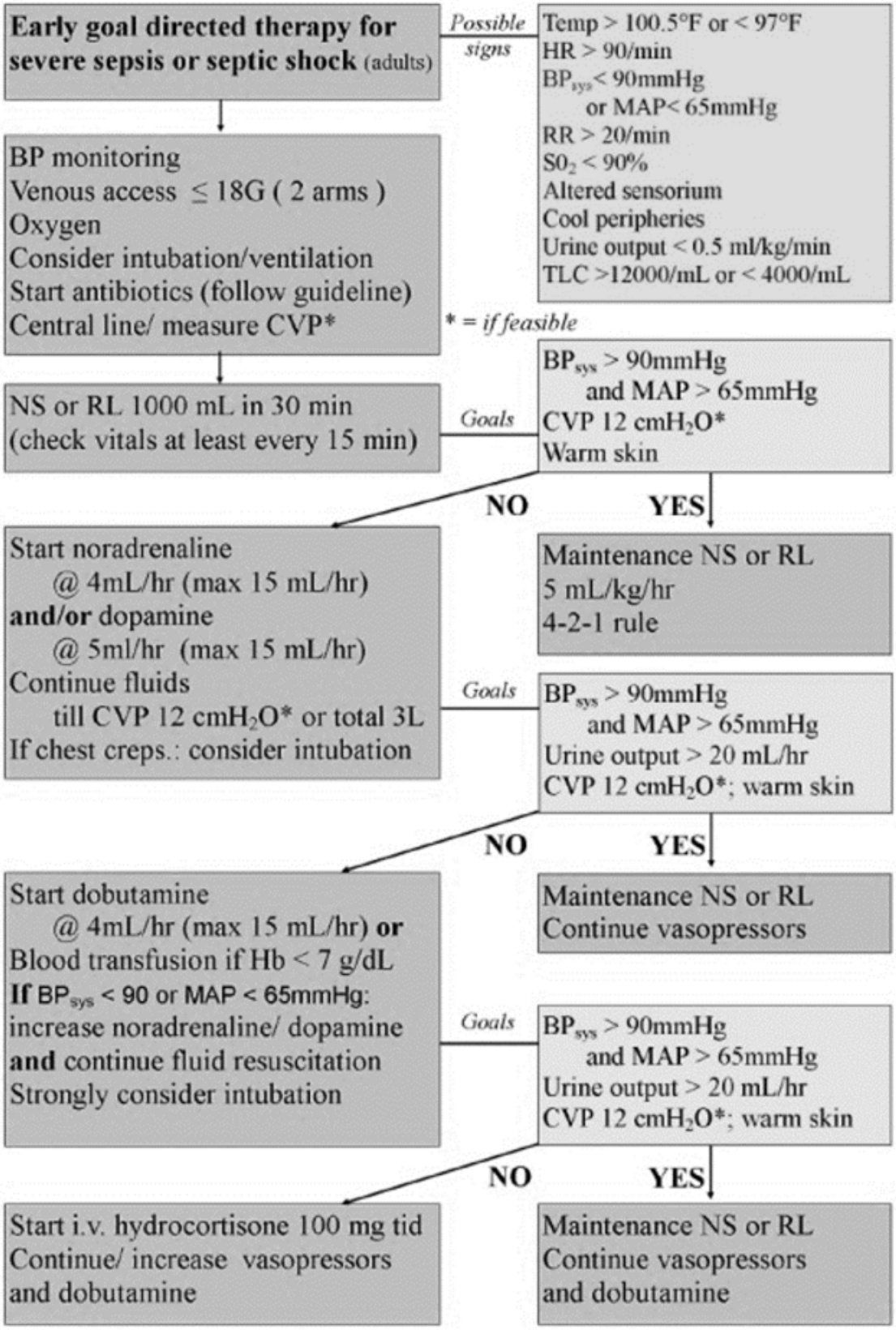
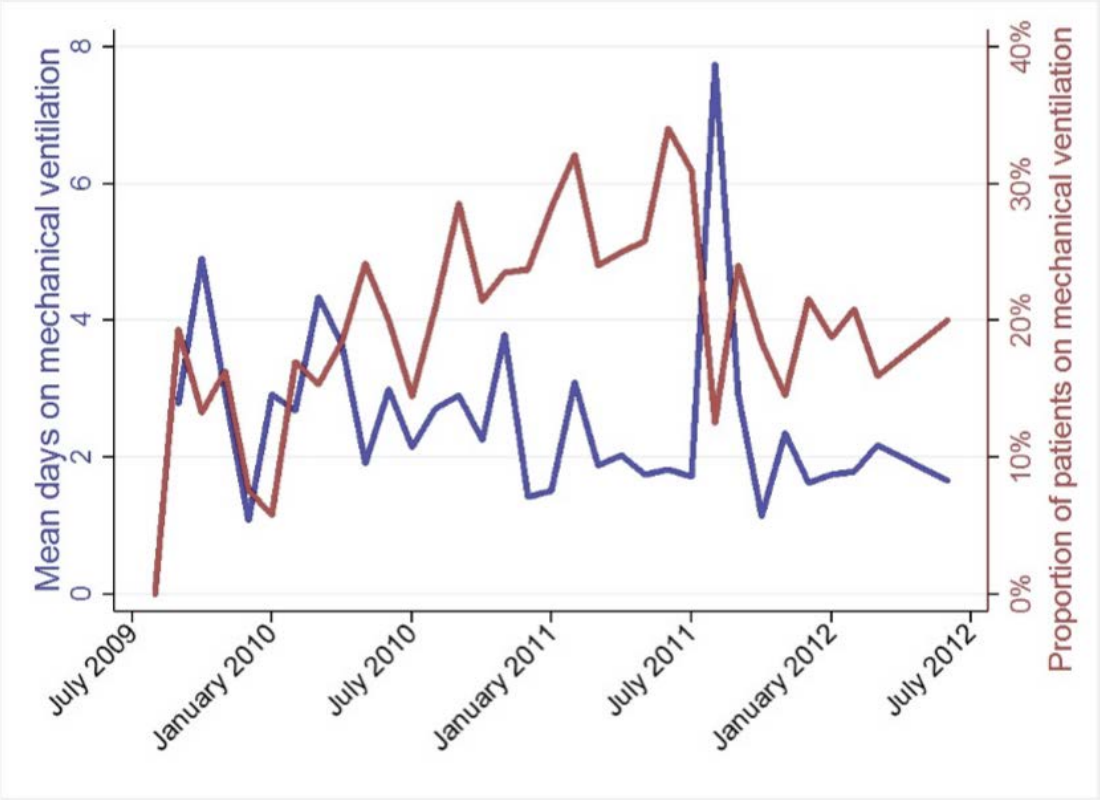

Early goal directed therapy for severe sepsis or septic shock (adults)
Possible signs
Temp > 100.5°F or < 97°F
HR > 90/min
BP$_{sys}$ < 90mmHg
or MAP < 65mmHg
RR > 20/min
SO_2 < 90%
Altered sensorium
Cool peripheries
Urine output < 0.5 ml/kg/min
TLC >12000/mL or < 4000/mL
BP monitoring
Venous access ≤ 18G (2 arms)
Oxygen
Consider intubation/ventilation
Start antibiotics (follow guideline)
Central line/ measure CVP*
* = if feasible
NS or RL 1000 mL in 30 min
(check vitals at least every 15 min)
Goals
BP$_{sys}$ > 90mmHg
and MAP > 65mmHg
CVP 12 cmH_2O*
Warm skin
NO
YES
Maintenance NS or RL
5 mL/kg/hr
4-2-1 rule
Start noradrenaline
@ 4mL/hr (max 15 mL/hr)
and/or dopamine
@ 5ml/hr (max 15 mL/hr)
Continue fluids
till CVP 12 cmH_2O* or total 3L
If chest creps.: consider intubation
Goals
BP$_{sys}$ > 90mmHg
and MAP > 65mmHg
Urine output > 20 mL/hr
CVP 12 cmH_2O*; warm skin
NO
YES
Maintenance NS or RL
Continue vasopressors
Start dobutamine
@ 4mL/hr (max 15 mL/hr) or
Blood transfusion if Hb < 7 g/dL
If BP$_{sys}$ < 90 or MAP < 65mmHg:
increase noradrenaline/ dopamine
and continue fluid resuscitation
Strongly consider intubation
Goals
BP$_{sys}$ > 90mmHg
and MAP > 65mmHg
Urine output > 20 mL/hr
CVP 12 cmH_2O*; warm skin
NO
YES
Start i.v. hydrocortisone 100 mg tid
Continue/ increase vasopressors
and dobutamine
Maintenance NS or RL
Continue vasopressors
and dobutamine

Figure 5.2.5 The relationship between duration of mechanical ventilation and proportion of patients being mechanically ventilated in Rourkela



5.3 Capacity building for critical care training delivery: development and evaluation of the NICS Training programme in Sri Lanka.

5.3.1 Background

The challenges of critical care capacity building in resource poor settings are complex [304], but ensuring sufficient numbers of competent staff is a prerequisite: a skilled inter-professional team is a resource at least as important as the availability of ventilators and vasoactive drugs [19, 111, 305]. This means that the capacity to provide effective critical care training will be crucial for LMICs to scale up the delivery of high quality critical care services.

In most countries, nurses constitute the largest proportion of the critical care workforce and thus the availability of skilled nurses is pivotal to high quality care.

Recommendations on training and competencies of critical care staff have been published in recognition of this [111], but large scale educational programmes targeted towards critical care in LMICs rarely focus on nurses.

Requirements for a sustainable nursing training model include a low cost approach, limited duration of the programme, course portability and a critical mass of well-trained faculty. Demonstrable skills acquisition is also important to show the benefit of releasing nurses to attend.

Sri Lanka is a LMIC with a national post-registration critical care nurse training programme, but only 11.4% of the critical care nursing workforce has attended this [37]. Training capacity is cited as the main barrier. The situation in Sri Lanka is similar to that in many resource-limited settings [306, 307].

The feasibility and effectiveness of a short course approach to critical care skills training for nurses in a LMIC was piloted and evaluated in Sri Lanka in June 2013 [39]. The programme was devised shortly after the initiation of the National Intensive Care Surveillance (NICS) system, an electronic bed availability and critical care registry [308]. Data input into NICS is predominantly undertaken by nurses and through this interaction we became aware of the desire of many nurses to receive training to help them provide better care to their patients. As mentioned above, only a minority of these nurses had received any formal critical care training. To address this issue, and to also acknowledge the efforts of these nurses in supporting the registry, NICST was designed. The short course format allowed for a large number of nurses to receive some foundation training in critical care whilst awaiting a place on the existing longer programme. The evaluation showed that a short, structured and practical course format was effective in improving knowledge and was also culturally acceptable.

Following this success, we designed a national training project for critical care nurses across Sri Lanka, based on 'Train the Trainer' (TTT) principles. The objectives of our project were to deliver and further evaluate our short critical care nurse training course nurses whilst simultaneously building local training capacity to ensure sustainability at scale.

5.3.2 Study aim

In this paper, we discuss the design, implementation and evaluation of the programme and the generalizability of the approach to other LMICs.

5.3.3 Study design

Training was delivered in seven blocks, run approximately every three months from June 2013 until November 2014. Each training block comprised a faculty development programme and three consecutive NICST courses, except in July 2014, which comprised two courses and September/November 2014 which comprised one course. All courses were delivered in English, the working language of the Sri Lankan health service, with local faculty using local languages (Sinhala / Tamil) when necessary and appropriate.

The core learning objectives of the NICST course were defined as:

1. Demonstration of the ability to use a structured approach to patient assessment (using an Airway, Breathing, Circulation, Disability, Exposure, Fluids and Goals- 'A to G' -approach)
2. The ability to recognise signs of physiological deterioration
3. An understanding of the organ support options provided within critical care
4. An understanding of the immediate, essential measures used to resolve life-threatening deterioration

5. An appreciation of the more advanced treatment options that may be used

The needs assessment, design and delivery of the first set of courses in June 2013 are described elsewhere [39]. These pilot courses were intended as a starting point from which an improved and context specific course could evolve.

Both course content and structure were refined with each subsequent iteration through review of each course's results, participant feedback, and faculty (local and overseas) reflection and discussion. This approach fostered a process of collaboration and course co-design between Sri Lankan and overseas trainers.

From the outset, a multi-modal approach combining short didactic sessions with small group workshops and skills stations was employed. All sessions were focused around the practical application of relevant knowledge to the clinical setting and patient care. For example, a short lecture of arterial blood gas (ABG) analysis was followed by facilitated small group workshops with multiple example ABGs to be discussed and analyzed, offering opportunities for coached attempts to apply new and existing knowledge effectively. This approach has been shown to achieve more active learning, better knowledge retention, higher candidate satisfaction and increased critical thinking and team-working [309]. Group sizes for workshops and skills stations were generally limited to 6 to 8 participants. An online platform providing pre-reading and other educational resources for participants was introduced in May 2014.

The current course outline is displayed in Table 5.3.1

Table 5.3.1 Intensive Care Skills Training: Course Content Outline

Day 1
Welcome
Assessment: Pre-course Multi-Choice Questionnaire (MCQ)
Lecture: Structured approach to the assessment of the critically ill patient
Demo: The 'A-G' approach
Lecture: Care of the ventilated patient
Break
Lecture: Arterial Blood Gas interpretation
Lecture: Recognising and managing shock
Skills Stations: Arterial Blood Gas (ABG) interpretation
Lunch
Skills Stations: Airway & breathing
1. Intubation drill
2. Nursing care of the intubated patient
3. Respiratory assessment and auscultation
4. Airway Assessment (non-ventilated patients) & airway adjuncts
Break
Lecture: Oliguria and Acute Kidney Injury
Skills Station: Haemodynamics
Questions

Day 2
Welcome
Lecture: Cardiac Rhythm Recognition
Skills Stations: Cardiac Rhythm Recognition
Lecture: Assessment of consciousness (Disability)
Lecture: Sedation and analgesia
Tea break
Skills Station: Assessment of consciousness using the Glasgow Coma Score
Lecture: Recognising and managing Sepsis
Lecture: Exposure and managing intravenous devices
Lecture: Fluid management and balance
Lecture: Setting and monitoring care goals
Problem Based Learning: Clinical Scenarios
Lunch
Demo: Objective Structured Clinical Assessment (OSCA)
Assessment: Post-course Multi-Choice Questionnaire (MCQ)
Assessment: Objective Structured Clinical Assessment (OSCA) stations
Tea
Feedback session
Summary and close

Nurse participants were identified by senior nurses and recruited from intensive care units (ICUs) around Sri Lanka participating in the National ICU registry network [308].The NICST team had no input into the choice of participants from

the ICUs island wide. Local nurse faculty were either nurse tutors with previous experience of ICU nursing or ICU nurses currently in practice. The latter were nurses from a pool of those who had previously attended the NICST course and who had achieved the highest marks in the post-course assessment. About half of these nurses accepted the invitation to join the faculty.

From September 2013 onwards a graded handover of training responsibilities from overseas to local faculty occurred with lectures, skills stations and workshops increasingly delivered by local faculty. From March 2014 onwards the course was delivered entirely by local faculty. This process was co-ordinated with a faculty development programme.

From the outset of the NICST project, creating a sustainable programme was a key goal, using a TTT approach and with early integration of all aspects of the course into existing local structures.

The Train the Trainer (TTT) programme

The TTT component of NICST was designed to up-skill and enable the local faculty to independently and effectively deliver the course. Each NICST block was preceded by a two day TTT programme when international trainers met with the local faculty away from candidates and provided opportunities for both clinical and educational skills development.

Many of the teaching methods utilised, in particular the interactive small group sessions, were new to the Sri Lankan team who were familiar with a more traditional, didactic presentation format. This interactive approach, where faculty had to respond to questions rather than deliver set content, also highlighted some clinical knowledge gaps amongst faculty members. Thus, initial TTT sessions combined clinical and pedagogical learning objectives and focused on ensuring

a basic level of ability to deliver the clinical content, with novice faculty still requiring some support in training delivery. As with most complex skill development, the process is iterative with proficiency developing through repeated practice. With each iteration of the TTT, further learning opportunities were provided, including: timetabling to allow faculty to switch sessions, encouraging competence in a wider range of subject areas; experienced faculty coaching new faculty; master classes in key clinical topics and workshops to further explore new teaching methods. Training materials to guide faculty in a stepwise manner through course delivery were distributed prior to the sessions.

Whilst faculty competence was not explicitly assessed, the TTT provided opportunity for coaching in these new training methods, with overseas faculty providing feedback and encouraging peer-review. A key feature of the TTT approach was that it included in vivo practice throughout delivery of the NICST course itself. Facilitated discussions after each course as well as detailed participant feedback were provided to help faculty reflect on their own progress.

Integration

Integration of the NICST course into existing training, government and clinical structures was initiated from the inception of the project. Commitment and collaboration was sought from the nursing directors of the Sri Lankan Ministry of Health (MoH) and those in charge of the PBCN. All courses to date have been hosted at the PBCN and all costs (including release of participants and faculty but excluding overseas nurse trainers' expenses) were covered by the MoH. The course was approved by the Nursing Council of Sri Lanka.

Evaluation

Our approach to evaluation of both educational outcome of the NICST course and building local capability was based on Kirkpatrick's Hierarchy of Learning [310]. Kirkpatrick's Hierarchy has been adopted by the Best Evidence in Medical Education (BEME) collaboration for evaluating the outcomes of clinical education and training and is particularly appropriate for structured training courses with objectively measurable outputs [311].

Participants' evaluation of the course was through end-of-course feedback questionnaires, with participants rating their agreement with evaluation statements on a 5-point Likert scale ('Strongly Agree; to 'Strongly Disagree') (Kirkpatrick Level 1). Session by session feedback forms (not detailed here) were distributed to garner detailed individual session level feedback which faculty used to assist post-course reflection on performance.

The impact of the course on participant knowledge and skills (Kirkpatrick Level 2) was evaluated through the assessment of the participating nurses using; an identical pre and post course Multi-Choice Questionnaire (MCQ) assessing clinical knowledge related to ICU nursing practice and a post-course only clinical skills assessment of application of patient assessment skills using an Objective Structured Clinical Assessment (OSCA). Results of the MCQ only are presented below.

The correct answers for the MCQ were not discussed with participants after the pre-test or at the end of the course. Over time the MCQ paper was modified in line with iterative course content changes and a second test paper was developed to minimise sharing of questions between training cohorts.

Assessing Kirkpatrick Level 3 (the change in clinical practice or behaviours seen

as a result of a training intervention) was beyond the scope of this project for evaluating the clinical outcomes of NICST. For the Faculty development, we specifically avoided formative faculty assessments due to the collaborative and co-designed nature of the work.

To evaluate the ability of local faculty to eventually run the course independently, the outcome goal of our TTT programme (Kirkpatrick Level 4), we used a difference in difference approach to compare the MCQ scores over two time periods. This approach measures the difference in pre and post MCQ scores in 2013, with courses led by overseas faculty, compared to the difference in scores in 2014, with courses led by local faculty.

5.3.4 Results

Since June 2013, 584 nurses (nearly 25% of all ICU nurses in Sri Lanka [37]) have been trained over sixteen courses. The NICST faculty now comprises twenty-nine tutors and ICU nurses. Table 5.3.2 describes the demographic information of participants while figure 5.3.1 shows the distribution of trained nurses nationwide demonstrating the national reach of the programme.

Kirkpatrick Level 1 - participant response

Selected participant feedback is displayed in Table 5.3.3 for each iteration of the course. Feedback revealed very high overall participant satisfaction with both the course and its delivery over the entire training period.

Kirkpatrick Level 2 – Learning

Pre and post MCQ results are shown in Figure 2. These indicate that with each iteration of the course, post-course MCQ results were significantly higher than pre-course results ($p=<0.0001$; Wilcoxon Sign Rank Test).

Kirkpatrick Level 4 - Results

Difference in difference analysis of the pre and post MCQ results between the year 2013 and 2014 are shown in Figure 3. There was no significant difference in MCQ scores between the two phases (p=0.186; independent sample T-test). This confirmed that the faculty and organisational changes made to facilitate sustainability was successful without compromising on course outcomes.

The approximate cost for the training programmes conducted in 2014 including the expenditure of foreign trainers was LKR 1283912/= (US$ 9170.8). The cost per participant was LKR 5731.75/= (US$ 40.94).

Table 5.3.2 Demographic information of participants (n=572)

Demography	**Number**	**Percentage (%)**
Age (years)		
< 30	133	23.3
30 – 39	286	50.0
40 – 49	59	10.3
50 – 59	12	2.1
Missing	*82*	*14.3*
Gender		
Male	55	9.6
Female	354	61.9
Missing	*163*	*28.5*
Total years of experience		
< 1 year	0	0
1 – 4 years	52	9.1
5 – 9 years	89	15.6

10 – 14 years	30	5.2
>15 years	24	4.2
Missing	*377*	*65.9*
Years of experience as a ICU nurse		
< 1 year	33	5.8
1 – 4 years	267	46.7
5 – 9 years	157	27.4
10 – 14 years	41	7.2
>15 years	15	2.6
Missing		*10.3*

Table 5.3.3 Selected evaluation responses from course participants

Evaluation statements	Course participant responses; strongly agree and agree ratings combined						
	June (n=113)	September (n=100)	December (n=121)	March (n=111)	June (n=78)	September (n=18)	November (n=31)
I found the content relevant to my practice	112 (100%)	95 (98.0%)	117 (98.4%)	93 (100%)	68 (98.6%)	18 (100%)	27 (93.1%)
I acquired new knowledge and skills	113 (100%)	97 (98.0%)	121 (100%)	97 (100%)	67 (98.5%)	18 (100%)	29 (96.7%)
The content was delivered in a culturally appropriate way	106 (94.6%)	80 (86.0%)	100 (86.9%)	81 (88%)	58 (89.2%)	16 (94.1%)	22 (88%)
I had adequate opportunity for hands-on experience	111 (99.1%)	88 (88.9%)	105 (87.5%)	83 (84.7%)	62 (89.9%)	15 (88.2%)	24 (96%)

The program was well organized	108 (96.4%)	91 (91%)	121 (100%)	92 (95.8%)	67 (98.5%)	16 (94.1%)	28 (96.6%)
I found the overall experience useful	111 (98.2%)	87 (90.7%)	117 (96.7%)	93 (96.9%)	68 (98.6%)	17 (100%)	24 (96%)

NB Some missing participant responses. % based upon number of completed responses.

5.3.5 Discussion

Our results show an ICU nurse training programme implemented in Sri Lanka can be a model for LMICs in building both critical care capability in the nursing workforce and local faculty training skills. In a relatively short period, structured training was delivered to nearly 25% of the critical care nursing population in Sri Lanka whilst building a local faculty of trainers.

Our data indicate that the NICST course can achieve high participant satisfaction and clinical knowledge acquisition, and that the use of a TTT approach can sustain these levels during and after the course handover from overseas to local faculty. This allows for optimism regarding sustainability of the programme, with capacity within the local faculty to continue to train nurses independently.

However, training to build skills is just one element of effective capacity building [304]. Community collaboration and ownership are essential to achieving longer term sustainability [312]. Within our project we have attempted to combine faculty skills acquisition with a ‘horizontal approach’ that fostered local ownership, utilized local knowledge and skills, and actively required local faculty participation in all aspects of the project..We have allied this with the wider goal of sustaining the critical care registry and creating an identity for the NICST program by active collaboration with the wider nursing population.

A novel approach chosen to facilitate collaboration and ownership has been the incorporation of ICU nurses into the NICST faculty, alongside the existing nursing tutor faculty (working in nursing schools). The combination and synergy of the differing skills sets and experiences of these professionals is creating a NICST ‘community of practice’ within Sri Lanka. A community of practice (CoP) can be defined as a group of people (in this case nursing tutors and nurses) who share common interests and goals (in this case improving critical care training in Sri

Lanka) and who develop new knowledge and skills with regard to this through ongoing social interaction [313]. The NICST CoP is supported through meetings and email contact between courses and specific faculty meetings and debriefing sessions held around the time of each NICST course. Additional activities beyond the NICST course, including low fidelity simulation training continue faculty contact time.

This CoP flattens existing hierarchies to encourage social interaction, knowledge sharing and creation as well as building a group identity as 'expert trainers' [313]. This, allied with the uptake of new insights into training delivery, has enhanced capacity building within the NICST programme, enabling overseas faculty to take an increasingly backstage role in each subsequent iteration of the training. "Readers familiar with South Asian culture may be unsurprised to learn that traditional hierarchies were still very visible during the first few months of the project. However, these began to overtly flatten out toward the end of the 3rd round of training (6 months into the project). Although still present to a small degree, a far more collaborative, 'all teach, all learn' approach began emerging across the faculty from 2014 onwards. We did not specifically evaluate this aspect of the programme but would hypothesise that, at least in part, the value proposition of the programme enthused the nursing faculty sufficiently to try and adopt the proposed new ways of working together. As the benefits and synergies of collaboration became clearer, the CoP was able to develop relatively rapidly.

Early integration of the course into existing local structures has been another vital aspect of the project. Trust was established at the initial pilot courses in June 2013 by seeking authorisation from the MoH and requesting little additional support. Ministry officials were encouraged to visit and observe this pilot course in action. Subsequent collaboration with the MoH ensured that logistics and

systemic and workload issues could be managed by local senior officials who 'bought in' to the projects' vision.

Crisp et al [312] define capacity building as; "irrespective of the processes and strategies used; this term can be applied to interventions which have changed an organization's or community's ability to address health issues by creating new structures, approaches and/or values. These will be ongoing without need for future funding" (p.100)[312]. Our interventions span three of the four capacity building domains described by these authors: bottom up, top down and community organising approaches)[312].

To our knowledge this is the first programme designed specifically to build training capacity and skills amongst critical care nurses in a LMIC setting. However, the programme evaluation did have some limitations. The main methodological weakness is that we have used 'naturally occurring' data as metrics to infer effective faculty development and course embedment. We did not acquire faculty level feedback nor did we use objective tests to measure the competence and ability of faculty over time as this would have been overly burdensome and in our opinion detrimental to the collaborative process. We do however have plans to now introduce faculty accreditation.

The generalisability of our training model to other LMICs and beyond is presently unknown. The presence of a largely centrally controlled health system, strong administrative structures within the health system, the ability of nurses to participate in training in English, the willingness of the Ministry of Health to integrate the programme and the presence of local nursing opinion leaders to champions NICST have all contributed to the programme in Sri Lanka. How essential these factors were to our programme and how generalizable they are can only be known if the process is tested elsewhere.

The future work includes ongoing support and facilitation to the NICST local faculty, both through the CoP itself and through continued overseas trainer visits. In parallel, in response to local requests, a ward based acute care training programme for nurses is being pioneered as well as simulation based training for doctors and nurses.

The effects of training on ICU performance and patient outcome data will be evaluated via the NICS ICU registry database over time but will require training to be provided in sufficient dosage to ICUs (in terms of numbers of nurses trained within a defined time period) for any training related effect to be discernible.

There have been exploratory requests from several countries from the region and beyond to assist in the rollout of a similar training model for critical care nursing; we hope to assist and establish wider collaborations and will expect to utilise the local expert trainers from Sri Lanka as seeds to deliver such programmes.

5.3.6 Conclusion

Roll out of sustainable, locally run ICU nursing training and its associated capacity building programme has fostered a new community of practice amongst the nursing workforce in Sri Lanka, focussed on improving critical care nursing skills and enhancing patient care. Our results provide optimism that this approach is effective at creating in-country capacity to deliver quality critical care skills training for a large workforce without formal critical care training. The programme may serve as a model for scaling up critical care training delivery in other LMICs.

Figure 5.3.1 Nationwide distribution of nurses attending the training programme.

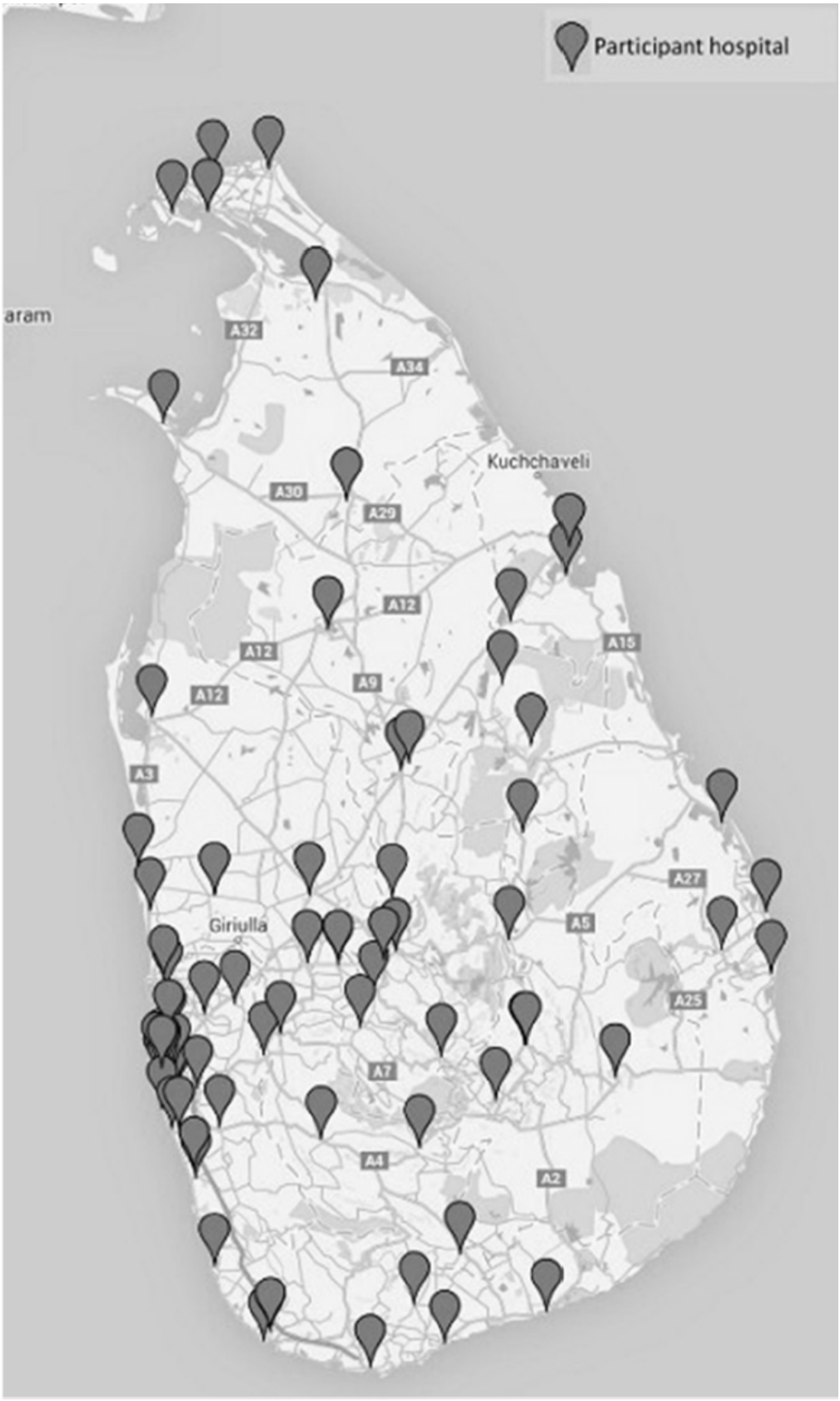


Figure 5.3.2 Comparison of pre and post mcq marks of year 2013 and 2014

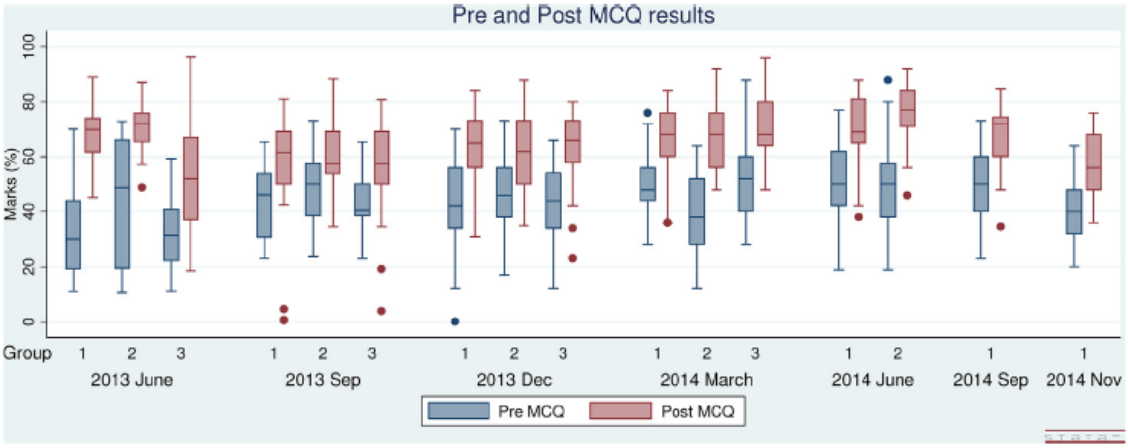
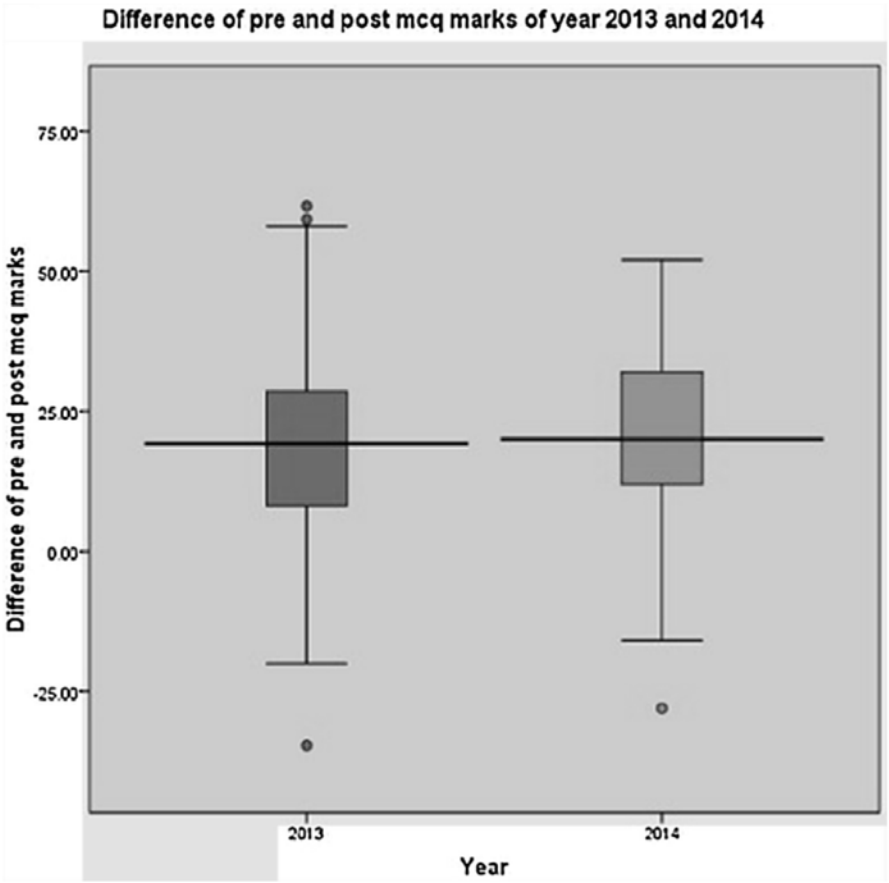


Figure 5.3.3 Comparison of difference in difference of pre and post MCQ score; 2013 and 2014



5.4 A peer-led national acute care training programme for newly qualified doctors

5.4.1 Background

Newly qualified doctors undertaking internships often carry a large responsibility in patient care, yet with little practical experience, which is associated with adverse consequences [314, 315]. The introduction of newly qualified medics into the clinical team is associated with omissions in the recognition of deteriorating patients and failed communications to senior team members, which can result in a failure to escalate treatments [316]. The ability to respond effectively to such emergency scenarios requires clinicians to be confident in applying their knowledge and clinical skills in practice [316-318]. It is often the junior members of the clinical team led by junior doctors who are the point of first contact for acutely unwell patients. Whereas undergraduate medical training lays the foundation for the knowledge and analytical skills that are required by junior doctors, there remains a gap in the translation of this knowledge into the skills needed to act quickly and confidently in emergency situations [318, 319].

In High Income Countries (HIC) including the UK, clinical and decision-making skills training has been increasingly incorporated into final year medical undergraduate training programmes to assist students in their transition to practice, and peer learning has been explored as a method of delivering skills training for junior doctors and nurses [38, 39, 86]. There is evidence that such a model may offer effective knowledge transfer, improve junior clinicians' ability to problem solve and make decisions based on systematic assessment in emergency scenarios [320, 321]. In Low and Middle Income Countries (LMIC), practical acute care skills training for frontline staff is limited, despite ongoing remedial efforts [38, 321]. Unaffordability of training courses, unavailability of

suitable trainers, traditional or didactic models of learning and lack of course material and equipment are contributory factors. In Sri Lanka, a LMIC, 1000 medical graduates begin internship annually, at least 150 of whom are overseas qualified graduates with limited exposure to the local healthcare system [322].

Historically, there has been minimal opportunity for these students to prepare for the practical components of internship and no opportunity for structured handover between the outgoing junior doctors and the incoming newly qualified doctors. As such there is little capacity for colleagues to share experiences or knowledge of the structures and processes necessary to survive life on the front line. Upon publication of their final results, graduates have an approximately 9-month gap (an administrative period) before commencing their first clinical post. During this time, many are involved in administrative or support roles within the university, with little opportunity to develop or consolidate clinical skills.

Since 2014 the “Good Intern Programme” (GIP) [292] has been piloted in Sri Lanka to help prepare graduates for transition to practice. This multi-component programme for newly qualified doctors includes essential information on health-care system infrastructure, cognitive skills for prescribing and medical documentation alongside lessons in regional dialects. In this paper we report the evaluation of the peer (fellow graduates from the same intake) delivered practical 2 day acute care skills training (ACST) course designed and delivered by a peer faculty, to improve participants knowledge, confidence and self- assessed skills to manage common acute medical and surgical emergencies.

5.4.2 Study design

All newly qualified doctors awaiting internship were contacted via their respective universities and their trainee representatives, and invited to participate in an online anonymous needs analysis to rate their competence and confidence to

perform essential clinical skills. The survey included self-evaluation of graduates' ability to undertake structured assessment, manage acutely unwell patients, and perform practical skills synonymous with advanced life support, including defibrillation, a structured systematic (A-E) assessment and airway manoeuvres. The findings of the needs analysis were used to devise the (ACST) course.

Course design and delivery

Course content was developed iteratively by an inter-professional collaboration from UK and Sri Lanka with expertise in critical care, resuscitation and simulation, and junior doctors who had recently completed internship in Sri Lanka. The course was designed to be practical, utilizing skills stations, clinical scenarios and small group sessions, to maximize participant participation and build confidence. Clinical scenarios were selected using a Delphi process [323] reflecting situations commonly encountered by junior doctors working in acute medical hospitals in Sri Lanka and for their opportunity to integrate essential management guidelines. Scenarios included; respiratory failure, sepsis, acute coronary syndrome, anaphylaxis after anti-venom, dengue fever and organophosphate poisoning.

The peer faculty was selected from newly qualified doctors participating in a series of Train the Trainer (TTT) session based on established methodology [38, 39, 320, 324]. Participants showing aptitude for teaching clinical skills-set and interest in building capacity within their profession were given preference to join the faculty [38, 86]. The faculty received training in skills instruction, facilitation, assessment (OSCE) structure and good practice, session setup, giving feedback and marking prior to the course and undertook observed practice.

The 2-day course was conducted for small groups of up to 20 doctors over 4 months. Enrolment for the program was voluntary, with publicity aimed at all

newly qualified doctors awaiting internship and had responded to the needs analysis. Synonymous with undergraduate training, English was the medium of instruction with discussion sometimes continuing in the local languages. Participants were invited to access course materials online (lecture materials, guidelines, audio lectures) using a learning management system [323]

Course assessment and feedback

Graduates knowledge was assessed by a randomized pre and post-course multiple choice test of 20 questions selected from a question bank designed to minimize sharing across participant groups. Participants were invited to assess their confidence after each of 5 skills stations (figure 2) and at the end of course using a 5 point Likert scale ranging from “strongly disagree” to “strongly agree” [325]. Skills ability (skills listed in figure 1) was rated by participants pre and post course using a 10 point Likert scale self-assessment questionnaire, comparable to those completed by doctors during foundation training in the UK [325-327].

In addition, 5 Objective Structured Clinical Examination (OSCE) stations were used to provide participants with objective feedback following course completion. The 5 stations covered were safe defibrillation, recognition and management of tachyarrhythmia, Basic Life Support, A-E structured assessment and emergency management of the airway [328]. A structured marking criteria based on participant’s ability to perform each aspect of the skill safely and competently was utilised [329]. The pass mark was set at 50%. In addition to the TTT sessions outlined above, the faculty undertook paired assessment for each OSCE station, to ensure validity and consistency in marking across the faculty group [38].

Participants were invited to provide feedback rating their learning experience, the opportunity to actively participate in the skills stations and scenarios, course

delivery and whether they felt learning objectives were achieved using the 5 point Likert scale described above. This feedback was collated electronically following each session and upon completion of the course. Suggestions for course improvement were requested in free-text format. A further 5 questions (figure 5.4.5) were used during feedback for the last three courses to evaluate the peer teaching process. All participants were not approached for these questions in order to limit the amount of feedback being sought from candidates.

5.4.3 Results

Seven hundred and thirty-two of 902 (81.1%) newly qualified doctors who responded to the survey wished to participate in a 2-day practically focused ACST course. Eight hundred and seventy five (97%) responders stated they would benefit from such an opportunity as part of preparation for internship. Five hundred and eighty-six of these 902 (64.9%) doctors reported that they had never practiced advanced airway manoeuvres or defibrillation either in vivo or in a training environment. Six hundred and six of the 902 participants (67.1%) of those surveyed indicated that they were not confident in performing these skills without supervision. Furthermore, 433 of the 902 (48.1%) reported lack of confidence in interpreting key investigations for management of emergency situations, including ECG and ABG results.

Course delivery

Between July and October 2015, 17 courses were delivered by a faculty consisting of 8 peer trainers, training 320 newly qualified doctors at venues across Colombo [308]. The estimated cost of delivering this 2-day course including refreshments in Sri Lanka was approximately 30 British Pounds (GBP).

Course assessment and feedback

The mean score of the MCQ pre-course was 71.03 (SD 13.19) compared to 77.98 (SD 7.70) post-course ($p<0.05$, n=320). Of the 283 participants who provided feedback, 97.2% (275) participants reported that the course had increased their overall confidence in managing ward emergencies (Figure 5.4.4). Participant feedback describes an increase in confidence in performing defibrillation (98.9%, 280), BLS (98.3% 278), A-E assessment (96.8% 274) and ABG interpretation (99.2%, 281). (Figure 5.4.2). Participants reported significantly higher ($p<0.05$) self-assessment ratings in all 12 assessed skills post-course, compared to pre-course (Figure 5.4.1).

All course participants chose to participate in the 5 station OSCE. The mean score for tachyarrhythmia management OSCE was 56.77 (SD 29.60), and for airway and breathing OSCE was 54.98 (SD 34.03). The lowest mean marks were observed for A to E assessment (49.94, SD 29.15) whilst the highest were for observed for BLS (67.02, SD 36.86) and safe defibrillation 57.65 (SD 33.95), with 232 (72.50%) and 206 (61.39%) of participants scoring over 50.0 % respectively.

Of the 320 newly qualified doctors who participated, 283 provided feedback on the overall course. All respondents (283, 100%) reported that the course improved their knowledge and 282 participants (99.3%) reported an improvement in their ability to perform skills (Figure 5.4.4). In feedback following the clinical scenarios, participants report that the peer faculty had provided an effective learning environment and given constructive feedback for these scenarios (Figure 5.4.3). A subsample of 66 participants, from the last three courses, reported that peer learning was an effective method of knowledge sharing, learning and confidence building (Figure 5.4.5).

One hundred and three of the 320 participants (32.25%) gave recommendations for improvement. Of these, 42 (41.2%) recommended that more medical and surgical scenarios would be beneficial for their clinical practice and 50 (48.3%) participants suggested that the addition of obstetric and paediatric emergency scenarios would be of benefit.

5.4.4 Discussion

The needs analysis highlighted the limited opportunities available during undergraduate training to practice essential clinical skills required for managing emergency clinical situations. The ACST course conducted for 320 graduate participants preparing for internship in Sri Lanka, demonstrates that this co-designed peer delivered course significantly increased knowledge, confidence and skills necessary to manage acute medical and surgical emergency scenarios, of graduate doctors preparing for their clinical practice. The OSCE's indicated that the majority of participants could demonstrate effective application of clinical knowledge within realistic clinical scenarios.

The post course MCQ scores were significantly higher when compared to pre-course MCQs. Greatest increase in both skill and confidence was reported in practical resuscitation skills such as defibrillation, BLS and ABG interpretation and when all candidates were enabled to participate and ask questions. This is perhaps not unsurprising given the low- pre course confidence levels reported by the both the needs assessment and pre course self-assessment. More advanced skills such as tachyarrhythmia management and intubation also resulted in increased ability, but with less marked increase in confidence- perhaps reflective of the complex nature of these procedures.

Prior knowledge from the expert faculty indicates that junior doctors are called upon to deliver complex skills such as intubation during internship in Sri Lanka.

Achieving measurable increase in competency of such complex skills in this learning forum is unrealistic, however it may be argued that inclusion of such skills provides opportunity for candidates to gain a level of situational awareness and preparedness- essential for safe delivery of such interventions that they would not otherwise experience. Internationally, similar programs have highlighted that whilst mastery of such complex skills requires repeated immersion in the situation, scenario based practical skills training may offer insights and useful preparatory learning for candidates [330, 331].

The results of the needs analysis, participant self-assessment, and feedback further add to the growing body of evidence in support of interactive, practical training methods, such as those utilised during this course, to improve recognition and management of acutely unwell patients [331, 332]. These practical training methods provide unique opportunity for learners to gain experience and confidence in the complex clinical decision-making needed to respond to emergency scenarios, and to reduce incidence of failure to rescue, without jeopardizing the safety of patients or colleagues [38, 39, 86, 318, 321].

This ACST course, perhaps uniquely, was designed and delivered by a group of newly qualified doctors. Course feedback demonstrates that participants found their peer faculty to be professional, knowledgeable and competent to deliver the course (Figure 5.4.2-5.4.5). Although requiring investment of time and expert faculty up-front, the TTT model [38, 39, 86] equipped newly qualified doctors with the skills and capacity to deliver an effective peer learning course, and offers sustainable solution for delivering similar courses with each batch of new graduates. Encouragingly for sustainability, since the inaugural year reported above, the peer-led ACST programme has trained over 700 more newly qualified graduates over the last 18 months, with the graduates paying a fee of

approximately 30 USD per person and no further subsidy from the Ministry.

Similarly the cost per participant was relatively modest compared with many expert faculty or simulation delivered courses [331]. Whilst expertise and training techniques including high fidelity simulation remains an essential part of developing specialist skills for trainees dealing with uncommon and complex emergencies [331, 333], these results would suggest that peer delivered practical courses may be cost-effective training method for large cohorts of medical graduates in preparation for managing common medical and surgical emergencies in clinical practice [334]. This co-design, peer-delivery method may also be beneficial for more senior doctors and interdisciplinary teams working in specialist areas, including critical care, to help refresh knowledge and provide opportunity for sharing of both knowledge and skills [318, 331, 334].

5.4.5 Limitations

Only 320 of the 902 needs assessment respondents attended the ACST course. This may in part have been due to the course venues only being available in Colombo. Participant numbers were reduced by the limited time available before commencement of internship in this inaugural year of the ACST course and high faculty to participant ratio. This led to some potential registrants not being invited to attend. Earlier start to the course in coming years and a larger group of peer trainers may help overcome this limitation. Newly qualified doctor's delivering the course necessitates repeated TTT and upskilling each year; the subsequent 18-month period has shown that this is achievable through this model. It is anticipated that over time experienced faculty will increasingly return to facilitate junior faculty upskilling. Long term knowledge retention and effect on patient outcomes are unknown and warrants further exploration. Paired (pre and post course) self-assessment was used as the primary tool to evaluate skills gain. This

method, although common in both undergraduate and postgraduate medical training, is questioned for validity. In postgraduate training doctors are often thought to overestimate their ability when completing self-assessment [326, 327, 335]. Perspectives of including more complex skills in such a course are discussed above. Course delivery and OSCE's were facilitated by the same faculty resulting in the potential for scoring bias. This methodology, whilst clearly having limitation, reflects the limited availability of skilled resources in this setting and mirrors practices of similar programmes internationally [38, 336].

5.4.6 Conclusion

This paper demonstrates the feasibility of a peer delivered training course in improving the knowledge, confidence and skills of newly graduated doctors in common medical and surgical emergencies as they prepare for clinical practice. Similar peer based courses may have utility beyond newly qualified doctors and beyond Sri Lanka, for honing essential practical skills in front-line staff in other LMIC settings.

Figure 5.4.1 Participant pre and post course self-assessment of skills

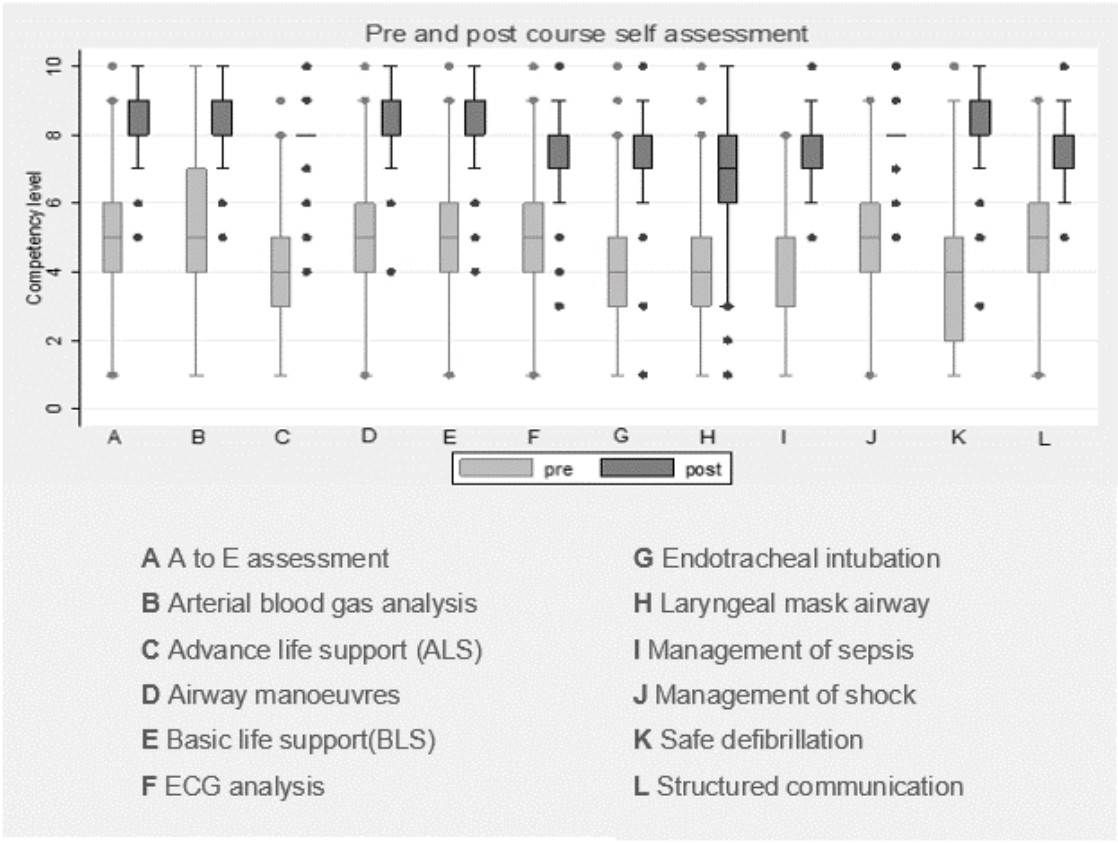


Figure 5.4.2 Session by session feedback for skills stations and scenarios.

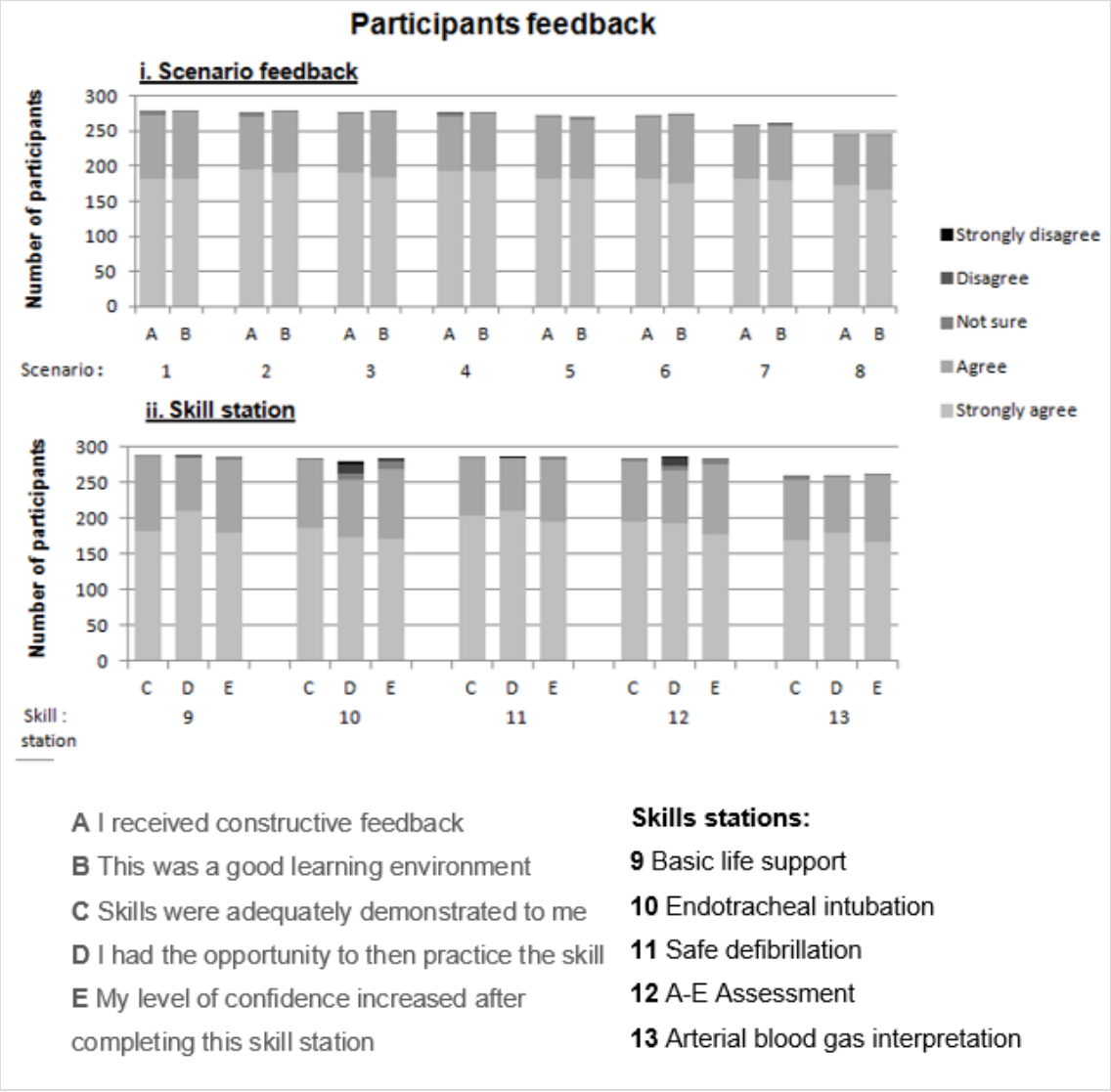


Figure 5.4.3 Distribution of marks for the five OSCE stations

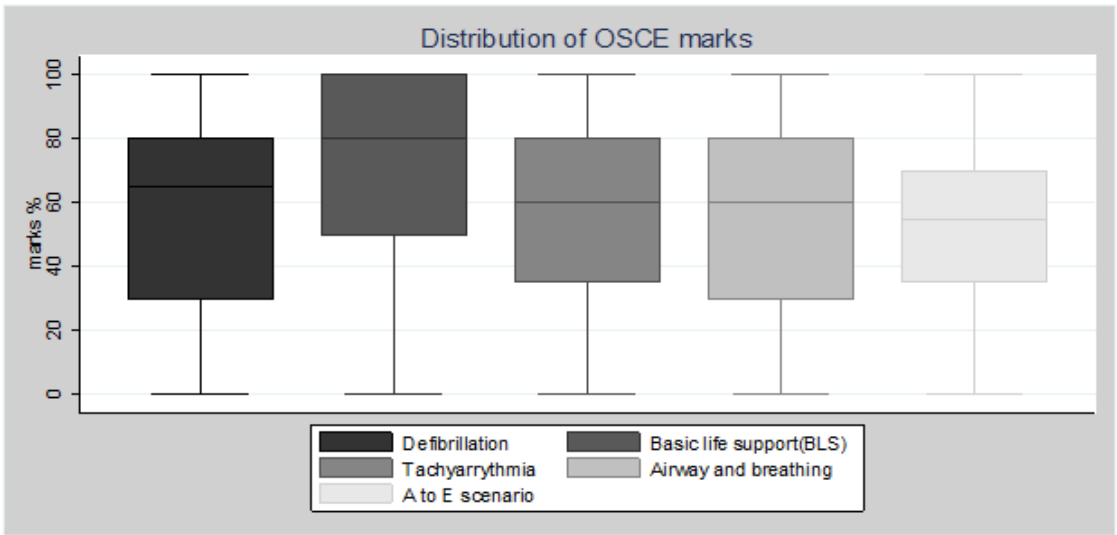


Figure 5.4.4 Overall feedback from course participants

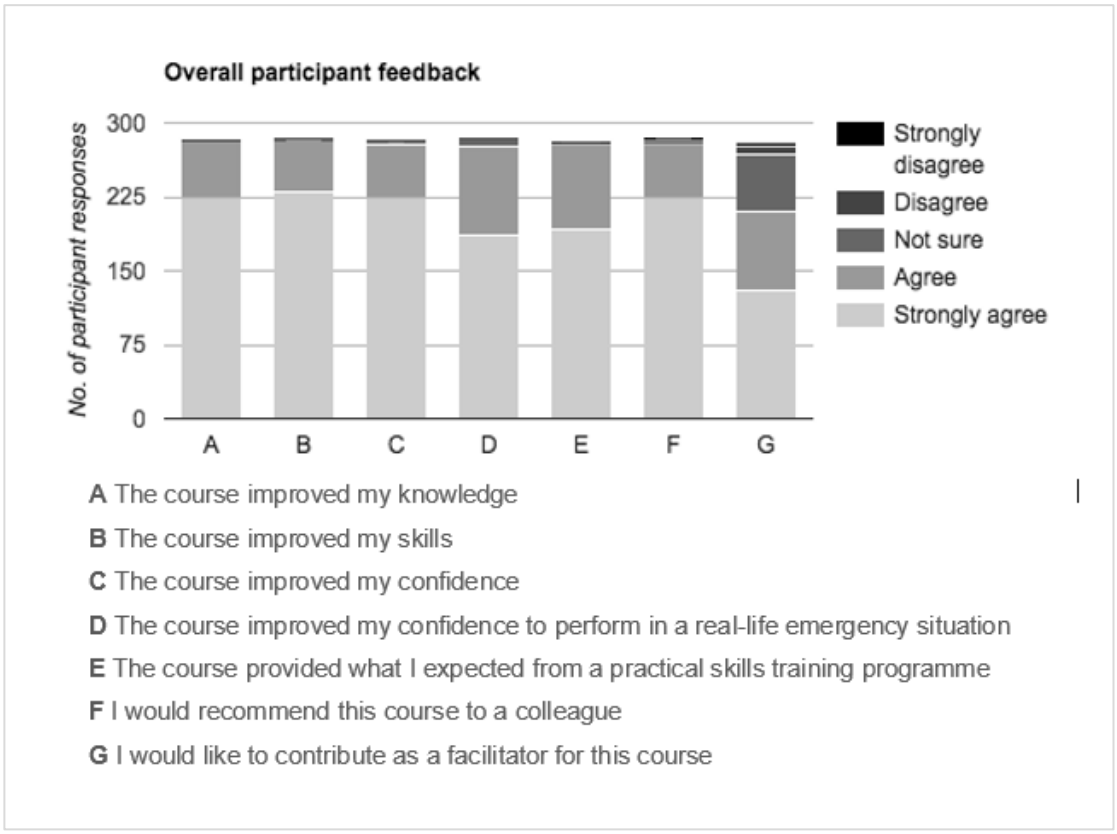
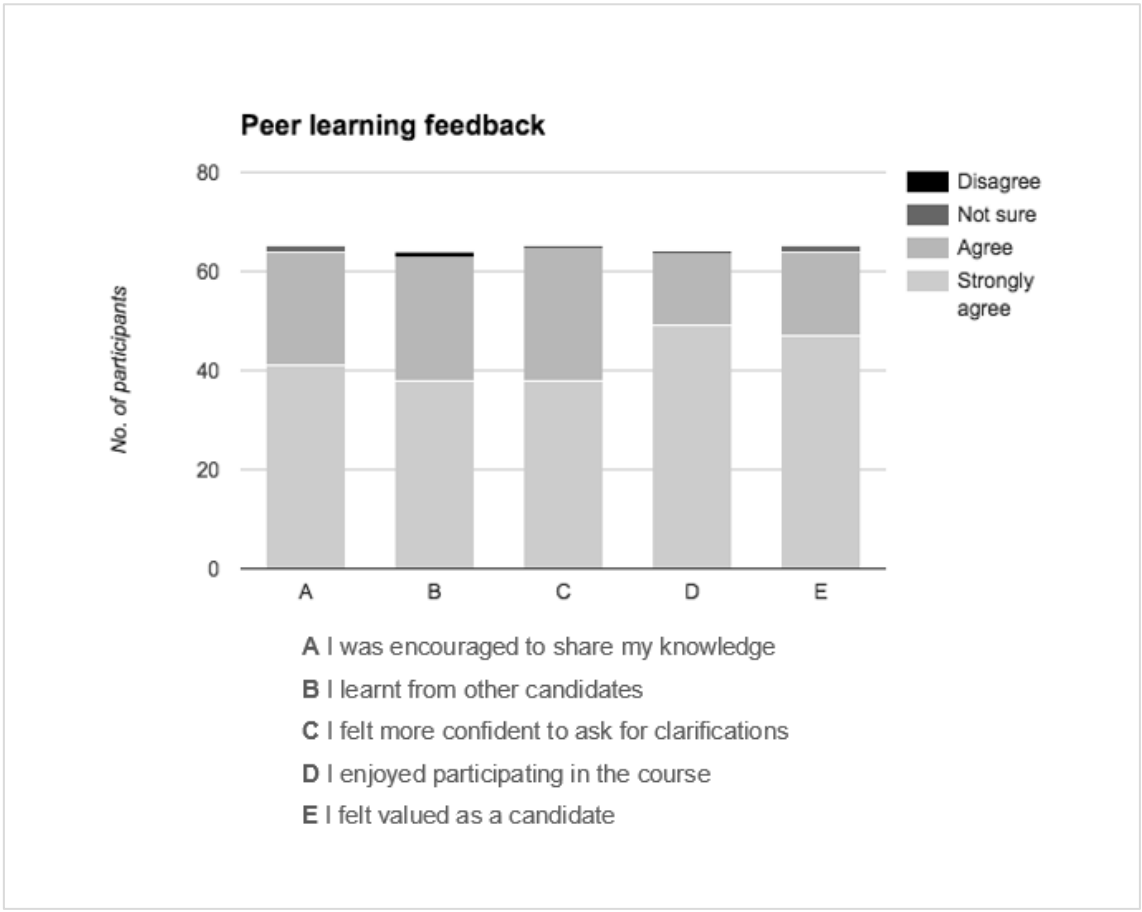


Figure 5.4.5 Participant feedback regarding peer-peer learning method.



6.0 Summary

6.1 Chapter 3 - a national profile of acute and critical care services and suggestions for service improvement

Nationally in Sri Lanka 99 CCUs contained 2.5 CCU beds per 100,000 population equating to 13 CCU beds per 1000 hospital beds. All CCUs had access to electricity, piped oxygen, multi-parameter monitoring and infusion pumps but no electronic health information systems. Blood gas machines and internet access were available in 65.6% and 4.2% of units respectively. Overall CCU mortality was 17% but no severity of illness data was available. CCUs were well staffed with 790 doctors (1.6 per bed) and 1989 nurses (3.9 per bed, 87.9% CCUs had 1:1 nurse to patient ratio). No critical care registry or emergency bed system was available.

A national survey of junior doctors revealed that DNAR instructions were infrequently used in hospital wards CPR was attempted prior to a majority of in-patient ward deaths. Successful outcomes following resuscitation in Sri Lanka are lower than in HIC settings. Most cardiac arrests were anticipated by junior medical staff, nearly one third of unsuccessful attempts do not appear to be concerted in nature and the likelihood of ROSC overall is low. LMICs such as Sri Lanka, would benefit from better training and systems to care for the acutely deteriorating patient, further development of DNACPR orders, and from research and training in end of life decision-making.

ICU workers from LMICs perceived lack of training of ICU workers, lack of nurses, and low wages as major barriers to ICU functioning in LMICs. Training, increase of nurse workforce, and collection of outcome data were proposed as useful strategies to improve LMIC ICU services. LMIC respondents judged that assistance of HIC ICU staff would be helpful to train LMIC ICU workers, develop

ICU registries and protocols as well as conduct research. Donation of equipment, drugs and supplies were perceived to be of limited usefulness. The most striking difference between HIC and LMIC staff was the perception on the lack of physician leadership as an obstacle to ICU functioning.

6.2 Chapter 4 – Tools for the evaluation of acute and critical care in LMICs.

A systematic review of critical care prognostic models in LMICs reviewed 160 models in 54 papers; robust interpretations on the applicability of prognostic models are currently hampered by missing values, known to be a major impediment in LMICs, being reported in only 26% of instances. Nevertheless, performance of mortality risk prediction models for ICU patients- predominantly developed in and for HIC settings- in LMICs is at most moderate, especially with regard to calibration. A multi-centre paper based study evaluating APACHE II performance in Sri Lanka using ICU outcomes confirmed the diverse challenges of acquiring a complete dataset, even when imputation techniques are utilised. Meanwhile, a single-centre study of TBI patients in a tertiary care centre reported poor long-term outcomes and poor performance of trauma prognostic models with a nearly complete dataset.

A suite of simplified prognostic models (TropICS) scored at admission to ICU without diagnostic coefficients, demonstrated comparable performance to the relatively complex APACHE II model, and need evaluation for wider applicability. A setting-adapted Sri Lankan electronic critical care registry implemented in nearly 80 adult ICUs generated a dataset of over 20,000 patients portending more rigorous future evaluation of critical care services; a multi-centre study of ICU survivors being one of the first outputs of the registry suggesting high post-ICU mortality. An adaptation of the registry platform to the ward setting in a DGH appears to improve observation availability from a low baseline, although the

utility of existing EWS models in this LMIC setting remain questionable.

6.3 Chapter 5 - Acute and critical care training for LMIC

The inadequacies in acute and critical care training in LMIC settings and the importance of corrective measures were highlighted from a multitude of viewpoints; junior and senior doctors; nurses; physiotherapists; wider critical care community in LMIC and HIC.

The pre and post-evaluation of the impact of a structured training programme focusing on the basic tenets of intensive care in Asia emphasised the importance not only of persevering with such training efforts, but also the requirement to develop sustainable, locally empowered training models. The feasibility and importance of systematic efforts to evaluate short and long-term impacts was also highlighted.

In Sri Lanka, following on the back of a setting adapted critical care registry, the rollout of a locally sustainable TTT based training programme has evolved into a multi-disciplinary training platform which has trained thousands of diverse healthcare workers while demonstrating short-term impact. The training program also has less directly quantifiable benefits such as incentivising data-entry and goodwill. The data and training platform can dovetail in the future in evaluating longer-term impact and in generating setting relevant research.

6.4 General conclusions

This thesis focuses on the shortcomings in the availability, collation and dissemination of information on ICU care, from individual patient's bedside observations, through to regional and national data in a LMIC. It explores how these challenges not only affect direct patient care, but also hamper surveillance, benchmarking, research, education and training. It further describes how a setting adapted electronic patient data system implemented in one LMIC, is being

utilised as an important tool to overcome these challenges. In addition, it considers how such an approach could both empower clinical team performance in critical care and enable us to understand and improve the complexity of healthcare priorities in LMIC's.

The hypotheses proposed in this thesis were:

- Critical care prognostic models from HIC are impractical in resource-limited settings.

Section 4.2 provides strong evidence that despite prospective data collection using a paper-based system with daily reminders, the robust evaluation of the relatively simpler APACHE II system across multiple ICUs in this LMIC was not feasible. Hospital outcomes were impractical to collect, serial recordings harder to access, complete case analysis could not be attempted and imputation techniques were unable to overcome the extent of the missingness. As paper based charting systems and notes are still in predominant use across LMICs, this finding is unlikely to be limited to South Asia. In addition, even where a relatively complete dataset was collected, a small study on TBI patients demonstrated in limitations in the generalisability of prognostic models developed in HIC.

- A simplified prognostic model can predict critical care outcomes in a resource-limited setting.

The same multi-centre study and the preceding systematic review (Section 4.1) demonstrated the extent of the difficulties posed by missing data and in recording hospital outcomes in LMICs. They also suggested that a prognostic model with variables more readily available and gathered at admission would provide a more complete dataset that could then be compared against

established models. Section 4.4 describes a suite of prognostic models, TropICS that are at least comparable to APACHE II but, with a lesser data collection burden.

- A clinician-led national acute and critical care surveillance data platform enables the evaluation of process and outcome measures in a resource-limited setting.

The implementation of a clinician-led electronic data platform, NICST, improves the availability and visibility of clinical information, as illustrated in Sections 4.5 and 4.6, in comparison to very low baseline availability in Sections 4.2 and 3.2. It is thus now possible to evaluate clinical tools, interventions and patient outcomes in a systematic and robust manner. The preliminary research study described in Section 4.7 is one example of such output.

- Single parameter (non-aggregate) EWS are comparable to multi-parameter (aggregate) EWS in detecting deterioration in a resource-limited setting.

In parallel with simpler prognostic models being shown to be at least as effective as more complicated tools, the large single centre study in Section 4.6 provides evidence that single parameter (non-aggregate) EWS, even where observations are limited to variables such as heart rate and respiratory rate, would have comparable performance to aggregate EWS.

- The introduction of a modular training program would lead to improvement in ICU performance indicators in a resource-limited setting.

The interventional study in three South Asian ICUs described in Section 5.2 provides evidence of improved patient outcomes after a modular practical training programme focused on the basic tenets of intensive care.

- A locally sustainable, predominantly peer-led practical national training programme in acute care skills can be established in a resource-limited setting.

Sections 5.3 and 5.4 provide strong evidence over an extended period that a predominantly or completely peer-led training programme for doctors and nurses can be instituted in a LMIC focused on a structured approach to the acutely unwell patient.

6.5 The present and the future

The NICST platform is a clinician-led, cloud based electronic system that serves to facilitate decision support for clinicians and administrators, to maximise utilisation of critical care beds, and to deliver and evaluate training. It is now being enhanced to empower patients and promote setting-relevant, locally driven research.

The platform is now deployed in 53 state hospitals across the island [34, 236] and has assisted clinicians in the care of approximately 100,000 patient episodes, providing information on patient care from admission through to 90 days following discharge. The patient platform provides clinicians with granular information necessary for individual patient care, aggregate information to enable evaluation of trends and with outcomes following acute admission. The platform has captured over 500,000 observations electronically in the care of acute and critically unwell patients. It is empowering nurses and doctors to use this information to facilitate observation reporting in the busy ward setting, and to evaluate trends in physiological variables essential for diagnosis and treatment decision making (figure 6.5.2, figure 6.5.3 i, ii).

The platform, displaying real time information, alerts clinicians to adverse

physiological variables and to trends in clinical data, acuity, and laboratory findings (figure 6.5.3 i, ii, vii). As part of a local research collaboration, adaptation of an early warning system to help detect patients at risk of deterioration has been undertaken (Figure 6.5.2 and 6.5.3, ii, vii) and has been used by clinicians as a tool for detecting over 4800 deteriorating patients. The related deployment of trained rapid response nurses to support ward staff in managing critically ill patient on the wards is a first for this setting, and links the platform to setting-adapted training (figure 6.5.3 iv). Such systems, which utilise simple physiological variables, are gaining popularity in LMICs; where early identification of unwell patients is of even greater benefit given the sparsity of critical care resources [30, 89].

The platform, linking clinical and organisational information, has gathered over 149800 bed occupancy reports and is the foundation of the ICU surveillance and bed availability system. It has supported clinicians in finding ICU beds for over 4500 patients within 94/105 of the island's critical care facilities. (Figure 6.5.3 v, vii [34]. Improving the understanding of ICU patient populations and their outcomes is enabling those responsible for healthcare service delivery to evaluate existing service provision, benchmark quality of care and prioritise resource allocation [32].

This increase in availability of granular and aggregate clinical information is enabling ongoing research such as, prognostic modelling in acute and critical illness and external validation of these models and related tools [35, 337, 338] Upcoming research outputs include risk stratification of surgical patients, impact of postoperative complications, quality of life for patients following critical illness and surgery, and determining patient experiences and satisfaction. The platform's real-time information capability creates opportunity for a more

responsive and dynamic quality improvement methodology (20). The platform's organisation, structure and internationally comparable terminology help overcome traditional barriers of paper based reporting and create opportunity for LMIC's participation in empiric evaluations synonymous with health informatics; SAILORS (an international external validation of qSOFA in LMIC's) and GOSSIS (A continually evolving and freely accessible large critical care database with potential for the development of tools such as a regularly updated international severity of illness score).

In response to demand for the opportunity to gain practical skills in critical care, resuscitation and research, NICST has partnered with medical and nursing institutions to deliver training to over 4,500 nurses, physiotherapists and doctors caring for acute and critical care patients nationally. These clinically focused programmes are locally delivered and often peer-led [38, 115] [figure 6.5.3 iii]). Information from participant's results, their feedback and their perceptions on how this informs their direct clinical care is captured and displayed through the platform. Output from the platform - surveillance, process measures, patient outcome and experience following illness-is now being used to inform undergraduate, graduate and bedside training programmes and to enable comparison with other local research [31, 115].

Whilst electronic systems in LMIC health care settings have an often-dubious history of functionality and reliability, the NICST data platform, designed and implemented in this setting, requires minimal IT infrastructure and exploits the increasingly pervasive mobile internet technology. Designed as part of an integrated approach to health improvement, the platform integrates with existing healthcare systems and has been developed with an understanding of the structures, limitations and processes that underpin healthcare in many LMIC

settings [34, 236, 246]

The challenges of information availability and the barriers to clinical care, research and quality improvement are not exclusively limited to critical care services in LMIC settings. Improving availability and accuracy of information is essential for disease surveillance and public health preventive strategies, for evaluation of non-communicable disease burden and for greater understanding of social, environmental and economic influences on disease epidemiology. With critical care beds at a premium in LMIC settings, the sickest patients within the healthcare system are often found outside of the ICU department [19]. This reality has motivated the deployment of the platform from critical care units to acute care settings, specialist units (e.g dialysis units) and, finally, the community. Further, a version of the platform was adapted to improve communication between patients, clinicians, public health workers and laboratory staff in the national rabies vaccination and treatment campaign [250].

The platform aims to improve treatment compliance in community mental health services and to initiate follow-up by connecting healthcare teams using mobile phone text messages. (Figure 6.5.3 vi).

The NICST platform has been successfully implemented within and outside critical care in Sri Lanka as a tool for clinical care, surveillance, identifying research priorities and evaluating training; exploration of its adaptability for other LMIC settings is required (See Appendix C for dashboard screenshots). Funding is being sought to partner with other LMICs, in the region and in Sub- Saharan Africa, who are keen to collaborate by adopting this methodology. In addition, given the platform’s generic nature and rapid deployability, its adaptation as a tool to combat the growing threat from infectious disease outbreaks, in the fight to accurately monitor antibiotic resistance and in spatiotemporal surveillance is

being explored. Greater investment in systems that enable us to better utilise the information available to us and indeed respond to environmental, economic and social influences that shape critical care needs and delivery is perhaps fundamental to building capacity for a sustainable future.

Figure 6.5.1 Schematic of the patient platform showing the realised and potential impact of the strategy for both individual patients and on service delivery.

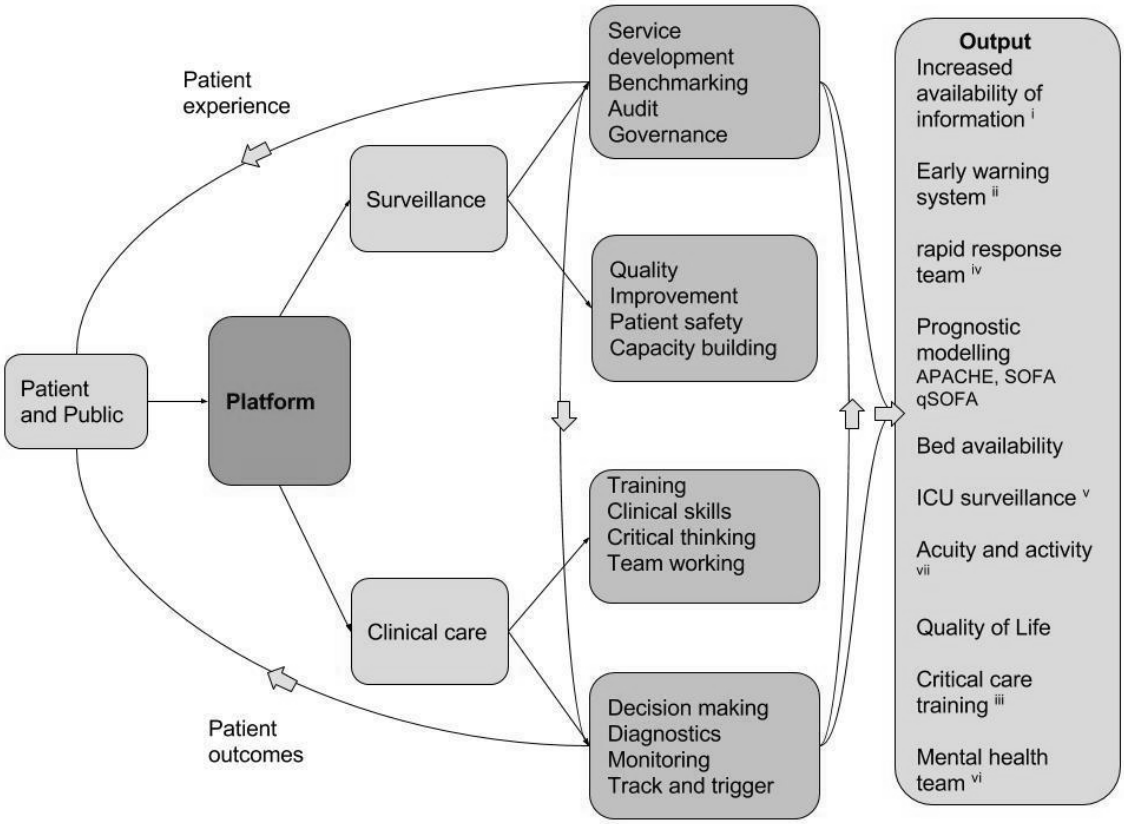


Figure 6.5.2 Observation reporting behaviours and admission activity captured by the platform. Unit of measure= weeks.

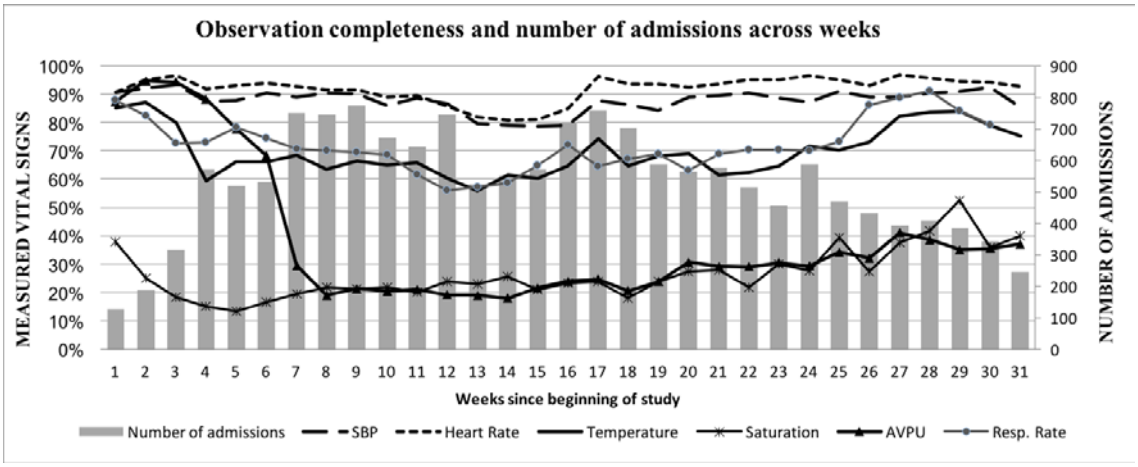
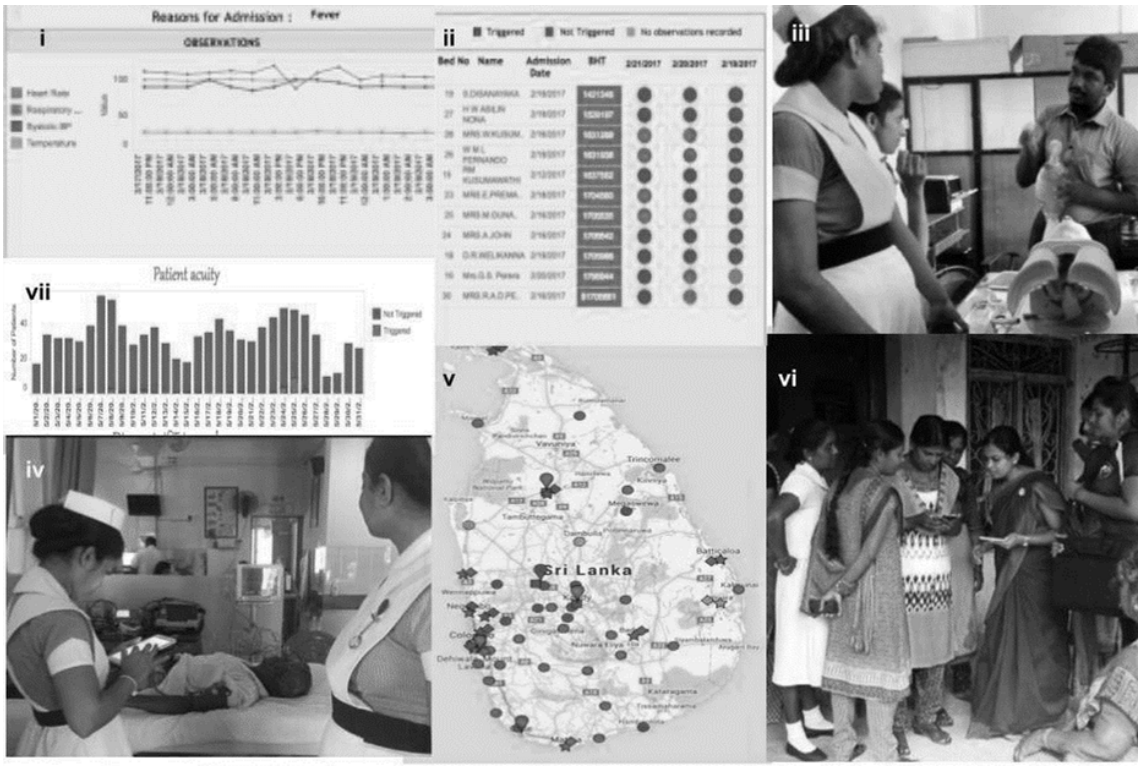


Figure 6.5.3 I The platform providing staff with live displays of trends in patient observations**, ii** the system alerts clinicians to patients with abnormal parameters, developed as part of a locally validated EWS, **iii** clinical skills training delivered in hospitals using locally upskilled doctors and nurses, **iv** Upskilled rapid response nurses using the mobile platform to monitor critically ill patients on the wards **, v** the island wide ICU surveillance system**, vi** highly adaptable, the platform is used by community mental health care team (MH) workers**, vii** acuity and admission surveillance.



8.0 Related publications

Aspects of this thesis were published or are undergoing peer review and have been incorporated.

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Acknowledgements

No project of this nature is possible without the kindness, generosity, collaboration and guidance of a multitude of individuals and organisations. As such, any effort to list their contributions through these pages is unlikely to do justice to their efforts and expertise, or express the gratitude that is felt in the journey we have made together.

So instead I would like to use this opportunity to acknowledge the patients who access acute and critical care services in LMICs -with life and death often in the balance- and to their families who then live with the consequences. All those who have contributed towards the work described in these pages, and those who will share the journey made possible by this work in the future are united by the desire to improve outcomes for these vulnerable patients and their families.

The greatest expression of gratitude is therefore to look forwards. I extend an invitation, to both existing and future collaborators to join together, renewed and strengthened in our goal to develop sustainable means of delivering, evaluating, and improving acute and critical care services in resource-limited settings.

Appendix A – Supplementary tables

Supplementary Table 4.1.1 Search terms

	Search area	Search terms
A	Critical Care	Critical care OR Intensive care [MeSH Terms:noexp]
B	Prognostic scoring system	Prognostic [MeSH Terms:noexp] OR Predictive [MeSH Terms:noexp] OR Mortality [MeSH Terms:noexp] OR Survival [MeSH Terms:noexp] AND Scoring system [MeSH Terms:noexp] OR Rating system [MeSH Terms:noexp] OR
C	Scoring systems	APACHE OR SAPS OR SOFA OR TISS OR MPM OR euroscore OR GCS OR IPS OR POSSUM OR ASA
D	Country	Middle income' OR 'Low income' OR 'Resource limited' OR 'Developing country'

(A and B) and (A and C) (A AND (B OR C))

D - hand searched after initial database search produced poor results.

Supplementary Table 4.1.2 Charms Checklist

Study	Scoring system	Source of data	ICU Type	Outcomes to be predicted	Predictors	Timings	Sample size	Missing data	Cal	Dis	Cla
Abhinandan and Vedavathi (2013)	APACHE II	A1	B1	C1	D1	E1	50	F1	G1	H1	I1
Abhinandan and Vedavathi (2013)	SOFA (Mean 24 hours)	A1	B1	C1	D1	E1	50	F1	G1	H1	I1
Abhinandan and Vedavathi (2013)	GSC	A1	B1	C1	D1	E1	50	F1	G1	H1	I1
Acharya et al (2006)	SOFA (Delta)	A1, A2	B2	C2	D1	E1	50	F2	G1	H2	I1
Acharya et al (2006)	SOFA (Initial)	A1, A2	B2	C2	D1	E1	50	F2	G1	H2	I1
Acharya et al (2006)	SOFA (Maximum)	A1, A2	B2	C2	D1	E1	50	F2	G1	H2	I1
Acharya et al (2006)	SOFA (Mean)	A1, A2	B2	C2	D1	E1	50	F2	G1	H2	I1
Aggarwal et al (2006)	MPM II (24h)	A1	B3	C2	D1	E1	459	F1	G2	H2	I2, I3, I4
Aggarwal et al (2006)	APACHE II	A1	B3	C2	D1	E1	459	F1	G2	H2	I2, I3, I4
Aggarwal et al (2006)	SAPS II	A1	B3	C2	D1	E1	459	F1	G2	H2	I2, I3, I4
Aggarwal et al (2006)	MPM II (initial)	A1	B3	C2	D1	E1	459	F1	G2	H2	I2, I3, I4
Ahluwalia (1999)	APACHE II	A1	B4	C2	D1	E2	79	F1	G1	H2	I2
Celik et al (2014)	SAPS II	A3, A4	B5, B6, B7	C3	D1	E1	545	F2	G1	H1	I1
Chang et la 2006	APACHE II	A1	B2	C2	D1	E1	1263	F1	G2	H2	I1

Chiavone and Rasslan (2005)	APACHE II	A1	B1	C2	D1	E1	94	F2	G3	H2	I1
Eapen et al (1997)	APACHE II (VM)	A1	B4	C4	D2	E1	500	F1	G1	H2	I1
Eapen et al (1997)	Organ Score Failure (VM)	A1	B4	C4	D2	E1	500	F1	G1	H2	I1
Evran et a; (2016)	APACHE II	A3	B2	C3	D3	E3	487	F1	G1	H2	I2, I3, I4
Evran et a; (2016)	APACHE IV	A3	B2	C3	D3	E3	487	F1	G1	H2	I2, I3, I4
Evran et a; (2016)	SAPS 3	A3	B2	C3	D3	E3	487	F1	G1	H2	I2, I3, I4
Fadaizadeh et al (2012)	APACHE II	A3	B3	C3	D1	E1	415	F1	G2	H2	I3
Fadaizadeh et al (2012)	SAPS II	A3	B3	C3	D1	E1	415	F1	G2	H2	I3
Faruq et al (2013)	APACHE II	A3, A4	B2	C3	D1	E1	194	F3	G2	H2	I1
Faruq et al (2013)	SAPS II	A1, A3	B2	C3	D1	E1	194	F3	G2	H2	I1
Galal et al (2013)	SAPS II	A1, A2	B3	C3	D1	E1	105	F1	G2	H2	I2, I4
Galal et al (2013)	SOFA (Initial)	A1, A2	B3	C3	D1	E1	105	F1	G2	H2	I2, I4
Galal et al (2013)	APACHE II	A1, A2	B3	C3	D1	E1	105	F1	G2	H2	I2, I4
Gilani et al (2014)	APACHE III	A1	B6	C2	D1	E1	202	F1	G2	H2	I2, I3
Gilani et al (2014)	SAPS II	A1	B6	C2	D1	E1	202	F1	G2	H2	I2, I3
Gilani et al (2014)	APACHE II	A1	B6	C2	D1	E1	202	F1	G2	H2	I2,I3
Godinjak et al (2017)	APACHE II	A1	B4	C2	D1	E1	174	F2	G1	H2	I2

Godinjak et al (2017)	SAPS II	A1	B4	C2	D1	E1	174	F2	G1	H2	I2
Gupta and Arora (2003)	APACHE II	A1	B3	C3	D1	E1	330	F1	G2	H2	I4
Haidri et al (2005)	APACHE II	A1	B3	C4	D1	E1	142	F2	G1	H2	I1
Halim et al (2009)	APACHE II	A1, A2	B2	C3	D1	E1	144	F1	G2	H2	I2, I3, I4
Halim et al (2009)	SOFA (Initial)	A1, A2	B2	C3	D1	E1	144	F1	G2	H2	I2, I3, I5
Halim et al (2009)	ModifiedSOFA (Initial)	A1, A2	B2	C3	D1	E1	144	F1	G2	H2	I2, I3, I6
Halim et al (2009)	ModifiedSOFA (Maximum)	A1, A2	B2	C3	D1	E1	144	F1	G2	H2	I2, I3, I7
Halim et al (2009)	SOFA (Maximum)	A1, A2	B2	C3	D1	E1	144	F1	G2	H2	I2, I3, I8
Halim et al (2009)	ModifiedSOFA (Mean)	A1, A2	B2	C3	D1	E1	144	F1	G2	H2	I2, I3, I9
Halim et al (2009)	SOFA (Mean)	A1, A2	B2	C3	D1	E1	144	F1	G2	H2	I2, I3, I10
Hamza et al (2009)	APACHE IV	A1, A2	B2	C3	D1	E1	264	F1	G2	H2	I1
Hamza et al (2009)	MPM II (initial)	A1, A2	B2	C3			264	F1	G2	H2	I1
Hamza et al (2009)	SAPS II	A1, A2	B2	C3			264	F1	G2	H2	I1
Hashmi et al (2016)	APACHE II (manual calculation)	A3	B6	C1	D1	E1	213	F1	G2	H2	I2, I4
Hashmi et al (2016)	APACHE II (automatic calculation using software TMT)	A3	B6	C1	D1	E1	213	F1	G2	H2	I2, I4

Hernandez and Palo (2014)	SAPS 3	A3	B2	C3	D1	E1	2426	F2	G2	H2	I1
Hosseini and Ramazani (2015)	APACHE II	A1, A2	B8	C3	D1	E1	150	F1	G2	H2	I2, I4
Hosseini and Ramazani (2015)	GCS (initial)	A1, A2	B8	C3	D1	E1	150	F1	G3	H3	I2, I5
Jain et al (2016)	SOFA (initial)	A1	B1	C3	D3	E4	44	F2	G1	H1	I1
Jain et al (2016)	SOFA (maximum)	A1	B1	C3	D3	E4	44	F2	G2	H2	I1
Jain et al (2016)	SOFA (mean)	A1	B1	C3	D3	E4	44	F2	G3	H3	I1
Juneja et al (2012)	APACHE II	A3	B1	C3	D1	E1	653	F1	G2	H2	I2
Juneja et al (2012)	APACHE III	A3	B1	C3	D1	E1	653	F1	G2	H2	I2
Juneja et al (2012)	APACHE IV	A3	B1	C3	D1	E1	653	F1	G2	H2	I2
Juneja et al (2012)	SAPS II	A3	B1	C3	D1	E1	653	F1	G2	H2	I2
Juneja et al (2012)	SAPS 3	A3	B1	C3	D1	E1	653	F1	G2	H2	I2
Juneja et al (2012)	MPM II (initial)	A3	B2	C3	D1	E1	653	F1	G2	H2	I2
Juneja et al (2012)	MPM III (initial)	A3	B1	C3	D1	E1	653	F1	G2	H2	I2
Juneja et al (2012)	SOFA (initial)	A3	B1	C3	D1	E1	653	F1	G2	H2	I2
Khan et al (2015)	SOFA (Mean 24 hours)	A1, A2	B2	C5	D1	E4	85	F1	G1	H2	I2
Khan et al (2015)	SAPS II	A1, A2	B2	C5	D1	E1	85	F1	G1	H2	I2
Khan et al (2015)	APACHE II	A1, A2	B2	C5	D1	E1	85	F1	G1	H2	I2

Khan et al (2015)	SAPS II (TM 48 hours)	A1, A2	B2	C5	D1	E4	85	F1	G1	H2	I2
Khan et al (2015)	SOFA (Mean 48 hours)	A1, A2	B2	C5	D1	E2	85	F1	G1	H2	I2
Khan et al (2015)	APACHE II (TM 48 hours)	A1, A2	B2	C5	D1	E2	85	F1	G1	H2	I2
Khawannimit and Geater (2007)	SAPS II	A1, A2	B6, B2	C2	D1	E1	1316	F3	G2	H2	I2, I3, I4
Khawannimit and Geater (2007)	APACHE II	A1, A2	B6, B2	C2	D1	E1	1316	F3	G2	H2	I2, I3, I4
Khwannimit and Bhurayanontachai (2011)	SAPS 3 (AUS)	A1	B2	C2	D1	E1	2022	F1	G2	H2	I2
Khwannimit and Bhurayanontachai (2011)	Customised SAPS 3 (AUS)	A1		C2	D1	E1	2022	F1	G2	H2	I2
Khwannimit and Bhurayanontachai (2011)	SAPS II	A1	B2	C2	D1	E1	2022	F1	G2	H2	I2
Khwannimit and Bhurayanontachai (2011)	Customised SAPS II	A1	B2	C2	D1	E1	2022	F1	G2	H2	I2
Khwannimit and Bhurayanontachai (2011)	SAPS 3	A1	B2	C2	D1	E1	2022	F1	G2	H2	I2
Khwannimit and Bhurayanontachai (2011)	APACHE II	A1	B2	C2	D1	E1	2022	F1	G2	H2	I2
Khwannimit and Bhurayanontachai (2011)	Customised APACHE II	A1	B2	C2	D1	E1	2022	F1	G2	H2	I2
Kiatboonsri and Charoenpan (1995)	APACHE II	A1	B2	C2	D1	E1	334	F1	G3	H2	I2, I3, I4

Liu et al (2016)	APACHE II	A1	B1	C5	D3	E3	137	F1	G1	H2	H3
Liu et al (2016)	SOFA (initial)	A1	B1	C5	D3	E3	138	F1	G1	H2	I2
Mohan et al (2015)	APACHE II	A1	B1	C3	D1	E1	100	F1	G2	H2	I2
Mohan et al (2015)	SAPS II	A1	B1	C3	D1	E1	100	F1	G2	H2	I2
Mohan et al (2015)	SAPS 3	A1	B1	C3	D1	E1	100	F1	G2	H2	I2
Mohan et al (2015)	SOFA (initial)	A1	B1	C3	D1	E1	100	F1	G2	H2	I2
N˜ amendys-Silva et al (2013)	MexSOFA (VM 48h)	A1, A2, A4	B2	C3	D2	E1	232	F1	G2	H2	I2
N˜ amendys-Silva et al (2013)	SOFA (Initial)	A1, A2, A4	B2	C3	D3	E3	232	F1	G1	H2	I1
N˜ amendys-Silva et al (2013)	MEXSOFA (VM initial)	A1, A2, A4	B2	C3	D2, D4		232	F1	GI	H2	I1
Nair et al (2016)	SOFA (initial)	A1	B4	C3	D3	E3	48	F1	G1	H2	I1
Nair et al (2016)	SAPS I	A1	B4	C3	D3	E3	48	F1	G1	H2	I1
Naqvi et al (2016)	APACHE II	A3	B2, B9	C3/ C2	D1	E4, E5	96	F2	G2	H2	I1
Naqvi et al (2016)	SOFA (initial)	A3	B2, B9	C3/ C2	D1	E4, E5	96	F2	G2	H2	I1
Naqvi et al (2016)	SAPS II	A3	B2, B9	C3/ C2	D1	E4, E5	96	F2	G2	H2	I1
Nassar Jr, et al (2012)	APACHE IV	A1	B2	C2	D1	E1	5780	F2	G2	H2	I1
Nassar Jr, et al (2012)	MPM III (initial)	A1	B2	C2	D1	E1	5780	F2	G2	H2	I1
Nassar Jr, et al (2012)	SAPS 3	A1	B2	C2	D1	E1	5780	F2, F3	G2	H2	I1

Naved et al (2011)	APACHE II (TM 48 hours)	A1	B10	C3	D1	E2	253	F2	GI	H1	I1
Nimgaonkar et al (2004)	ANN 22 (MTM)	A1	B2	C2	D1	E1	2962	F1	G2	H2	I1
Nimgaonkar et al (2004)	ANN 15 (MTM)	A1	B2	C2	D1	E1	2962	F1	G2	H2	I1
Nimgaonkar et al (2004)	APACHE II	A1	B2	C2	D1	E1	2962	F1	G3	H2	I1
Nouira et al (1998)	MPM I (24h)	A1	B4, B6	C2			1325	F1	G4	H2	I3
Nouira et al (1998)	APACHE II	A1	B4,B6	C2	D1	E1	1325	F1	G1	H2	I3
Nouira et al (1998)	MPM I (initial)	A1	B4,B6	C2	D1	E1	1325	F1	G1	H2	I3
Nouira et al (1998)	SAPS II	A1	B4,B6	C2	D1	E1	1325	F1	G1	H2	I3
Ratanarat et al (2005)	SAPS I	A3	B4	C3	D1	E1	482	F1	G1	H2	I2
Ratanarat et al (2005)	APACHE II	A3	B4	C3	D1	E1	482	F1	G1	H2	I2
Riviello et al (2016)	MPM III (initial)	A1	B1	C2	D1	E1	425	F3	G2	H2	I1
Sathe and Bapat (2014)	SAPS II	A1, A2	B2	C2	D1	E1	1543	F1	G2	H2	I1
Sathe and Bapat (2014)	APACHE II	A1	B2	C2	D1	E1	1543	F1	G2	H2	I1
Sekulic et al (2015)	MPM II (initial)	A1	B6	C3	D1	E1	60	F1	G2	H2	I2
Sekulic et al (2015)	MPM II (24 hours)	A1	B6	C3	D1	E1	61	F1	G2	H2	I2
Sekulic et al (2015)	MPM II (48 hours)	A1	B6	C3	D1	E1	62	F1	G2	H2	I2
Sekulic et al (2015)	MPM II (72 hours)	A1	B6	C3	D1	E1	63	F1	G2	H2	I2

Sekulic et al (2015)	MPM II (7days)	A1	B6	C3	D1	E1	64	F1	G2	H2	I2
Sekulic et al (2015)	SOFA (24 hours)	A1	B6	C3	D1	E1	65	F1	G2	H2	I2
Sekulic et al (2015)	SOFA (48 hours)	A1	B6	C3	D1	E1	66	F1	G2	H2	I2
Sekulic et al (2015)	SOFA (72 hours)	A1	B6	C3	D1	E1	67	F1	G2	H2	I2
Sekulic et al (2015)	SOFA (7days)	A1	B6	C3	D1	E1	68	F1	G2	H2	I2
Sekulic et al (2015)	SAPS II	A1	B6	C3	D1	E1	69	F1	G2	H2	I2
Sekulic et al (2015)	APACHE II	A1	B6	C3	D1	E1	70	F1	G2	H2	I2
Shoukat et al (2016)	APACHE IV	A1	B6	C1	D1	E1	155	F1	G2	H2	
Shrestha et al (2012)	SOFA (Initial)	A1	B2	C3	D1	E1	117	F1	G2	H2	I2, I3, I4
Shrestha et al (2012)	APACHE III	A1	B2	C3	D1	E1	117	F1	G2	H2	I2, I3, I4
Silva Junior et al (2010)	SAPS 3	A1	B2	C2	D1	E1	1310	F1	G2	H2	I2
Soares and Salluh (2006)	SAPS 3 (CSA)	A1	B2	C2	D1	E1	952	F3	G2	H2	I1
Soares and Salluh (2006)	SAPS 3	A1	B2	C2	D1	E1	952	F3	G2	H2	I1
Soares and Salluh (2006)	SAPS II	A1	B2	C2	D1	E1	952	F3	G2	H2	I1
Soares et al (2004)	SAPS II	A1, A2	B2	C2	D1	E1	1257	F3	G2	H2	I1
Soares et al (2004)	APACHE II	A1, A2	B2	C2	D1	E1	1257	F3	G2	H2	I1
Soares et al (2004)	MPM II (24h)	A1, A2	B2	C2	D1	E1	1257		G2	H2	I1

Soares et al (2004)	APACHE III	A1, A2	B2	C2	D1	E1	1257	F3	G2	H2	I1
Soares et al (2004)	MPM II (initial)	A1, A2	B2	C2	D1	E1	1257	F3	G2	H2	I1
Soares et al (2010)	SAPS 3 (CSA)	A1	B1	C2	D1	E1	717	F3	G2	H2	I1
Soares et al (2010)	MPM III (24hours)	A1	B1	C2	D1	E1	717	F3	G2	H2	I1
Soares et al (2010)	SAPS 3	A1	B1	C2	D1	E1	717	F3	G2	H2	I1
Soares et al (2010)	SAPS II	A1	B1	C2	D1	E1	717	F3	G2	H2	I1
Sutheechet (2009)	MPM II (24h)	A1	B6, B2	C2	D1	E1	639	F1	G2	H2	I2, I3, I4
Sutheechet (2009)	SAPS II	A1	B6, B2	C2	D1	E1	639	F1	G2	H2	I2, I3, I4
Teoh et al (1997)	APACHE II	A1	B1	C2	D1	E1	100	F1	G1	H1	I1
Turner et al (1989)	APACHE II	A1	B3	C3	D1	E1	728	F1	G1	H1	I1
Turner et al (1989)	TISS	A1	B3	C6	D1	E1	728	F1	G1	H1	I1
Wilairatana et al (1995)	APACHE III	A1	B2	C2	D1	E1	209	F2	G1	H2	I2, I4
Wilairatana et al (1995)	TISS	A1	B2	C2	D1	E1	209	F2	G1	H2	I2,I4
Wilairatana et al (1995)	SAPS II	A1	B2	C2	D1	E1	209	F2	G1	H2	I2, I5
Wilairatana et al (1995)	APACHE II	A1	B2	C2	D1	E1	209	F2	G1	H2	I2,I5
XueZhong et al (2015)	APACHE II	A3	B1	C2	D1	E1	981	F1	G2	H2	I1
XueZhong et al (2015)	APACHE IV	A3	B1	C2	D1	E1	982	F1	G2	H2	I1

XueZhong et al (2015)	SAPS 3	A3	B1	C2	D1	E1	983	F1	G2	H2	I1
Yamin et al (2011)	APACHE IV	A1, A2	B4, B6, B11	C3	D1	E1	162	F1	G1	H1	I1
Yousef and Suliman (2013)	SOFA (Mean)	A1	B1	C3	D1	E1	90	F1	G1	H2	I2, I3
Zhao et al (2013)	GCS (initial)	A1	B11	C3	D1	E1	1684	F1	G2	H2	I2, I4
Zhao et al (2013)	GCS (24h)	A1	B11	C3	D1	E1	1684	F1	G2	H2	I2, I4
Zhao et al (2013)	GCS (48h)	A1	B11	C3	D1	E2	1684	F1	G2	H2	I2, I4
Zhao et al (2013)	GCS (72h)	A1	B11	C3	D1		1684	F1	G2	H2	I2, I4
Zhao et al (2013)	SAPS II (initial)	A1	B11	C3	D1	E1	1684	F1	G2	H2	I2, I4
Zhao et al (2013)	SAPS II (TM 48 hours)	A1	B11	C3	D1	E2	1684	F1	G2	H2	I2, I4
Zhao et al (2013)	SAPS II (24h)	A1	B11	C3	D1	E1	1684	F1	G2	H2	I2, I4
Zhao et al (2013)	SAPS II (TM 72 hours)	A1	B11	C3	D1	E6	1684	F1	G2	H2	I2, I4
Zhao et al (2013)	Simplified SAPS II (VM)	A1	B11	C3	D2	E4, E5	1684	F1	G1	H1	I1

Source of Data	ICU type	Outcomes to be predicted	Predictors
A1 Prospective cohort **A2** Observational cohort **A3** Retrospective cohort **A4** Descriptive cohort	**B1** Not specified **B2** Multidisciplinary ICU **B3** Respiratory ICU **B4** Medical ICU **B5** Internal medicine ICU **B6** Surgical ICU **B7** Anaesthesia ICU **B8** Post-Anaesthesia Care Unit **B9** High dependency unit **B10** General ICU **B11** Neurology ICU	**C1** Mortality (not specified - most likely ICU) **C2** Hospital mortality **C3** ICU Mortality **C4** Not specified **C5** 28 day mortality **C6** Mortality not specified (but most likely hospital)	**D1** Predictors as original **D2** Predictor(s) excluded **D3** Not specified (assumed to be as original) **D4** Ratios used for assesment changed

Timings	Missing data	Calibration	Discrimination	Classification
E1 Timings as original **E2** 48 hours **E3** Not specified (assumed to be as original) **E4** Timings as in original and at 48 hours **E5** Timing as in original and at 72 hours **E6** 72 hours	**F1** Not reported **F2** Exclusion **F3** Normal values substituted	**G1** Not reported **G2** Hosmer Lemeshow **G3** Other	**H1** Not reported **H2** AUROC curve **H3** Not AUROC	**I1** Not reported **I2** Sensitivity, specificity **I3** NPV, PPV **I4** accuracy

Supplementary Table 4.1.3 Description of studies

Study	Scoring system/s investigated	Country	Number and type of hospital	Number and type of ICU	Study period	Number of patients	Age of patients (years)	Study outcomes
Abhinandan and Vedavathi (2013)	APACHE II SOFA GCS	India	1 General	1 ICU (not specified)	November 2010 to September 2012	50	18 to 90 48.36 (Mean)	Mortality (Not specified)
Acharya et al (2006)	SOFA	Nepal	1 General	1 Multidisciplinary ICU	June 2005 to October 2015	50	15 to 70 34 ±14.4 (Mean)	Hospital mortality
Aggarwal et al (2006)	APACHE II SAPS II, MPM II 0 MPM II 24	India	1 General	1 Respiratory ICU	4-year period (specific dates not mentioned)	459	16 to 80	Hospital mortality
Ahluwalia (1999)	APACHE II New Score*	India	1 General	1 Medical ICU	Not mentioned	79	13 to80 46 (Mean)	Hospital mortality
Celik et al (2014)	SAPS II	Turkey	1 General	1 Internal medicine ICU 1 Surgery ICU 1 Anaesthesia ICU	January 2006 to January 2011	545	Above 18 years	ICU mortality
Chang et al (2006)	APACHE II	Taiwan	1 Oncology	1 Medical-Surgical ICU	January 1996 to December 2000	1263	13-92 56 (Mean)	Hospital mortality

Chiavone and Rasslan (2005)	APACHE II	Brazil	1 General	1 Surgical -ICU	August 2002 to July 2003	94	16 to 97	Hospital mortality
Eapen et al (1997)	OSF (modified)APACHE II (modified)	India	1 General	1 Medical ICU	December 1991 to March 1993	500	13 to 84	Mortality
Evran et a; (2016)	APACHE II APACHE IV SAPS 3	Turkey	1 General	1 ICU (not specified)	July 2010 and July 2011	487	18 to 96 58.58 ± 18 (Mean)	ICU mortality
Fadaizadeh et al (2012)	APACHE II SAPS II	Iran	1 Respiratory	1 Respiratory ICU	1 year period (specific dates not mentioned)	415	49.28 ± 0.94 (Mean)	ICU mortality
Faruq et al (2013)	APACHE II SAPS II,	Bangladesh	2 General	General ICU	January to December 2008	194	61.06 ± 15.42 (Mean)	ICU Mortality
Galal et al (2013)	APACHE II SAPS II, SOFA	Egypt	1 Respiratory	1 Respiratory ICU	Not mentioned	105	20 to 88 54.59 ± 15.75 (Mean)	ICU mortality
Gilani et al (2014)	APACHE II APACHE III SAPS II	Iran	1 General	1 Surgical -ICU	April 2010 to September 2010	202	14 to 85 53.1 ± 20.3 (Mean)	Hospital mortality
Godinjak et al (2017)	APACHE II SAPS II	Bosnia and Herzegovina	1 General	1 Medical ICU	October 2014 to September 2016	174	19 to 87 61.7±16.3 (Mean)	Hospital mortality

Gupta and Arora (2003)	APACHE II	India	1 Respiratory	1 Respiratory ICU	September 2001 to February 2003	330	43.32 ±16.22 (Mean)	ICU mortality
Haidri et al (2005)	APACHE II	Pakistan	1 General	1 Respiratory ICU	January 2009 to December 2009.	142	15-90 53.16±19.29 (Mean)	ICU mortality
Halim et al (2009)	APACHE II SOFA MSOFA	Indonesia	1 General	1 Medical Surgical ICU	January 2008 to December 2008	144	15 - 85 47.33 ± 17.17 (Mean)	ICU mortality
Hamza et al (2009)	APACHE IVSAPS IIMPM II0	Egypt	1 General	1 Mixed medical, surgical and coronary care unit	February 20, 2008 until March 20, 2008.	265	57.07±16.6 (Mean)	ICU mortality
Hashmi et al (2016)	APACHE II	Pakistan	1 General	1 Surgical ICU	January 2011 to December 2012	213	46.31 ±18.43 (Mean)	Mortality (Not specified)
Hernandez and Palo (2014)	SAPS 3	Philippines	1 General	1 Medical ICU	1 January 2011 to 31 August 2013.	2426	62 ±17 (Mean)	ICU mortality
Hosseini and Ramazani (2015)	APACHE II GCS	Iran	1 General	1 Post-Anaesthesia Care Unit	July 2011 to February 2012	150	3 to 97	ICU mortality
Jain et al (2016)	SOFA	India	1 General	1 ICU (not specified)	8-week period (dates not specified)	44	40 ± 16 (Mean)	ICU mortality
Juneja et al (2012)	APACHE II APACHE III APACHE IV SAPS II SAPS 3	India	1 General	1 General ICU	July 2008 to September 2009	653	58.48±18.6 (Mean)	ICU mortality

	MPM II (0) MPM III (0) SOFA							
Khan et al (2015)	APACHE II SAPS II, SOFA	India	1 General	1 Medical Surgical ICU	November 2009 and March 2011	85	39.14 ±17.3 (Mean)	28-day mortality
Khawannimit and Geater (2007)	APACHE II SAPS II	Thailand	1 General	1 Surgical ICU 1 Medical ICU 1 Coronary ICU	July 2004 until October 2005	1316	55.6 ± 18.2 (Mean)	Hospital mortality
Khwannimit and Bhurayanontachai (2011)	APACHE IISAPS 3SAPS IICustomised APACHE IICustomised SAPS IICustomised SAPS 3	Thailand	1 General	1 Medical-Coronary ICU	March 2007 to August 2009	2022	62 (49-73)(median (IQR))	Hospital mortality
Kiatboonsri and Charoenpan (1995)	APACHE II	Thailand	1 General	1 Medical ICU	June 1989 to June 1990	334	15 to 98 56.01 ± 18.23 (Mean)	Hospital mortality
Liu et al (2016)	APACHE II SOFA	China	1 General	1 ICU (not specified)	March 2013 to February 2015	137	69.53 ± 9.28 (Mean)	28 day mortality
Mohan et al (2015)	APACHE II SAPS II SAPS 3 SOFA	India	1 General	1 Medical ICU	June 2010 and June 2012	100	Survivors - 44.29 ± 15.53 (Mean) Non-survivors -	ICU mortality

							57.37 ± 20.42 (Mean)	
Nair et al (2016)	SOFA SAPS	India	1 General	1 Medical ICU	June to September 2014	48	survivors - 53.56 (Mean) non-survivors - 47.78 (Mean)	ICU mortality
N˜ amendys-Silva et al (2013)	SOFAMexSOFA (modified scoring system)	Mexico	1 General	1 Multidisciplinary ICU	April 2009 to December 2009	232	48 ± 20 (Mean)	ICU Mortality
Naqvi et al (2016)	APACHE II SAPS SOFA	Pakistan	1 General	1 Medical ICU 1 HDU	April 2012 to August 2012	96	32.93±16.61 (Mean)	ICU mortality
Nassar Jr, et al (2012)	APACHE IV SAPS 3 MPM III	Brazil	1 General	3 Medical-Surgical ICUs	July 2008 to December 2009	5780	66 (47-79) (median (IQR))	Hospital mortality
Naved et al (2011)	APACHE II	Pakistan	1 General	1 General ICU (University hospital)	May 2005 to May 2006.	253	15 to 84 51.26 ± 17.9 (Mean)	ICU mortality Length of stay
Nimgaonkar et al (2004)	APACHE II Artificial Neural Network	India	1 General	1 Medical-Neurological ICU	January 1996 and May 1998	2962	37.5 ±16.1 (Mean)	Hospital mortality

	(ANN22) and (ANN15)							
Nouira et al (1998)	APACHE II SAPS II MPM 0 MPM 24	Tunisia	1 General	2 Medical ICU 1 Surgical ICU	January 1994 to July 1995	1325	46.6 ± 20.4 (Mean)	Hospital mortality
Ratanarat et al (2005)	APACHE II SAPS I	Thailand	1 General	1 Medical ICU	January 1999 and December 2000.	482	56 ± 21 (Mean)	ICU mortality
Riviello et al (2016)	MPM (0) III R-MPM* Simplified R-MPM*	Rwanda	2 General	2 General ICUs	August 2013 to October 2014	427	34 (IQR 25–47) (Median)	Hospital mortality
Sathe and Bapat (2014)	APACHE IISAPS II,	India	1 General	1 Multidisciplinary ICU	January 1 to December 31, 2011	1543	53.9 ± 16.8 (Mean)	Hospital mortality
Sekulic (2015)	APACHE II SAPS II MPM II (0) SOFA	Serbia	1 General	1 Surgical ICU	February 2013 to February 2014	60	59.0±15.8 (Mean)	ICU mortality
Shoukat et al (2016)	APACHE IV	Pakistan	1 General	1 Surgical ICU	June 2013 to November 2014	155	13 and 70 38.39 ±13.61 (Mean)	Mortality (Not specified)
Shrestha et al (2012)	APACHE III SOFA	Nepal	1 General	1 Multidisciplinary ICU	September 2009 to March 2010	117	16 to 84 43.18 ± 18.49 (Mean)	ICU mortality

Silva Junior et al (2010)	SAPS 3	Brazil	2 General	2 Surgical ICUs	March 2008 to March 2009	1310	67.1 ± 15.3 (Mean)	Hospital mortality
Soares and Salluh (2006)	SAPS II SAPS 3	Brazil	1 Oncology	1 Medical Surgical Oncological ICU	January 2003 to December 2005,	952	>18 years Mean 58.3 ± 23.1	Hospital mortality
Soares et al (2004)	APACHE II APACHE III SAPS II, MPM II 0 MPM II 24	Brazil	1 Oncology	1 Medical Surgical Oncological ICU	May 2000 to July 2003	1257	18 to 93 56.0 ± 16.7 (Mean)	Hospital mortality
Soares et al (2010)	SAPS IISAPS 3MPM III (24)Cancer Mortality Model	Brazil	17 Not specified	28 General and oncological ICUs	1 August 2007 until 30 September 2007	717	61.2 ± 15.4 (Mean)	Hospital mortality
Sutheechet (2009)	SAPS II MPM II (24)	Thailand	1 General	1 Surgical ICU 1 Mixed medical and coronary care unit	May 1, 2008, to March 15, 2009	639	18 to 100 56.9 ± 20.6 (Mean)	Hospital mortality
Teoh et al (1997)	APACHE II	Malaysia	1 General	1 General ICU	August 1990 to September 1990	100	1 month - 82 years	Hospital mortality
Turner et al (1989)	APACHE II TISS	South Africa	1 General	1 Respiratory ICU	1985 to 1986	728	12 to 88 43 (Mean)	Mortality (Not specified)

	Organ failure (defined*)							
P Wilairatana et al (1995)	APACHE II APACHE III SAPS II TISS	Thailand	1 General	1 Medical ICU 1 Surgical ICU	November 1993 to January 1994	209	16 to 93 55.36 ± 17.44 (Mean)	Hospital mortality
XueZhong et al (2015)	APACHE II APACHE IV SAPS 3	China	1 Oncology	1 General ICU	October 2008 and September 2010	981	64.8±12.1 (Mean)	Hospital mortality
Yamin et al (2011)	APACHE IV	Pakistan	1 General	1 Medical ICU 1 Surgical ICU 1 Neurocoma ICU	January 2009 to September 2009	162	9 to 90 38.024 (Mean)	ICU mortality Length of stay
Yousef and Suliman (2013)	Serum level of TNF-αSOFA	Egypt	1 General	1 ICU (not specified)	Not mentioned	90	Sepsis group - 62.8 ± 14.5 (Mean)SIRS group - 59.6 ± 12.6 (Mean)	ICU mortality
ZHAO Xiao-xia et al (2013)	SAPS II (original and modified) GCS	China	1 General	1 Neuro-ICU	January 2005 to December 2011	1684	18 to 98 58.93±18.30 (Mean)	ICU mortality

Supplementary Figure 4.1.4 Model performance

Study	Scoring system	SMR	Discrimination (AUROC)	Calibration	Sensitivity	Specificity	Accuracy	Positive Predictive Value	Negative Predictive Value
Abhinandan and Vedavathi (2013)	APACHE II	---	---	---	---	---	---	---	---
Abhinandan and Vedavathi (2013)	SOFA	---	---	---	---	---	---	---	---
Abhinandan and Vedavathi (2013)	GSC	---	---	---	---	---		---	---
Acharya et al (2006)	SOFA (Delta)	---	0.625	---	---	---	---	---	---
Acharya et al (2006)	SOFA (Initial)	---	0.708	---	---	---	---	---	---
Acharya et al (2006)	SOFA (Maximum)	---	0.817	---	---	---	---	---	---
Acharya et al (2006)	SOFA (Mean)	---	0.825	---	---	---	---	---	---

Aggarwal et al (2006)	MPM II (24h)	1.57 (1.33–1.83)	0.733	C- statistics χ2= 73.1 (p<0.001) H-statistics χ2= 69.7 (p<0.001)	48.1% (39.9–56.2) (Decision criteria 25%) 24.0% (17.5–31.6) (Decision criteria 50%) 14.35 (9.2–20.8) (Decision criteria 75%)	0.836 (0.789–0.876) (Decision criteria 25%) 0.956 (0.927–0.977) (Decision criteria 50%) 0.990 (0.971–0.998) (Decision criteria 75%)	0.715 (0.671–0.756) (Decision criteria 25%) 0.712 (0.668–0.754) (Decision criteria 50%) 0.701 (0.657–0.743) (Decision criteria 75%)	0.602 (0.509–0.689) (Decision criteria 25%) 0.740 (0.597–0.854) (Decision criteria 50%) 0.880 (0.688–0.975) (Decision criteria 75%)	0.757 (0.707–0.802) (Decision criteria 25%) 0.709 (0.662–0.753) (Decision criteria 50%) 0.691 (0.645–0.734) (Decision criteria 75%)
Aggarwal et al (2006)	APACHE II	1.70 (1.44–1.99)	0.713	C- statistic χ2= 119.3 (p<0.001) H-statistic χ2= 81.1 (p<0.001)	48.% (39.9–56.2) (Decision criteria = 25%) 20.1% (14.1–27.3) (Decision criteria = 50%) 3.2% (1.1–7.4)	0.84 (0.796–0.882) (Decision criteria 25%) 0.96 (0.927–0.977) (Decision criteria 50%) 0.977 (0.981–1.000)	0.719 (0.675–0.760) (Decision criteria 25%) 0.699 (0.651–0.743) (Decision criteria 50%) 0.668 (0.623–	0.612 (0.519–0.699) (Decision criteria 25%) 0.705 (0.548–0.832) (Decision criteria 50%) 0.833 (0.359–	0.758 (0.708–0.803) (Decision criteria 25%) 0.699 (0.651–0.753) (Decision criteria 50%) 0.666 (0.620–

					(Decision criteria= 75%)	(Decision criteria 75%)	0.711) (Decision criteria 75%)	0.996) (Decision criteria 75%)	0.710) (Decision criteria 75%)
Aggarwal et al (2006)	SAPS II	1.88 (1.59–2.20)	0.781	C- statistic χ2= 195.6 (p<0.001) H-statistic χ2= 159.6 (p<0.001)	0.461 (0.381–0.543) (Decision criteria 25%) 27.35 (0.204–0.350) (Decision criteria 50%) 10.4% (0.061–0.163) (Decision	89.3% (0.852–0.925) (Decision criteria 25%) 95.6% (0.927–0.977) (Decision criteria 50%) 98.7% (0.966–0.996) (Decision criteria 75%)	0.746 (0.703–0.785) (Decision criteria 25%) 0.723 (0.680–0.764) (Decision criteria 50%) 0.686 (0.641–0.728) (Decision criteria 75%)	0.689 (0.591–0.777) (Decision criteria 25%) 0.764 (0.630–0.868) (Decision criteria 50%) 0.800 (0.563–0.943) (Decision criteria 75%)	0.762 (0.714–0.806) (Decision criteria 25%) 0.718 (0.671–0.762) (Decision criteria 50%) 0.681 (0.634–0.724) (Decision criteria 75%)

					criteria 75%)				
Aggarwal et al (2006)	MPM II (initial)	2.74 (2.33–3.20)	0.665	C- statistics $\chi2$= 599.2 (p<0.001) H-statistics $\chi2$= 456.4 (p<0.001)	27.9% (0.210–0.355) (Decision criteria 25%) 11.4% (0.069–0.174) (Decision criteria 50%) 2.5% (0.007–0.064) (Decision	0.920 (0.884–0.948) (Decision criteria 25%) 0.980 (0.957–0.993) (Decision criteria 50%) 0.993 (0.976–0.999) (Decision criteria 75%)	0.699 (0.655–0.741) (Decision criteria 25%) 0.682 (0.637–0.724) (Decision criteria 50%) 0.660 (0.615–0.703) (Decision criteria 75%)	0.647 (0.522–0.759) (Decision criteria 25%) 0.750 (0.533–0.902) (Decision criteria 50%) 0.667 (0.223–0.957) (Decision criteria 75%)	0.708 (0.661–0.753) (Decision criteria 25%) 0.678 (0.632–0.722) (Decision criteria 50%) 0.660 (0.614–0.704) (Decision criteria 75%)

					criteria 75%)				
Ahluwalia (1999)	APACHE II	Up to 12 hours = 0.69 Over 12 hours = 1.36 overall = 1.21	0.74	---	93%	23.6%	---	---	---
Celik et al (2014)	SAPS II	---	---	---	---	---	---	---	---
Chang et al (2006)	APACHE II	---	0.82	$\chi 2$ =9.8 (p =0.28)					
Chiavone and Rasslan (2005)	APACHE II	---	0.729 (0.63-0.83)	Other	---	---	---	---	---
Eapen et al (1997)	APACHE II (VM)	---	0.6068	---	---	---	---	---	---

Eapen et al (1997)	Organ Score Failure (VM)		0.7062	---	---	---	---	---	---
Evran et a; (2016)	APACHE II	---	Figure (values cannot be estimated)	---	---	---	81.30%	59.50%	95.30%
Evran et a; (2016)	APACHE IV	---	Figure (values cannot be estimated)	---	---	---	79.30%	56.40%	95.40%
Evran et a; (2016)	SAPS 3	---	Figure (values cannot be estimated)	---	---	---	81.30%	59.20%	96.20%
Fadaizadeh et al (2012)	APACHE II	0.90	0.897 (0.858-0.937)	C statistic $\chi 2$= 3:27 (p = 0:916)	0.9 (cut off point = 13.5 Youden value = 0.65)	0.75 (Cut off point 13.5 Youden value 0.65)	---	---	---
Fadaizadeh et al (2012)	SAPS II	0.22	0.887 (0.847-0.926)	C statistic $\chi 2$= 7014 (p = 0:522)	0.83 (cut off point 86.5 Youden value 0.60)	0.77 (cut off point 86.5 Youden value 0.60)	---	---	---
Faruq et al (2013)	APACHE II	---	0.75 (0.67-0.82)	C- statistics $\chi 2$ = 8.304 (p=0.40)	---	---	---	---	---

Faruq et al (2013)	SAPS II	---	0.74 (0.66-0.81)	C- statistics $\chi 2$ = 9.040 (p=0.34)	---	---	---	---	---
Galal et al (2013)	SAPS II	---	0.59	$\chi 2$= 7.2, p = 0.3	0.534 (cut off =40)	0.62 (cut off =40)	57.10%	---	---
Galal et al (2013)	SOFA (Initial)	---	0.63	$\chi 2$= 4.82, p = 0.78	0.34 (cut off -7.5)	0.90 (cut off -7.5)	64.70%	---	---
Galal et al (2013)	APACHE II	---	0.6	$\chi 2$= 7.34, p = 0.39	0.93 (cut off =11)	0.24 (cut off =11)	55.20%	---	---
Gilani et al (2014)	APACHE III	---	0.78	$\chi 2$ =8.442 (p = 0.392)	0.823 (cut off point = 24)	0.58 (cut off point = 24)	---	34.10%	96.50%
Gilani et al (2014)	SAPS II	---	0.78	$\chi 2$ = 8.575(p= 0.379)	0.705 (cut off point =13)	0.63 (cut off point =13)	---	28.60%	94.20%
Gilani et al (2014)	APACHE II	---	0.828	$\chi 2$ = 5.419 (p= 0.712).	0.882 (cut of point = 19)	0.655 (cut of point = 19)	---	27.9%	91.40%
Godinjak et al (2017)	APACHE II	---	0.920 (0.87-0.97)	---	74.5% (cut off point =27.5)	93.4% (cut off point =27.5)	---	---	---

Godinjak et al (2017)	SAPS II	---	0.892 (0.84-0.94)	---	90.2% (cut off point =50.5)	75.7% (cut off point =50.5)	---	---	---
Gupta and Arora (2003)	APACHE II	1.65 (0.4 to 3.0)	0.63	$\chi 2$ = 10.34 (p>0.05)	---	---	Overall correct classification = 89.7% (cut off 70% decision criterion)	---	---
Haidri et al (2005)	APACHE II	---	---	---	---	---	---	---	---
Halim et al (2009)	APACHE II	---	0.694	$\chi 2$= 10.627 (p = 0.014)	0.83	0.552	0.66	0.547	0.828
Halim et al (2009)	SOFA (Initial)	---	0.732	$\chi 2$= 5.684 (p = 0.128)	0.70	0.678	0.688	0.588	0.7760
Halim et al (2009)	ModifiedSOFA (Initial)	---	0.751	$\chi 2$= 6.034 (p = 0.303)	0.75	0.678	0.708	0.606	0.808
Halim et al (2009)	ModifiedSOFA (Maximum)	---	0.901	$\chi 2$= 13.189 (p = 0.068)	0.895	0.816	0.850	0.761	0.922
Halim et al (2009)	SOFA (Maximum)	---	0.909	$\chi 2$= 5.901 (p = 0.316)	0.895	0.793	0.830	0.739	0.920

Halim et al (2009)	ModifiedSOFA (Mean)	---	0.903	---	0.772	0.897	0.847	0.83	0.86
Halim et al (2009)	SOFA (Mean)	---	0.917	---	0.789	0.908	0.861	0.849	0.868
Hamza et al (2009)	APACHE IV	1.49 (1.1-1.88)	0.845 (0.786-0.904)	H statistic $\chi2$ =5.123 (p=0.744)	---	---	---	---	---
Hamza et al (2009)	MPM II (initial)	1.01 (.86-1.16)	0.81 (0.738-0.882)	H statistic $\chi2$ =8.825 (p =0.357)	---	---	---	---	---
Hamza et al (2009)	SAPS II	0.58 (.42-1.14)	0.845 (0.787-0.903)	H statistic $\chi2$ =12.140 (p=0.145)	---	---	---	---	---
Hashmi et al (2016)	APACHE II (manual calculation)	1.00	0.823 (0.76-0.88)	$\chi2$ = 11.76(p=0.16)	51.42%	90.91%	77.9% (predicted)	73.47%	79.27%
Hashmi et al (2016)	APACHE II (automatic calculation using software)	1.00	0.827 (0.77-0.88)	$\chi2$ = 5.46(p=0.71)	55.71%	90.21%	78.87% (predicted)	73.58%	80.62%
Hernandez and Palo (2014)	SAPS 3	0.36 (0.26–0.81)	0.8 (0.78-0.81)	C statistic $\chi2$= 11.5 (p = 0.18)	---	---	---	---	---

Hosseini and Ramazani (2015)	APACHE II	---	0.857 (0.788-0.925)	$\chi 2 = 10.203$ ($p= 0.251$)	96.6%,	62.80%	79.70%	---	---
Hosseini and Ramazani (2015)	GCS (initial)	---	0.861 (0.786-0.937)	$\chi 2 = 5.177$ ($p= 0.521$)	82.8%	82.60%	82.70%	---	---
Jain et al (2016)	SOFA (initial)	---	---	---	---	---	---	---	---
Jain et al (2016)	SOFA (maximum)	---	---	---	---	---	---	---	---
Jain et al (2016)	SOFA (mean)	---	---	---	---	---	---	---	---
Juneja et al (2012)	APACHE II	0.632 (0.52-0.76)	0.894 (0.864-0.925)	$\chi 2 = 7.959$ ($p=0.438$)	74.8% (cut off point >20.5)	84.9% (cut off point >20.5)	---	---	---
Juneja et al (2012)	APACHE III	---	0.922 (0.894-0.949)	$\chi 2 = 3.674$ ($p=0.885$)	78.6% (cut off point >73)	86% (cut off point >73)	---	---	---
Juneja et al (2012)	APACHE IV	0.868 (0.714-1.044)	0.928 (0.903-0.953)	$\chi 2 = 8.790$ ($p=0.360$)	93.2% (cut off point >12.5)	66.9% (cut off point >12.5)	---	---	---
Juneja et al (2012)	SAPS II	0.536 (0.441-0.644)	0.899 (0.870-0.928)	$\chi 2 = 14.097$ ($p=0.079$)	83.5% (cut off point >47.5)	83.5% (cut off point >47.5)	---	---	---

Juneja et al (2012)	SAPS 3	0.763 (0.628-0.918)	0.901 (0.871-0.932)	$\chi 2$ = 13.123 (p=0.108)	76.7% (cut off point >56.5)	84.7% (cut off point >56.5)	---	---	---
Juneja et al (2012)	MPM II (0)	0.532 (0.438-0.64)	0.928 (0.904-0.952)	$\chi 2$ = 8.627 (p=0.375)	95.1% (cut off point >27)	68.2% (cut off point >27)	---	---	---
Juneja et al (2012)	MPM III (0)	0.794 (0.653-0.955)	0.947 (0.927-0.967)	$\chi 2$ = 13.835 (p=0.086)	94.2% (cut off point >19)	80.2% (cut off point >19)	---	---	---
Juneja et al (2012)	SOFA	---	0.893 (0.857-0.929)	$\chi 2$ = 8.369 (p=0.301)	71.8% (cut off point >7.5)	88.5% (cut off point >7.5)	---	---	---
Khan et al (2015)	SOFA (Mean 24 hours)	---	0.687 (0.572-0.803)	---	35.3% (cut off ->7.5)	0.824 (cut off ->7.5)	---	---	---
Khan et al (2015)	SAPS II	1.32 (1.23 - 1.54)	0.718 (0.608-0.828)	---	0.706 (cut off ->30)	0.608 (cut off ->30)	---	---	---
Khan et al (2015)	APACHE II	1.09 (0.97-1.21)	0.785 (0.69-0.88)	---	0.944 (cut off ->9.5)	0.49 (cut off ->9.5)	---	---	---
Khan et al (2015)	SAPS II (TM 48 hours)	1.26 (1.19-1.43)	0.871 (0.794-0.948)	---	0.706 (cut off ->30)	0.863 (cut off ->30)	---	---	---

Khan et al (2015)	SOFA (Mean 48 hours)	---	0.905 (0.844-0.966)	---	0.765 (cut off ->7.5)	0.863 (cut off ->7.5)	---	---	---
Khan et al (2015)	APACHE II (TM 48 hours)	1.09 (0.97-1.21)	0.933 (0.873-0.992)	---	0.941 (cut off ->9.5)	0.863 (cut off ->9.5)	---	---	---
Khawannimit and Geater (2007)	SAPS II	0.77 (0.69-0.86)	0.888 (0.867-0.909)	C-statistic $\chi2 = 71.44$ ($p < 0.001$) H -statistic $\chi2 = 54.01$($p < 0.001$)	0.7065 (CI 95%, 65.23-75.66)	0.89 (CI 95% (87.08-91.02)	0.85 (CI 95% 82.75-86.70)	0.73 (CI 95% 67.65-77.78)	0.9078 (CI 95% 88.81-92.52)
Khawannimit and Geater (2007)	APACHE II	0.936 (0.925-0.947)	0.911 (0.891-0.93)	C-statistic $\chi2 = 66.65$ ($p < 0.001$) H statistic $\chi2 = 66.59$ ($p < 0.001$)	0.7387 (CI 95%, 65.23-75.66)	0.92 (CI 95% (89.66-93.20)	0.87 (CI 95% 85.47-89.13)	0.73 (CI 95% 67.65-77.78)	91.92% (CI 95% 90.05-93.53)
Khwannimit and Bhurayanontachai (2011)	SAPS 3 (AUS)	0.89 (0.75-0.96)	0.917 (0.902-0.929)	C statistic $\chi2 = 170$ ($p<0.001$) H statistic $\chi2 = 79.9$ ($p<0.001$)	---	---	---	---	---
Khwannimit and Bhurayanontachai (2011)	Customised SAPS 3 (AUS)	0.98 (0.83-1.06)	0.917 (0.902-0.929)	C statistic $\chi2 = 8.2$ ($p=0.61$) H statistic	---	---	---	---	---

				χ2 = 79.9 (p<0.001)					
Khwannimit and Bhurayanontachai (2011)	SAPS II	0.914 (0.901-0.928)	0.919 (0.899-9.24)	C statistic χ2 = 124.9 (p<0.001) H statistic χ2 = 97.5 (p<0.001)	---	---	---	---	---
Khwannimit and Bhurayanontachai (2011)	Customised SAPS II	0.98 (0.83-1.06)	0.919 (0.899-9.24)	C statistic χ2 = 8.6 (p=0.57) H statistic χ2 = 9.6 (p=0.48)	---	---	---	---	---
Khwannimit and Bhurayanontachai (2011)	SAPS 3	0.81 (0.74-0.88)	0.914 (0.901-0.928)	C statistic χ2 = 176.3 (p<0.001) H statistic χ2 = 101.6 (p<0.001)	---	---	---	---	---
Khwannimit and Bhurayanontachai (2011)	APACHE II	0.8 (0.68-0.87)	0.936 (0.925-0.947)	C statistic χ2 = 104.2(p<0.001) H statistic χ2 =	---	---	---	---	---

				113.1(p<0.001)					
Khwannimit and Bhurayanontachai (2011)	Customised APACHE II	0.97 (0.82-1.05)	0.936 (0.925-0.947)	C statistic $\chi2$ = 16.1 (p=0.09) H statistic $\chi2$ = 14.1(p<0.17)	---	---	---	---	---
Kiatboonsri and Charoenpan (1995)	APACHE II	1.17	---	---	0.6 (risk level of 50%)	0.95 (risk level of 50%)	0.83 (risk level of 50%)	0.88 (risk level of 50%)	---
Liu et al (2016)	APACHE II	---	0.813 ± 0.055	---	89.6% (cut off point≥15.0)	74.8% (cut off point ≥15.0)	---	---	---
Liu et al (2016)	SOFA	---	0.779 ± 0.075	---	80.7% (cut off point =≥8.50)	72.1% (cut off point =≥8.50)	---	---	---
Mohan et al (2015)	APACHE II	---	---	---	---	---	---	---	---
Mohan et al (2015)	SAPS II	---	---	---	81.1% (cut off point >35)	59.5% (cut off point >35)	---	---	---

Mohan et al (2015)	SAPS 3	---	---	---	81.1% (cut off point >47)	51.1% (cut off point >47)	---	---	---
Mohan et al (2015)	SOFA	---	---	---	69.8% (cut off point >6)	72.3% (cut off point >6)	---	---	---
N˜ amendys-Silva et al (2013)	MexSOFA (VM 48h)	---	0.73 (0.66-0.78)	$\chi 2=3.54$ (p=0.896)	---	---	---	---	---
N˜ amendys-Silva et al (2013)	SOFA (Initial)	---	0.69 (0.62-0.74)	---	---	---	---	---	---
N˜ amendys-Silva et al (2013)	MEXSOFA (VM initial)	---	0.79 (0.72-0.86)	---	---	---	---	---	---
Nair et al (2016)	SOFA (initial)	---	0.748	---	77.8% (cut off point =9.5)	84.6% (cut off point =9.5)	83.33%	53.80%	94.30%
Nair et al (2016)	SAPS	---	0.742	---	44.4% (cut off point =61)	94.9% (cut off point =61)	85.42%	66.70%	88.10%
Naqvi et al (2016)	APACHE II	---	0.835	$\chi 2 = 3.199$ (p=0.866)	---	---	---	---	---
Naqvi et al (2016)	SOFA (initial)	---	0.75	$\chi 2 =7.679$ (p=0.362)	---	---	---	---	---
Naqvi et al (2016)	SAPS II	---	0.75	$\chi 2 = 3.724$ (p=0.811)	---	---	---	---	---

Nassar Jr, et al (2012)	APACHE IV	0.79 (0.6-0.98)	0.883 (0.874-0.891)	C statistic $\chi2 = 53.7$ ($p<0.01$)	---	---	---	---	---
Nassar Jr, et al (2012)	MPM III (initial)	0.61(0.53-0.7)	0.84 (0.83-0.849)	C statistic $\chi2 = 134.2$ ($p<0.01$)	---	---	---	---	---
Nassar Jr, et al (2012)	SAPS 3	0.46 (0.37-0.54)	0.855 (0.846-(0.864)	C statistic $\chi2 = 226.6$ ($p<0.01$)	---	---	---	---	---
Naved et al (2011)	APACHE II (TM 48 hours)	---	---	---	---	---	---	---	---
Nimgaonkar et al (2004)	ANN 22 (MTM)	---	0.87	H statistic $\chi2=22.4$ ($p<0.05$)	---	---	---	---	---
Nimgaonkar et al (2004)	ANN 15 (MTM)	---	0.88	H statistic $\chi2=27.7$ ($p<0.05$)	---	---	---	---	---
Nimgaonkar et al (2004)	APACHE II	---	0.77	H statistic $\chi2=123.5$ ($p<0.05$)	---	---	---	---	---
Nouira et al (1998)	MPM I (24h)	---	0.88	C-statistic $\chi2 = 29.59(p< 0.001)$ H statistic	---	---	---	Presented for survivors and non-survivors separately as correctly	Presented for survivors and non-survivors separately as correctly

				$\chi 2 = 19.9$ ($p < 0.05$)				predicted and wrongly predicted values	predicted and wrongly predicted values
Nouira et al (1998)	APACHE II	---	0.82	C-statistic $\chi 2 = 25.95$ ($p< 0.001$) H statistic $\chi 2 = 32.15$ ($p < 0.05$)	---	---	---	Presented for survivors and non-survivors separately as correctly predicted and wrongly predicted values	Presented for survivors and non-survivors separately as correctly predicted and wrongly predicted values
Nouira et al (1998)	MPM I (initial)	---	0.85	C-statistic $\chi 2 = 36.66$ ($p< 0.001$) H statistic $\chi 2 = 38$ ($p < 0.05$)	---	---	---	Presented for survivors and non-survivors separately as correctly predicted and wrongly predicted values	Presented for survivors and non-survivors separately as correctly predicted and wrongly predicted values
Nouira et al (1998)	SAPS II	---	0.84	C-statistic $\chi 2 = 73.78$ ($p< 0.001$) H statistic	---	---	---	Presented for survivors and non-survivors separately as correctly	Presented for survivors and non-survivors separately as correctly

				$\chi2 = 76.89$ ($p < 0.05$)				predicted and wrongly predicted values	predicted and wrongly predicted values
Ratanarat et al (2005)	SAPS I	---	0.746	---	0.702 (cut off point 15)	0.671 (cut off point 15)	---	---	---
Ratanarat et al (2005)	APACHE II	---	0.788	---	0.809 (cut off point 20)	0.632 (cut off point 20)	---	---	---
Riviello et al (2016)	MPM III (initial)	---	0.72	$\chi2 = 17.66$ (0.024)	---	---	---	---	---
Sathe and Bapat (2014)	SAPS II	0.95	0.83 (0.81-0.86)	$\chi2= 26.6$ ($p = 0.001$)	---	---	---	---	---
Sathe and Bapat (2014)	APACHE II	0.88	0.86 (0.83-0.88)	$\chi2= 12.8$ ($p = 0.03$)	---	---	---	---	---
Sekulic (2015)	MPM II (0)	---	0.654	$\chi2 =6.90$ ($p =0.548$)	85.20%	Fig	---	---	---
Sekulic (2015)	MPM II (24)	---	Fig	$\chi2 =16.23$ ($p =0.039$)	Fig	Fig	---	---	---
Sekulic (2015)	MPM II (48)	---	0.836	$\chi2 =11.37$ ($p =0.181$)	Fig	Fig	---	---	---
Sekulic (2015)	MPM II (72)	---	0.817	$\chi2 =6.04$ ($p =0.534$)	Fig	Fig	---	---	---

Sekulic (2015)	MPM II (TM 7days)	---	1.0	$\chi 2$ =0.00 (p =1.000)	100.00%	Fig	---	---	---
Sekulic (2015)	SOFA (24)	---	Fig	$\chi 2$ =13.35 (p =0.038)	Fig	Fig	---	---	---
Sekulic (2015)	SOFA (48)	---	Fig	$\chi 2$ =9.12 (p =0.332)	Fig	Fig	---	---	---
Sekulic (2015)	SOFA (72)	---	0.821	$\chi 2$ =8.83 (p =0.265)	Fig	Fig	---	---	---
Sekulic (2015)	SOFA (7d)	---	0.981	$\chi 2$ =0.85 (p =0.991)	Fig	100.00%	---	---	---
Sekulic (2015)	SAPS II	---	0.69	$\chi 2$ =4.41 (p =0.732)	Fig	Fig	---	---	---
Sekulic (2015)	APACHE II	---	0.623	$\chi 2$ =3.05 (p =0.931)	Fig	81.80%	---	---	---
Shoukat et al (2016)	APACHE IV	---	---	---	---	---	---	---	---
Shrestha et al (2012)	SOFA (Initial)	---	0.881 (0.822-0.94)	χ 2=7.140 (p=0.522)	0.91	0.6567	75.21%	70.50%	83.60%
Shrestha et al (2012)	APACHE III	---	0.895 (0.839-0.952)	χ 2=16.904 (p=0.031)	0.91	0.7397	80.34%	65.90%	90.40%
Silva Junior et al (2010)	SAPS 3	1.04 (1.03-1.07)	0.86 (0.83-0.88)	C statistic $\chi 2$ =10.47 (p = 0.234)	0.75 (cut off point = 57)	0.86 (cut off point = 57)	---	---	---

Soares and Salluh (2006)	SAPS 3 (CSA)	0.95 (0.84-1.07)	0.87 (0.85-0.9)	C statistic $\chi2$ =9.132 (p =0.33)	---	---	---	---	---
Soares and Salluh (2006)	SAPS 3	1.19 (1.04-1.37)	0.87 (0.85-0.9)	C statistic $\chi2$ =13.637 (p =0.092)	---	---	---	---	---
Soares and Salluh (2006)	SAPS II	1.28 (1.11-1.47)	0.88 (0.86-0.9)	C statistic $\chi2$ = 32.136 (p < 0.001)	---	---	---	---	---
Soares et al (2004)	SAPS II	1.17 (1.03-1.34)	0.916 (0.899-0.933)	H statistic $\chi2$= 29.400 (p<0.001)	---	---	---	---	---
Soares et al (2004)	APACHE II	1.41 (1.22-1.62)	0.888 (0.868 - 0.907)	H statistic $\chi2$= 78.181(p<0.001)	---	---	---	---	---
Soares et al (2004)	MPM II (24h)	1.5 (1.3-1.73)	0.909 (0.891-0.926)	H statistic $\chi2$= 114.713 (p<0.001)	---	---	---	---	---
Soares et al (2004)	APACHE III	1.41 (1.22-1.62)	0.915 (0.898-0.933)	H statistic $\chi2$= 117.206 (p<0.001)	---	---	---	---	---
Soares et al (2004)	MPM II (initial)	2.12 (1.8-2.5)	0.854 (0.83-0.878)	H statistic $\chi2$= 373.317 (p<0.001)	---	---	---	---	---

Soares et al (2010)	SAPS 3 (CSA)	1.02 (0.87-1.19)	0.84 (0.81-0.87)	C statistic $\chi2 = 12.608$ (p=0.126)	---	---	---	---	---
Soares et al (2010)	MPM III (24hours)	3.41 (2.63-4.41)	0.71 (0.67-0.75)	C statistic $\chi2 = 14.242$ (p=0.076)	---	---	---	---	---
Soares et al (2010)	SAPS 3	1.29 (1.09-1.53)	0.84 (0.81-0.87)	C statistic $\chi2 = 15.804$ (p=0.045)	---	---	---	---	---
Soares et al (2010)	SAPS II	1.49 (1.24-1.79)	0.84 (0.81-0.87)	C statistic $\chi2 = 21.143$ (p=0.007)	---	---	---	---	---
Sutheechet (2009)	MPM II (24h)	0.89 (0.78-1.01)	0.91 (0.88-0.93)	C statistic $\chi2 = 14.45$ (p=0.07)	Individual values for each risk level	Individual values for each risk level	Individual values for each risk level	Individual values for each risk level	Individual values for each risk level
Sutheechet (2009)	SAPS II	0.83 (0.74-0.92)	0.88 (0.85-0.91)	C statistic $\chi2 = 20.65$ (p=0.008)	Individual values for each risk level	Individual values for each risk level	Individual values for each risk level	Individual values for each risk level	Individual values for each risk level
Teoh et al (1997)	APACHE II	---	---	---	---	---	---	---	---
Turner et al (1989)	APACHE II	---	---	---	---	---	---	---	---
Turner et al (1989)	TISS	---	---	---	---	---	---	---	---

Wilairatana et al (1995)	APACHE III	---	0.694	---	0.798 (cut off point =60)	0.66 (cut off point =60)	72.4%	---	---
Wilairatana et al (1995)	TISS	---	0.7	---	0.742 (cut off point = 20)	0.6 (cut off point = 20)	68.4%	---	---
Wilairatana et al (1995)	SAPS II	---	0.71	---	0.742 (cut off point = 14)	0.6 (cut off point = 14)	68.40%	---	---
Wilairatana et al (1995)	APACHE II	---	0.723	---	0.774 (cut off point =19)	0.611 (cut off point =19)	70.8%	---	---
XueZhong et al (2015)	APACHE II	0.72	0.863 (0.804-0.923)	$\chi 2$ =3.486 (p =0.900)	---	---	---	---	---
XueZhong et al (2015)	APACHE IV	1.17	0.873 (0.813-0.934)	$\chi 2$ =3.756 (p =0.878)	---	---	---	---	---
XueZhong et al (2015)	SAPS 3	1.5	0.948 (0.914-0.982)	$\chi 2$ =4.987 (p =0.759)	---	---	---	---	---
Yamin et al (2011)	APACHE IV	1.09	---	---	---		62.10%	---	---
Yousef and Suliman (2013)	SOFA (Mean)	---	---	---	---	0.88	98.50%	72.40%	100%
Zhao et al (2013)	GCS (initial)	---	0.667 (0.636-0.698)	$\chi 2$ = 11.226 (p=0.189)	71%	65%	78.10%	---	---

Zhao et al (2013)	GCS (24h)	---	0.718 (0.688-0.748)	χ2 = 8.442 (p=0.392)	71%	65%	79.00%	---	---
Zhao et al (2013)	GCS (48h)	---	0.719 (0.686-0.751)	χ2 = 9.641 (p=0.291)	71%	65%	81.50%	---	---
Zhao et al (2013)	GCS (72h)	---	0.727 (0.692-0.762)	χ2 = 8.341 (p=0.401)	71%	65%	83.70%	---	---
Zhao et al (2013)	SAPS II (initial)	---	0.776 (0.75-0.802)	χ2 = 8.332 (p=0.402)	85%	74.30%	80.00%	---	---
Zhao et al (2013)	SAPS II (TM 48 hours)	---	0.821 (0.795-0.848)	χ2 = 11.294 (p=0.186)	85%	74.30%	83.80%	---	---
Zhao et al (2013)	SAPS II (24h)	---	0.826 (0.803-0.85)	χ2 = 12.176 (p=0.144)	85%	74.30%	82.40%	---	---
Zhao et al (2013)	SAPS II (TM 72 hours)	---	0.859 (0.833-0.885)	χ2 = 9.169 (p=0.328)	85%	74.30%	86.70%	---	---
Zhao et al (2013)	Simplified SAPS II (VM)	---	---	---	---	---	---	---	---

Supplementary Figure 4.1.5 Model performance when AUROC was not reported

Study	Model	Performance
Abhinandan and Vedavathi (2013)	APACHE II	Student t-test
Abhinandan and Vedavathi (2013)	SOFA	
Abhinandan and Vedavathi (2013)	GSC	
Celik et al (2014)	SAPS II	Student t-test The mean SAPS II score of the patients who died (59.37±16.50) was significantly higher than the patients who were discharged (33.70±13.90) from hospital (t=18.85, p=0.000).
Haidri et al (2005)	APACHE II	Comparison of means between those who survived and those who died The mean 24 hours APACHE II score discharged -18.93 ± 7.19 died -22.33 ± 7.80
Jain et al (2016)	SOFA (initial)	
Jain et al (2016)	SOFA (maximum)	
Jain et al (2016)	SOFA (mean)	
Kiatboonsri (1995)	APACHE II	At risk level 50% - Sensitivity -60%, Specificity = 95%, Accuracy -83%,PPV - 88%
Mohan et al (2015)	APACHE II	

Mohan et al (2015)	SAPS II	
Mohan et al (2015)	SAPS 3	
Mohan et al (2015)	SOFA	
Naved et al (2011)	APACHE II (48 hours)	Chi square test Significant relationship between outcome and APACHE-II score ($\chi 2 = 58.7$, $p=0.001$))
Shoukat et al (2016)	APACHE IV	
Teoh et al (1997)	APACHE II	The APACHE II scores were correlated with hospital mortality (bar graph). Mortality was higher with a higher APACHE II score. There were no deaths in the 0-4 APACHE n score group. In the higher ranges of APACHE IT score of 30 onwards, there was a 100% mortality except for APACHE n score of 45-49 for which there were no admissions within this group.
Turner et al (1989)	APACHE II	The APACHE II scores were correlated with hospital mortality (bar graphs plotted)
Turner et al (1989)	TISS	The APACHE II scores were correlated with hospital mortality (bar graphs plotted)
Yamin et al (2011)	APACHE IV	Accuracy - 62.1%
Yousef (2013)	SOFA	Specificity = 88.4% (cut off >9), Accuracy -98.5%, PPV - 72.4%, NPV - 100%
Zhao et al (2013)	SAPS II	A correlation was suggested between the simplified SAPS II score at each time point and outcome with OR of 1.109 (P=0.000), regardless of the diagnosis.

Supplementary Table 4.1.6 Comparison of AUROC between modified and original models

Study	Discrimination	
	Original scoring system	**Modified scoring system**
First level customisation		
Khwannimit and Bhurayanontachai (2011)	0.913 (0.899-0.924) SAPS 3 (AUS) (entire population n=2022)	0.917 (0.897-0.937) Customised SAPS 3 (AUS) (validation data set n=1011)
Khwannimit and Bhurayanontachai (2011)	0.914 (0.901-0.928) SAPS II (entire population n=2022)	0.919 (0.9-0.938) Customised SAPS II (validation data set n=1011)
Khwannimit and Bhurayanontachai (2011)	0.936 (0.925-0.947) APACHE II (entire population n=2022)	0.936 (0.925-0.947) Customised APACHE II (validation data set n=1011)
Variable modification		
Namendys et al (2013)	0.69 (95%CI = 0.62-0.74) SOFA at admission	0.73 (95%CI = 0.66-0.78) MEXSOFA at admssion 0.79 (95%CI = 0.72-0.86) MEXSOFA at 48 hours
Temporal modification		
Khan et al (2015)	0.785 (CI 95% -0.690 -0.880) APACHE II at 24 hours	0.933 (CI 95% -0.873 -0.992) APACHE II at 48 hours

Khan et al (2015)	0.718 (CI 95% -0.608 -0.828) SAPS II at 24 hours	0.871 (CI 95% -0.794 -0.948) SAPS II at 48 hours
Sekulic et al (2015)	0.654 MPM II (0) Fig MPM II (24) 0.836 MPM II (48) 0.817 MPM II (72)	1.0 MPM II at 7days
Zhao et al (2013)	0.776 (95% CI 0.750–0.802) SAPS II at admission 0.826 (95% CI 0.803–0.850) SAPS II at 24 hours	0.821 (95% CI 0.795–0.848) SAPS II at 48 hours 0.859 (95% CI 0.833–0.885) SAPS II at 72 hours
Modelling technique modification		
Hashmi et al (2016)	0.823 (0.76-0.88) APACHE II (manual calculation)	0.827 (0.77-0.88) APACHE II (software calculation)
Nimgaonkar et al (2004)	0.77 APACHE II in the first 24 hours	0.87 (p<0.002) ANN 22 0.88 (p<0.001) ANN 15

Supplementary Table 4.1.7 Calibration vs. AUROC

AUROC	Good calibration number	Good calibration percentage %	Poor calibration number	Poor calibration percentage%	Not reported number	Not reported percentage%	Total
Excellent	13	50.0%	9	34.6%	4	15.4%	26
Very good	29	54.7%	19	35.8%	5	9.4%	53
Good	13	38.2%	6	17.6%	15	44.1%	34
Moderate	7	46.7%	3	20.0%	5	33.3%	15
Poor	1	100.0%	0	0.0%	0	0.0%	1
Not reported	2	7.4%	1	3.7%	24	88.9%	27
Total							156

Supplementary Table 5.1.8 Description and results of new model development

Study	Ahluwalia et al (1999)	Riviello et al (2016)	Riviello et al (2016) 2	Turner et al (1989)
Model	New score	MPM III (R-MPM)	MPM III (Simplified R-MPM)	Organ failure score
Source	Prospective cohort	Prospective	Prospective	Prospective cohort

Participants	Consecutive admissions(>13years) to 8 bedded medical ICU, India inclusion period NR.	Consecutive patients (>15 years) admitted to 2 ICUs in different hospitals Exclusion criteria - Not specified August 2013 to October 2014	Consecutive patients (>15 years) admitted to 2 ICUs in different hospitals Exclusion criteria - Not specified August 2013 to October 2014	All patients admitted from all departments to the Respiratory Intensive Care Unit (RICU), teaching hospital, South Africa Exclusion - primary cardiac disease (usually admitted to a specialised coronary care unit) 1985 and 1986
Outcomes	Hospital mortality	Hospital mortality	Hospital mortality	Mortality (Not specified)
Predictors	1. pH (at admission) 2. serum albumin (at admission) 3. heart rate (at 48 hours) 4. GCS (at 48 hours) 5. bilirubin (at 48 hours)	Only the following 5 variables were included: 1. Age 2.Confirmed or suspected infection within 24 hours of ICU admission 3. Hypotension or shock as a reason for ICU admission 4. Heart rate at ICU admission 5. GSC at time of admission	Altered mental status on ICU admission (present versus not present) was used in place of the GCS score in the R-MPM (see previous).	1. Renal - Creatinine> 150 I'mol/l 2. Cardio vascular -Systolic blood pressure < 80 mmHg (or requiring inotropes to maintain blood pressure) with adequate volume replacement 3. Respiratory - Requiring IPPV or Pao2 < 15 kPa on Fio2 0,5 4. CNS - Unconscious (no response to verbal command in absence of sedation) 5. Hepatic - Bilirubin or liver enzymes> twice normal 6. Haematological - Platelets < 50 x 109 /1 or white cell count 20 190

Sample size	79 (Participant age range -13 to 80, mean = 46)	427 Participant age range 34years (IQR 25–47) (Median)	427 Participant age range 34years (IQR 25–47) (Median)	728 (Participant age range 12 to 88, mean =43)
Missing data	Not reported	Normal values for attributed as in original study. 2 patients excluded due to lack of discharge status	Normal values for attributed as in original study. 2 patients excluded due to lack of discharge status	Not mentioned
Model development	Based on APACHE II (Knaus et al 1985) and 11 other clinical and laboratory parameters. Backward step method was used to remove non-significant (p>0.05) variables (of univariate analysis)	Based on the 16 MPM III (initial) and additional variables. Variables for inclusion in model selected from the univariate analyses, based on their predictive power (as determined by a p value< 0.05) as well as their ease of capture based on experience, the proportion of missing values in the dataset, and their clinical significance.	Based on the 16 MPM III (initial) and additional variables. Variables for inclusion in model selected from the univariate analyses, based on their predictive power (as determined by a p value< 0.05) as well as their ease of capture based on experience, the proportion of missing values in the dataset, and their clinical significance.	Definition of Organ Failure: Renal - Creatinine> 150 l'mol/l Cardiovascular - Systolic blood pressure < 80 mmHg (or requiring inotropes to maintain blood pressure) with adequate volume replacement Respiratory -Requiring IPPV or Pao2 < 15 kPa on Fio2 0,5 CNS - Unconscious (no response to verbal command in absence of sedation) Hepatic - Bilirubin or liver enzymes> twice normal Haematological -Platelets < 50 x 109 /1 or white cell count <2xl09/1

Model performance	Discrimination measured in terms of AUROC, sensitivity and specificity. Multivariate and univariate regression.	Discrimination measured in terms of AUROC Multivariate and univariate regression.	Discrimination measured in terms of AUROC. Multivariate and univariate regression.	Summary statistics only. Comparison of mean scores and percentage mortality.
Model evaluation	Developmental dataset only- no further evaluation. (compared with APACHE II at 48 hours)	Internal validation with bootstrapping. (compared with MPM III (initial))	Internal validation with bootstrapping. (compared with MPM III (initial))	Developmental dataset only- no further evaluation. (compared with apache II and TISS)
Results	New score ROC - 0.90 Sensitivity - 98.2% Specificity - 66.6% APACHE II (after 48h) ROC -0.74 Sensitivity - 92.8% Specificity - 23.6%	Rwanda MPM (R-MPM) AUROC- 0.81 (0.77- 0.86) Calibration- $\chi 2 = 11.94 (p=0.154)$ MPM III (initial) AUROC - 0.72 Calibration - $\chi 2 = 17.66 (0.024)$	Simplified R-MPM AUROC- 0.76 Calibration- $\chi 2 = 11.46 (p=0.177)$ MPM III (initial) AUROC - 0.72 Calibration - $\chi 2 = 17.66 (0.024)$	Organ failure score The organ failure score showed the best relation between increase in score and mortality The APACHE 11 system is likely to be the most useful in comparing different therapies and intensive care units, while the organ failure system was more accurate in predicting outcome.

Appendix B – Supplementary files

Supplementary file 3.1.1 ICU survey form

ICU survey form

Record ID _____

ICU name _____

Name of the person providing information _____

Designation
- ○ Sister in charge
- ○ Nursing in charge
- ○ Nurse

General information of the ICU

What Type of patients admitted to the unit ?

General Surgical
- ○ Yes
- ○ No

Medical
- ○ Yes
- ○ No

Pediatric
- ○ Yes
- ○ No

Gyn & Obs
- ○ Yes
- ○ No

Coronary care
- ○ Yes
- ○ No

Cardiothoracic
- ○ Yes
- ○ No

Neurosurgical
- ○ Yes
- ○ No

Trauma/Emergency
- ○ Yes
- ○ No

Transplant
- ○ Yes
- ○ No

Other frequent admissions _____

No of total beds in the unit _____

No of beds currently closed _____

Total admissions 2016 _____

Total deaths 2016 _____

Model of care

ICU has access to multiple doctors who are free to admit and manage their patients (open unit)	○ Yes ○ No
Admission, discharge and referral policies are under the control of consultant of ICU only. (closed unit)	○ Yes ○ No

Source of admission

Patients are admitted from the wards in the hospital (Internal)	○ Yes ○ No
Patients are admitted from any of the hospital in the country (External)	○ Yes ○ No
ICU beds can be booked for a later date (Booked)	○ Yes ○ No
Admissions can be done without prior booking as an emergency	○ Yes ○ No
Admissions can be done without prior booking directly from ward	○ Yes ○ No
Admissions can be done without prior booking directly from OPD	○ Yes ○ No

Specialist staff

Besides the 24 hr in house medical staff of the ICU, which of the following doctors are available on call basis.

Anaesthesiologist	◯ Yes ◯ No
General physician	◯ Yes ◯ No
General surgeon	◯ Yes ◯ No
Neurosurgeon	◯ Yes ◯ No
Obstetric-gynaecologic	◯ Yes ◯ No
Cardiothorasic surgeon	◯ Yes ◯ No
Cardiologist	◯ Yes ◯ No
Nephrologist	◯ Yes ◯ No
Gastroenterologist (emergency Endoscopies)	◯ Yes ◯ No
Neurologist	◯ Yes ◯ No
Microbiologist	◯ Yes ◯ No
Respiratory disease Specialist	◯ Yes ◯ No
Urologic surgeon	◯ Yes ◯ No
Haematologist	◯ Yes ◯ No
Pathologist	◯ Yes ◯ No
Orthopaedic surgeon	◯ Yes ◯ No
Paediatrician	◯ Yes ◯ No

ICU staff

Nursing in charge of the ICU

Who is the in charge of the ICU	◯ Nursing Sister ◯ Nursing in charge
In charge of the ICU specially trained in intensive care nursing	◯ Yes ◯ No

Consultant in charge of the ICU(ICU Consultant)

Is the consultant in overall charge of the ICU an Anaesthetist	◯ Yes ◯ No
If not what is their specialty	_____
Minimum Frequency of ward rounds done by the medical officer in charge (cons.) per day (1, 2, 3)	_____

Minimum Frequency of ward rounds done by the medical officer in charge (cons) per week.

Week days	_____
Saturday	_____
Sunday	_____
Is the cons. On call available 24/7 over the phone	◯ Yes ◯ No
If not who can be contacted	_____

In house Medical officers of the ICU

Total No. of Doctors in the unit	_____
Minimum No. of ICU allocated Doctors in Day time(morning and evening)	_____
Minimum No. of ICU allocated Doctors in Night time	_____
Documented daily night time ward rounds done by doctors	◯ Yes ◯ No
Number participated in special ICU training	_____ ((Should be asked from the doctors in the unit at that time))
Do they participate in continuing professional development (CPD)	◯ Yes ◯ No ((Annual Scientific Session, outside lecture, Workshop, Symposium, Training programme))
If yes when was the last training attended	_____
If yes how many participate during last training	_____

Nursing staff of the ICU

Total no. of nurses in the unit _____

Number of nurses per shift: (when beds are full)

Morning (Minimum number) _____ (7am - 1pm)

Morning (Maximum number) _____ (7am - 1pm)

Evening (minimum number) _____ (1pm - 7pm)

Evening (maximum number) _____ (1pm - 7pm)

Night (minimum number) _____ (7pm - 7am)

Night (maximum number) _____ (7pm - 7am)

Number of nurse needed to run ICU at one shift. (I.e. in the opinion of the sister in charge, the number of nurses needed to run the unit safely when all beds are full)

Morning _____

Evening _____

Night _____

Nurse/patient ratio ○ 1:1 ○ 1:2 ○ 1:3 ○ other

If other, specify _____

Number of nurses participated in ICU training

Formal training:(specialized unit three months training conducted by ministry) _____

Informal training: (same unit, near by hospital units etc..) _____

Do they participate in continuing training (CPD) (Classes on Resuscitation etc.....) ○ Yes ○ No

If yes when was the last training attended _____

If yes how many participate during last training _____

Total no of HCAs / Trained labourers in the unit _____

Minimum Number of HCAs/Labours during day shift _____

Minimum Number of HCAs/Labours during night shift _____

Do HCA participate in continuing training (CPD) ◯ Yes ◯ No

If yes when was the last training attended _____

If yes how many participate during last training _____

Number of nurses who have participated in disaster management training _____

Physiotherapist:

A dedicated physiotherapist available ◯ Yes ◯ No

ECG Technician:

Available ◯ Yes ◯ No

On 24 h basis ◯ Yes ◯ No

Only in day time ◯ Yes ◯ No

Radiology technicians for portable X ray

Available ◯ Yes ◯ No

Around the clock ◯ Yes ◯ No

Only day time ◯ Yes ◯ No

Dietician / Diet clerk:

Available during working hours ◯ Yes ◯ No

Religious leader

Available ◯ Yes ◯ No

Around the clock ◯ Yes ◯ No

Only day time ◯ Yes ◯ No

Social Worker

Available	◯ Yes ◯ No
Around the clock	◯ Yes ◯ No
Only day time	◯ Yes ◯ No

ICU allocated cleaning staff

Cleaning staff allocated to ICU	◯ Yes ◯ No
Around the clock	◯ Yes ◯ No
Only day time	◯ Yes ◯ No

What would be done in case of fault of a medical equipment

Bio medical technician available in the unit	◯ Yes ◯ No
Bio engineering division available in the hospital	◯ Yes ◯ No

ICU Design and facilities

Shape of the ICU	◯ U shaped ◯ X shaped ◯ line shaped ◯ other
Two doors	◯ Yes ◯ No
Air locked	◯ Yes ◯ No
Controlled access	◯ Yes ◯ No
Air conditioning	◯ Yes ◯ No
Frequent breakdown	◯ Yes ◯ No

Priority horizontal access from:

Accident & Emergency Department	◯ Yes ◯ No
Operating Theatre	◯ Yes ◯ No
Laboratory	◯ Yes ◯ No
Casualty	◯ Yes ◯ No
Labour room	◯ Yes ◯ No
Recovery Room	◯ Yes ◯ No

Patient area

Patients area is divided into	◯ Cubicles ◯ Separate rooms ◯ Curtained off ◯ Not divided

Visiting

When can patient's family visit the ICU? please mention vising hours	_____
Is there a relative area?	◯ Yes ◯ No

Sockets and service outlets

Electric power source per bed	◯ Yes ◯ No
If not each for bed, how many are total?	_____
Vacuum per bed	
Wall suction	◯ Yes ◯ No
If not each for bed, how many are total?	_____
Sucker machines	◯ Yes ◯ No
If not each for bed, how many are total?	_____
Oxygen per bed (cylinder)	◯ Yes ◯ No
If not each for bed, how many are total?	_____
Compressed air per bed (tubing)	◯ Yes ◯ No
If not each for bed, how many are total?	_____
Airway maintenance material Per bed	◯ Yes ◯ No
If not each for bed, how many are total?	_____
Monitor per bed	◯ Yes ◯ No
If not each for bed, how many are total?	_____
Infusion pump per bed	◯ Yes ◯ No
Syringe pump per bed (brand)	◯ Yes ◯ No
Ventilator per bed	◯ Yes ◯ No
If not ventilator per bed, number of ventilators in total	_____
Paediatric ventilators / Paediatric mode per bed	◯ Yes ◯ No

Water supply

No of sinks in patient area for hand washing	_____
Elbow/foot operated taps	◯ Yes ◯ No
Soap	◯ Yes ◯ No
Disinfectant (hibiscrub)	◯ Yes ◯ No
Hand disinfection facility at each bed side (Hand scrub)	◯ Yes ◯ No
Hand-drying facilitie	◯ paper towels ◯ hand dryer ◯ cloth ◯ none ◯ other

Monitoring

At bedside: Visual alarm	◯ Yes ◯ No
Audio alarm and audible alarms at each bed side (Monitor alarm and indicating lights working properly)	◯ Yes ◯ No
At nurses station Visual alarm visible	◯ Yes ◯ No
Audio alarm visible (Integrated monitor system present)	◯ Yes ◯ No
Unobstructed comfortable viewing from nursing station	◯ Yes ◯ No

Is the following monitoring present at each bed side (If no, for each how many beds have it)

ECG monitoring per bed	◯ Yes ◯ No
If not per bed how many?	_____
Invasive Arterial pressure per bed	◯ Yes ◯ No
If not per bed how many?	_____
Central venous pressure per bed	◯ Yes ◯ No
If not per bed how many?	_____
Central venous pressure type	◯ Manual ◯ Electronic ◯ Both)
Temperature per bed	◯ Yes ◯ No
If not per bed how many?	_____

Temperature measure type	◯ Mercury ◯ Digital ◯ Tympanic ◯ Forehead ◯ Rectal
If not per bed how many?	_____
Pulse Oxymetry per bed	◯ Yes ◯ No
If not per bed how many?	_____
Non-invasive blood pressure monitoring per bed	◯ Yes ◯ No
If not per bed how many?	_____
End tidal CO2 monitoring per bed (capnography)	◯ Yes ◯ No
If not per bed how many?	_____
Cardiac output monitoring per bed	◯ Yes ◯ No
If not per bed how many?	_____
If yes what is the method	_____

For the whole unit

12 lead ECG available 24/7 within the unit	◯ Yes ◯ No
USS machine available 24/7 in the unit	◯ Yes ◯ No
Echo machine available 24/7 on the unit	◯ Yes ◯ No
Bronchoscope accessible 24/7	◯ Yes ◯ No
Difficult or specialized airway trolley available in unit	◯ Yes ◯ No
Blood gas machine available 24/7 in the unit	◯ Yes ◯ No
If yes; how many	_____
If yes; does it measure Hb	_____
If yes does it measure lactate	_____

Central nursing station

Computer terminals (integrated computer for patients monitoring)	◯ Yes ◯ No
Telephone	◯ Yes ◯ No
If yes,	◯ Direct ◯ Intercom
If direct, provided by	☐ NICS ☐ Hospital
Internet	◯ Yes ◯ No

Internet given by	☐ Hospital ☐ NICS ☐ Staff ☐ Other
Emergency call system (To call the staff in an emergency)	◯ Yes ◯ No
Hand washing	◯ Yes ◯ No
Drug preparation area	◯ Yes ◯ No

Utility

Clean utility room / cupboard within the unit	◯ Yes ◯ No
Dirty utility room with separate way out with in the unit	◯ Yes ◯ No

Electricity back up

All ventilators have backup battery	◯ Yes ◯ No
If no how many of each is present	_____
All monitors have backup battery	◯ Yes ◯ No
If no how many of each is present	_____
All infusion pumps backup battery	◯ Yes ◯ No
If no how many of each is present	_____
All syringe pumps have backup battery	_____
If no how many of each is present	_____
Backup generator (Hospital/Unit)	◯ Yes ◯ No
If no how many of each is present	_____
Does it kick in automatically	◯ Yes ◯ No
How many times did the unit experience a power cut in the last month	◯ none ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 ◯ more.

Clinical investigation reporting and documentation

Bedside patient observations	◯ Electronic ◯ Paper printouts ◯ Hand writing
Laboratory results	◯ Electronic ◯ Paper printouts ◯ Hand writing
Microbiology reports	◯ Electronic ◯ Paper printouts ◯ Hand writing

ABG results	◯ Electronic ◯ Paper printouts ◯ Hand writing
Radiology (CXR)	◯ Electronic ◯ Paper printouts ◯ Hand writing
Radiology (CT/ MRI scans)	◯ Electronic ◯ Paper printouts ◯ Hand writing
nursing documentation	◯ Electronic ◯ Paper printouts ◯ Hand writing
doctors documentation	◯ Electronic ◯ Paper printouts ◯ Hand writing
Other clinical staff notes (dieticians/ physiotherapist)	◯ Electronic ◯ Paper printouts ◯ Hand writing
Surgical / operation reports	◯ Electronic ◯ Paper printouts ◯ Hand writing
Is there separate documents for nursing and medical documentation?	◯ Yes ◯ No

Supply of sterile material

From CSSD in the hospital	◯ Yes ◯ No
If no how you get it?	_____
Have sterilization facility inside the unit	◯ Yes ◯ No
if yes what are the methods available and what equipments are sterilized	_____

Following supplies are available for the staff in adequate amount during last 1 month period

Clothing (Gowns)	◯ Yes ◯ No
Masks	◯ Yes ◯ No
Gloves	◯ Yes ◯ No
Boots/slippers	◯ Yes ◯ No
Is there any availability of staff respirator masks for Pandemic/ respiratory disease outbreak?	◯ Yes ◯ No
How many times the unit was closed during past I YEAR?	_____
What were reason for that?	_____

Clinical Waste management

Which of the following are available in supply?	☐ sharps bin ☐ Clinical waste bins ☐ General waste
Are these being cleaned regularly?	☐ sharps bin ☐ Clinical waste bins ☐ General waste

Planning

Does the unit have a policy for pandemic/ epidemic	◯ Yes ◯ No (please show this)
Does the unit have a policy for disaster managemnt?	◯ Yes ◯ No

Supplementary File 4.7.1 ICU experiences survey form

Demographic data

1. I am

I. Male	
II. Female	

2.Date of birth	Year

Consciousness

3. Do you remember your admission to hospital?

I. Yes	
II. No	

4. Do you remember your admission to the Intensive Care Unit (ICU)?

I. Yes	
II. No	

5. What do you think regarding the memory of your ICU stay?

I. I prefer not to remember	
II. I don't remember anything	
III. I don't mind to remember	
IV. I want to remember everything	
V. None of them	

Previous admission

6. Have you been previously admitted in an ICU?

I. Once for the same reason	
II. Twice or more for the same reason	
III. Once for a different reason	
IV. Never been admitted in an ICU	

The ICU

7. How do you describe the environment in the ICU?

I.	Friendly and calm	
II.	Confused and frightening	
III.	Unfriendly and tense	
IV.	I don´t remember	

The waiting room

8. Was a waiting room available in the ICU?

I. Yes	
II. No	

Experiences

9. How do you classify your sleep during ICU stay?

I.	Excessive	
II.	Sufficient and restoring	
III.	Insufficient	

10. How difficult to tolerate were the following experiences / procedures in the ICU?

0 - I don’t remember

1 - It was not hard

2 - It was indifferent

3 - It was hard, but it had to be

4 - It was very hard

5 - It was awful

a. Daily needle punctures	
b. Nose tube	
c. Bladder tube	
d. Noise from conversation	
e. Noise from machines and ventilators	
f. Pain	
g. Being limited to bed	
h. Music in the ICU	

i. Comments from doctors and nurses

j. Noisy and bad sleeping nights

k. Ventilator dependence

l. Doctors and nurses dependence

m. Lack of privacy in hygiene

n. Communication difficulties

o. Brightness from artificial lights

p. Fear of dying, uncertainty in the future

q. General discomfort

r. Fear of being disconnected from the ventilator

s. Medical rounds near the patient's bed

t. Fear of medical procedures

u. Loosing time orientation

v. Family worries

x. Economic worries

11. Have you had any dreams during ICU stay

I. Yes

II. No

12. If yes how frequently did they occur

I. Daily

II. Twice a week

III. Other, specify:……

13. Have you had any nightmares during ICU stay

I. Yes

II. No

14. If yes how frequently did they occur

I. Daily

II. Twice a week

III. Other, specify:……

Satisfaction with care

Concerns & caring

15. The courtesy, respect and compassion given by nurses was

I. Excellent	
II. Very good	
III. Good	
IV. Fair	
V. Poor	
VI. N/A	

16. The courtesy, respect and compassion given by doctors was

I. Excellent	
II. Very good	
III. Good	
IV. Fair	
V. Poor	
VI. N/A	

Symptom management

17. How well the ICU staff treated your symptoms

Pain

I. Excellent	
II. Very good	
III. Good	
IV. Fair	
V. Poor	
VI. N/A	

Breathlessness

I. Excellent	
II. Very good	

III. Good

IV. Fair

V. Poor

VI. N/A

Agitation

I. Excellent

II. Very good

III. Good

IV. Fair

V. Poor

VI. N/A

Team work

coordination of care

18. The team work of all the ICU staff who take care of you

I. Excellent

II. Very good

III. Good

IV. Fair

V. Poor

VI. N/A

Nurses

Skill & competence of ICU nurses

19. How well the nurses cared for you

I. Excellent

II. Very good

III. Good

IV. Fair

V. Poor

VI. N/A

Doctors

Skill & competence of ICU doctors

20. How well the doctors cared for you

I. Excellent	
II. Very good	
III. Good	
IV. Fair	
V. Poor	
VI. N/A	

Level of health care

21. How satisfied were you with the level of health care received in the ICU

I. Very dissatisfied

II. Slightly dissatisfied

III. Slightly satisfied

IV. Mostly satisfied

V. Very satisfied

22. Do you have any suggestions on how to make care provided in the ICU better?

……
……
……

23. Do you have any comments on thing ICU staff did well?

……
……
……

24. Please add any comments or suggestions that you feel may be helpful to the staff of this ICU.

……
……
……

Supplement 5.2.1 Description of training program

The training program across all three sites consisting of 6 modules commenced in April 2010 and continued till January 2012 as indicated in table 1, below.

Table 1: Timeline of the training program in Rourkela, Chittagong and Patan

Module	Time	Rourkela	Chittagong	Patan
1	**April/May 2010**	Basic care for critically ill		
2	**September 2010**	Care on admissions and emergencies	Care beyond the initial phase	Shock and its treatment
3	**January 2011**	Shock and its treatment	Care on admissions and emergencies	Feeding, glucose control and monitoring
4	**May 2011**	Feeding, glucose control and monitoring	Shock and its treatment	Care beyond the initial phase
5	**September 2011**	Care beyond the initial phase	Feeding, glucose control and monitoring	Care on admissions and emergencies
6	**January 2012**	Recap of above modules and tackling of any remaining issues		

Each module was led by an experienced intensivist and nurse from the UK, US, Belgium and the Netherlands. The list of trainers and their affiliations is listed at the end of this supplement. Each module lasted between two and three weeks with the trainers being on site and working as a team throughout this period.

The material and methods used for each training module were not tightly controlled. The trainers were provided with the main components of each module and allowed shared use of the material developed by other trainers. The main components of each teaching module the training team were requested to focus were as follows:

Module 1--- basic care for critically ill

- ward rounds and handover for doctors and nurses
- airway management and mechanical ventilation
- source control and treatment of infection

Module 2 - Care on admissions and emergencies

- admission protocols and policies
- teamwork in managing emergency situations
- fluid management and resuscitation

Module 3 -Care beyond the initial (admission) phase

- use of sedation and paralysis
- care of the unconscious critically ill patient
- pain and delirium management

Module 4 - Shock and its treatment

- cardiovascular monitoring of the shock patient
- use of inotropes and vasopressor drugs
- reassessment and targets for resuscitation

Module 5 - Feeding, glucose control and monitoring (use of tests/imaging)

- feeding – timing, route and benefits
- glucose control
- Use of tests and imaging for monitoring critically ill patient

Module 6 - Recap of above modules and tackling any remaining issues

A stepwise approach to implementation of therapy or strategies was utilised as follows for each module:

- **A brief situational analysis and environmental scan focusing on the therapy or strategy of interest** – assessment of current practice and knowledge regarding the specific therapy or strategy, and identification of benefits or risks
- **Identification of fears, barriers and facilitators for the therapy or strategy of interest** – fears and barriers identified and rationalized; facilitators identified who can be used to further implementation process
- **Development of local guidelines on the therapy or strategy of interest** – appropriate guidelines developed in collaboration with the local team and reviewed several times until all caregivers involved in the performance understand all parts
- **Application of the guidelines on the therapy or strategy of interest** – encourage use of the guidelines guided by peers, who were involved in the development of the guidelines

When appropriate, as in the treatment of shock, local staff in collaboration with the trainers were encouraged to produce locally adapted treatment guidelines, for instance on severe sepsis management (see supplement 2, below).

The following is an example of topics addressed at the bedside by one team to train the local doctors and nurses on mechanical ventilation:

- recognize respiratory failure
- determine the cause of respiratory failure
- recognition of effective and ineffective ventilation
- initiate mechanical ventilation by setting the ventilator
- clearing the airway and bag–squeezing
- guiding mechanical ventilation – management of CO2 removal (minute ventilation), management of oxygenation (PEEP, recruitment), timing of change form mandatory to spontaneous breathing
- understand the role of mechanical ventilation in lung injury
- lung protective mechanical ventilation and recognition of associated complications
- recognize problems with mechanical ventilation through airway pressure tracings
- monitoring a patient during weaning and interpretation of weaning parameters

A breakdown of a typical training day is as follows:

0900: recap of previous days training

0915---1000: septic shock – introduction and pathophysiology

1000---1100: septic shock---treatment goals and barriers

1130---1230: local septic shock guidelines – group work: plan for design 1330---1630: bedside teaching on patients with sepsis and septic shock to highlight learning goals from the day

1630---1700: debrief, summary and plan for next day

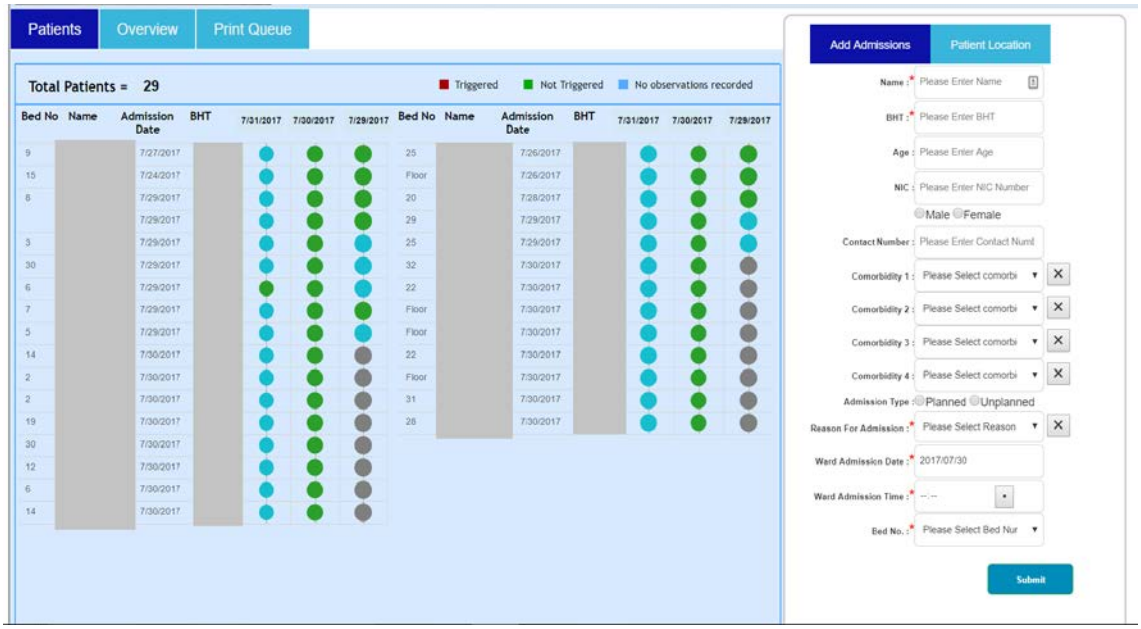
The list of trainers (alphabetically) with their affiliations, who delivered training in the three sites (some delivered training in more than one site): Wim van den Berg, MD Department of Critical Care University Medical Center Groningen, The Netherlands Helga Birkhoff, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands: Rebecca Boonman, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Andreas Brunauer, MD Anesthesiology and Intensive Care, Landeskliniken Salzburg, Austria; , Evelyne Desmet, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Roelie Deuten, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Arjen Dondorp MD, University of Oxford, UK; Frank Dullemeijer, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands;, Henrik Endeman, MD Department of Intensive Care, Onze Lieve

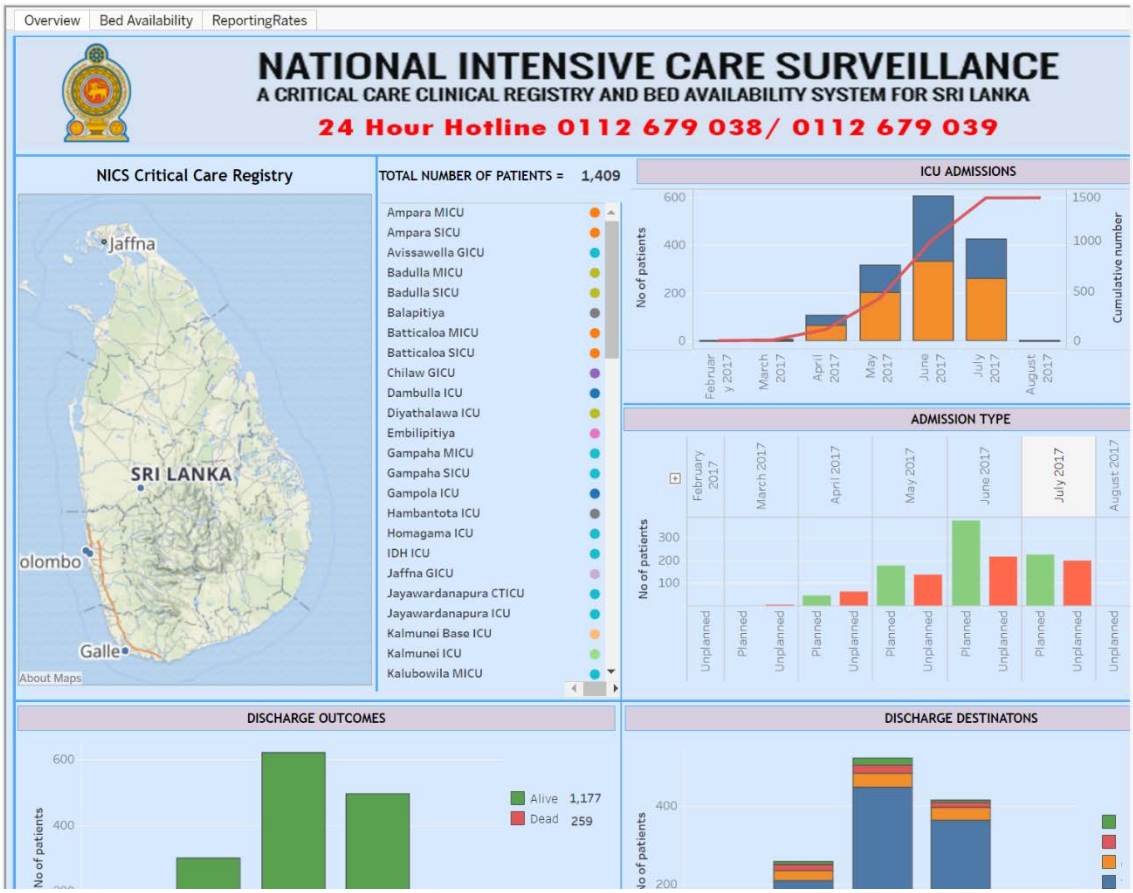
Vrouwe Gasthuis, Amsterdam, The Netherlands; Timothy McErlane, MD ICU Royal Berkshire Hospital, UK; Siebe van der Geest ICU Maastricht University Medical Center, The Netherlands; Rashan Haniffa, MD University of Oxford; Janneke Horn, MD ICU Academic Medical Center, Amsterdam, The Netherlands; Nicole Juffermans, MD ICU Academic Medical Center, Amsterdam, The Netherlands; Wendy van de Laar, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Erik---Jan van Lieshout, MD ICU Academic Medical Center, Amsterdam, The Netherlands; Elly Nederstigt ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands;, Anne---Cornelie de Pont, MD Academic Medical Center, Amsterdam, The Netherlands; Ton van Rijn, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Louise van

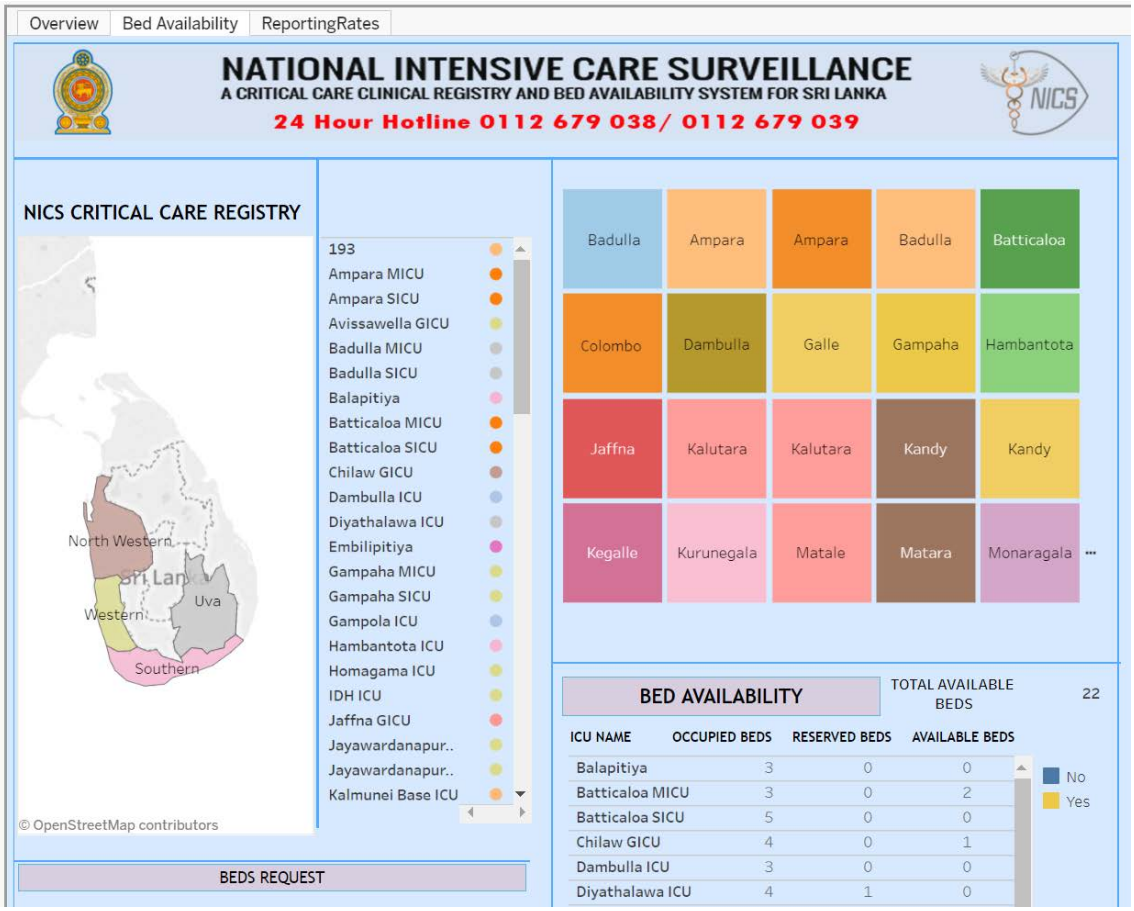
Rossum, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Krishna Sadhoe, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Miet Schetz, MD Department of Intensive Care, University Hospital Leuven, Belgium; Marcus Schultz, MD Academic Medical Center, Amsterdam, The Netherlands; Lesley van Sonsbeek, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Peter Spronk, MD ICU, Gelre Hospitals Apeldoorn, The Netherlands; Lucia Stena, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Nancy Sterkenburg, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Rianne Verhoef, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Andy Walden, MD ICU Royal Berkshire Hospital, UK; Ducky de Vries, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Eoin West, MD Harborview Medical Center, University of Washington, Seattle, USA, Tineke Winters, ICU RN ICU Academic Medical Center, Amsterdam, The Netherlands; Tineke Zwiers, ICU RN ICU Academic Medical Center, Amsterdam, The rlands.

Appendix C

NICST data platform dashboards






Overview
Bed Availability
ReportingRates
NATIONAL INTENSIVE CARE SURVEILLANCE
A CRITICAL CARE CLINICAL REGISTRY AND BED AVAILABILITY SYSTEM FOR SRI LANKA
24 Hour Hotline 0112 679 038/ 0112 679 039
NICS
NICS CRITICAL CARE REGISTRY
North Western
Uva
Western
Southern
© OpenStreetMap contributors
193
Ampara MICU
Ampara SICU
Avissawella GICU
Badulla MICU
Badulla SICU
Balapitiya
Batticaloa MICU
Batticaloa SICU
Chilaw GICU
Dambulla ICU
Diyathalawa ICU
Embilipitiya
Gampaha MICU
Gampaha SICU
Gampola ICU
Hambantota ICU
Homagama ICU
IDH ICU
Jaffna GICU
Jayawardanapur..
Jayawardanapur..
Kalmunei Base ICU
Badulla
Ampara
Ampara
Badulla
Batticaloa
Colombo
Dambulla
Galle
Gampaha
Hambantota
Jaffna
Kalutara
Kalutara
Kandy
Kandy
Kegalle
Kurunegala
Matale
Matara
Monaragala
BED AVAILABILITY
TOTAL AVAILABLE BEDS
22
ICU NAME
OCCUPIED BEDS
RESERVED BEDS
AVAILABLE BEDS
Balapitiya 3 0 0
Batticaloa MICU 3 0 2
Batticaloa SICU 5 0 0
Chilaw GICU 4 0 1
Dambulla ICU 3 0 0
Diyathalawa ICU 4 1 0
No
Yes
BEDS REQUEST

Memorandum of Understanding

Between

The Ministry of Health, Sri Lanka (MOH),

Wellcome Mahidol Oxford Tropical Medicine Research Unit (MORU)

and

The Department of Intensive Care, Academic Medical Centre, University of Amsterdam (AMC)

1. This Memorandum of Understanding (MoU) is a statement of the intention of MOH, MORU and AMC to collaborate on the establishment and operation of a National Intensive Care Surveillance System (NICS) to monitor the population of critically ill patients admitted to Intensive care units in Sri Lanka leading to the development of a predicting scoring system for the developing world

   This tri party MOU is entered in Colombo between Dr Ravindra Ruberu, Secretary Health, Ministry of Health, 385, Ven. Baddegama Wimalawansa Thero Mawatha, Colombo 10, Sri Lanka, Prof Arjen Dondorp of the Mahidol Oxford Tropical Medicine Research Unit, Faculty of Tropical Medicine, Mahidol University, 3/F, 60th Anniversary Chalermprakiat Bldg, Rajvithi Road 420/6, Bangkok 10400, Thailand and Prof Macus J Schultz, Professor of intensive care medicine at the Department of intensive care medicine, mail stop at C3–415, Academic Medical Center at the University of Amsterdam | Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands.

2. Purpose of MOU and objectives

- To establish a centralised system, predominantly electronic and web based, to monitor each critical care admission to state ICUs in Sri Lanka.
- To determine patient characteristics, source, severity of illness, organ support, course of illness and outcome of these critically ill patients
- To validate existing critical care scoring systems and to develop a new predictive scoring system for the developing world.
- To determine the utilisation of resources (human and otherwise) and describe the availability of such resources island wide.
- To coordinate a national emergency bed management system for critical care patients

- To utilise this critical care network for knowledge sharing, better resource management, cost analysis and health care planning

3. Legal status

Although this MoU is not legally binding on either party, MOH, MORU and AMC agree to honour the following approach to collaboration.

4. Duration

It is expected that the initial period of collaboration will last from 1st December 2011 until 31 December 2013 and may be extended with the agreement of both parties

5. Effective date

The MOU shall be effective from the date of the signature of all parties or the last of the signatories, whichever is the latest.

6. Project Directors

The collaboration will be led jointly by Dr. A. Pubudu De Silva, Consultant Community Physician (Acting) from the Office of Deputy Director General (Medical Service) I, for the MOH and Dr. Rashan Haniffa as honorary director for MORU/AMC.

7. The role of the Directors

The directors will be jointly be responsible to

- Achieve the objectives of the collaboration
- Prepare and implement standard operating procedures and protocols
- Convene and be part of a steering committee to provide governance and strategic direction
- Liaise with National Intensive Care Evaluation (NICE), an organisation based at the Academic Medical Centre (AMC), University of Amsterdam, which has experience in running similar projects
- Promote NICS to recruit critical care units, raise its profile amongst the healthcare profession and identify its future direction
- Provide supervision to those employed at NICS
- Ensure good governance, data confidentiality and auditing of operations

The parties agree to meet regularly to discuss progress of the project according

to an overall schedule to be developed by the directors.

8. Responsibilities of the parties - MOH MOH will be responsible to provide

- Premises for the management of the project and the location of NICS
- Staffing for NICS
- Training of nursing staff
- IT resources to develop and maintain the system.

9. Responsibilities of the parties - MORU

- Provide start-up funding up to an amount agreed by both parties
- Seek grants to provide funding for NICS
- Provide technical and methodological assistance to the project
- Provide additional project support staff as required

10. **Responsibilities of the parties - AMC**

- Provide methodological and technical support for NICS
- Liaise with Information Technology counterparts based at MOH and elsewhere
- Provide research students to develop the software and other operating procedures for NICS
- Promote and coordinate involvement with NICE in general and both Dr Nicolette F de Keizer and Prof Ameen Abu Hanna in particular**.**
- Ensure NICS maintains international standards in governance, data validity and audit

11. Ownership of data and publication rights

All data collected as part of this collaboration shall be owned jointly by MOH, MORU and AMC. Both parties must consent prior to data being shared with any third parties. Any publications arising from this collaboration will include authors from the MOH, MORU and AMC. The Directors will discuss any proposed publications arising from this project before they are submitted for publication.

Any presentation of results arising from this collaboration will acknowledge the contributions made by collaborators on the project from MOH, MORU and AMC.

12. Governance

NICS will be guided strategically with regard to research direction, project

expansion, and collaboration with other organisations by a steering committee. In addition to the Directors, this committee will be composed of nominees from professional medical and allied organisations in Sri Lanka, which are stakeholders in critical care medicine.

13. Changes to this Memorandum of Understanding

Any changes to this MoU shall be discussed in good faith between MOH, MORU and AMC, and if jointly agreed, be made in writing. Such amendments would serve as an addendum to this document.

14. Withdrawal and suspension

Both parties to this MoU agree to act in good faith to complete the project in a spirit of academic collaboration. However either party may withdraw from or suspend this MoU for any reason at its sole discretion upon giving the other party written notice of at least 6 months duration.

15. Dispute resolution

All parties agree to meet and discuss in good faith any dispute, controversy or claim arising out of or relating to this MoU with a view to reconciliation and continuation of the collaboration. In the event that reconciliation is not achievable any party may withdraw from or suspend the MoU as above.

16. Annexure

(a) "Research pre proposal" for NICS as submitted for ethical clearance to the Faculty of Medicine, University of Colombo.

(b) Exemption for ethical clearance granted by the Faculty of Medicine, University of Colombo.

Communication and Correspondence

All correspondence related this MoU should be directed as follows:

For MOH

Dr. A. Pubudu De Silva, Consultant Community Physician (Acting)

Office of Deputy Director (Medical Services) I

Ministry of Health

Sri Lanka

For MORU/AMC

Dr Rashan Haniffa

Wellcome Mahidol Oxford Tropical Medicine
Research Unit, Bangkok,

Thailand

rashan@tropmedres.ac

In witness whereof the parties have set their hands in Colombo and in the Netherlands on the following dates.

Signed for and on behalf of the Ministry of Health, Sri Lanka

Dr Ravindra Ruberu, Secretary to Ministry of Health, Sri Lanka.

Date

Signed for and on behalf of Wellcome Mahidol Oxford Tropical Medicine Research Unit

Dr Rashan Haniffa, Research Physician, MORU on behalf of Prof Arjen Dondorp, Deputy Director, MORU

Date

Signed for and behalf of Academic Medical Centre, University of Amsterdam

Dr Rashan Haniffa for Professor Marcus Schultz (countersigned by Prof Schultz) Professor of Intensive Care

Academic Medical Centre, University of
Amsterdam Date

Excerpts from the Data dictionary

Source of admission

Field:	Source of admission
Entry type:	Alphabet letters

Number of entries:	One
Unit of measurement:	None
Options:	Operating room from nursing ward same hospital Operating room from emergency room same hospital Emergency room same hospital Nursing ward same hospital CCU/IC same hospital Recovery same hospital Special/Medium care same hospital Operating room from nursing ward different hospital Operating room from emergency room different hospital Emergency room different hospital Nursing ward different hospital CCU/IC different hospital Recovery different hospital Special/Medium care different hospital Home Different Different location same hospital, transported by ambulance

---

Definition of data entries:

The location where the patient came from just before admission to ICU

Justification

Source of admission is used to calculate *APACHE IV*.

Motor response at admission

Field:	Motor response at admission
Entry type:	Alphabet letters
Number of entries:	One
Unit of measurement:	None
Options:	No response Stretching out Decortication reflex Spastic response Localising pain Follows verbal commands

Definition of data entries:

Motor response at ICU admission (part of GCS)

Be careful:

- If the patient is sedated or intubated, points are assigned as follows:

  if the patient was awake and is sedated, estimate the score before sedation; if the patient was not awake and is sedated, and probably has brain damage, estimate the score during sedation.

- Always choose the best side (in the case of an "haemiparesis") at the moment of ICU admission.

- Anaesthesic and sedation effects may not be included. Patients admitted in ICU directly postsurgical, but still under anaesthia, have maximum score.

- The only exceptions to this rule are patients who, presurgical, already were less conscious.

- These patients are included with, in principle, the same GCS as pre-surgical.

Justification

Motor response at admission is used to calculate *Mortality Probability Model.*

Quarterly report



1

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Introduction

We thank you for the support rendered to the National Intensive Care Surveillance (NICS) of Ministry of Health in implementing NICS at your ICU. This is the Quarterly report of your ICU for the period of October 2013 to December 2013.

The aim of this feedback report is to send information back to you and your ICU as a way of improving the quality of care and the quality of data. We hope you find this report informative and relevant.

The information in this report is based on the records that were submitted to us through the NICS database. All due care has been taken in the preparation of this. If you feel there have been errors or there misrepresentations, then we will be happy to attend to these. We are also very happy to work with your ICU to improve data quality.

We are continually looking to improve our services. Please feel free to make any suggestions.

Once again, many thanks to your contribution to NICS.

Please direct any comments/queries/criticisms to the NICS Project Director, Dr P Athapattu at the Ministry of Health, Colombo or NICS Project Co-ordinator, Dr Rashan Haniffa at rashan@nicslk.com.

Tel: 0112679038

Fax: 0112679039

ICU bed availability system and issues reporting is LIVE!

We have two updates for the NICS network this quarter!

ICU bed availability system is now LIVE!

It is now possible for any doctor caring for a patient in a state sector Hospital to locate the nearest available ICU bed by contacting NICS on 112679039 (Monday to Friday 8 am to 8 pm, Saturday, Sunday and public holidays 8 am to 4 pm).

Of course, as always, any decision to accept the patient or not will always rest with the ICU Consultant. NICS will only be helping with the contact process so time and resources can be better utlised to use state resources for patients needing critical care. Thank you for your help in this process!

ICU issue reporting system will go LIVE soon!

As per the feedback received from Doctors and nurses in the network, the NICS application now allows logistical issues/faults in ICU to be reported on a dynamic basis along with bed states and patient data.

This includes issues related to equipment, disposables, staffing to be reported. This information is passed on to the relevant authorities at Ministry of Health for corrective action. This leads to better service delivery in the future with timely action form the reported data.

This benchmarking of ICU patient outcomes along with staffing numbers, ICU workload and now logistical challenges faced is a unique system to enable better understanding of critical care epidemiology.

Further information

info@nicslk.com / Tel: 011 2679 039



Quality Indicators and Outcomes
ICU I
1st October 2013 to 31st December 2013
(n=117)

REPORT SUMMARY from 01/10/2013 to 31/12/2013

The following are the main findings:

1. The number of admissions from October 2013 to December 2013 was 117.
2. The commonest (21, 18%) APACHE IV diagnostic category was post-operative gastro Intestinal surgery .
3. Overall bed occupancy rate was 79 % (+/- SD 25%)
4. The mean age of the patients was 49 (+/- SD 20) years.
5. The ratio of male to female patients was 1.7 :1
6. The average length of ICU stay was 5 days (+/- SD 5.1) while the median length of stay was 3 days. (range 8 hours to 33 days)
7. The longest length of stay for those discharged in the period was 34 days.
8. The average APACHE II score was 20 (+/- SD 10 , range 1 to 43).
9. Most (54, 46%) of the admitted patients were admitted from the nursing ward of the same hospital.
10. The number of mechanically ventilated patients was 63 (54 %)
11. The crude mortality of the ICU was 21 %
12. The number of admissions with CPR 24 hours before admission to ICU was 8 (6.8%).
13. The reported major co morbid factors were- COPD (4%), DM (11%), stroke (4%), poisoning (4%) and burns (1%).
14. The standardized mortality ratio was 0.68.
15. The nurse: patient ratio of the ICU was 1.5.

Please note that all terms are defined in the glossary, at the end of the report

SECTION A: DATA QUALITY

Figure 1: Bed reports received rate compared with other NICS ICUs in Kurunegala district

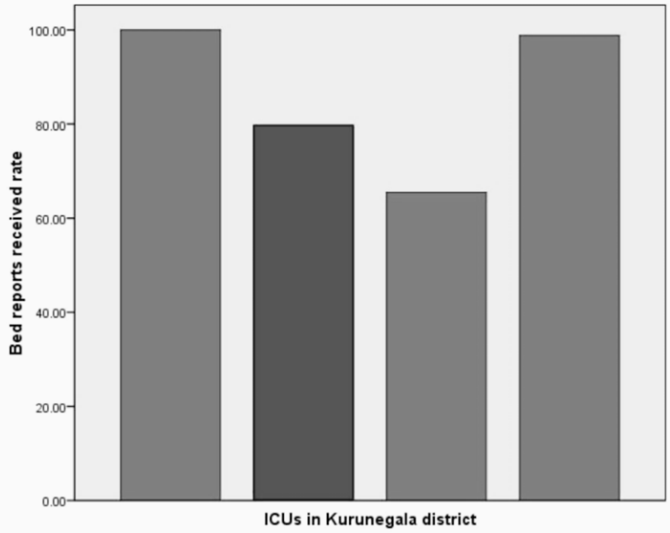

Figure 2 : Bed reports received rate compared with other NICS ICUs in North western province

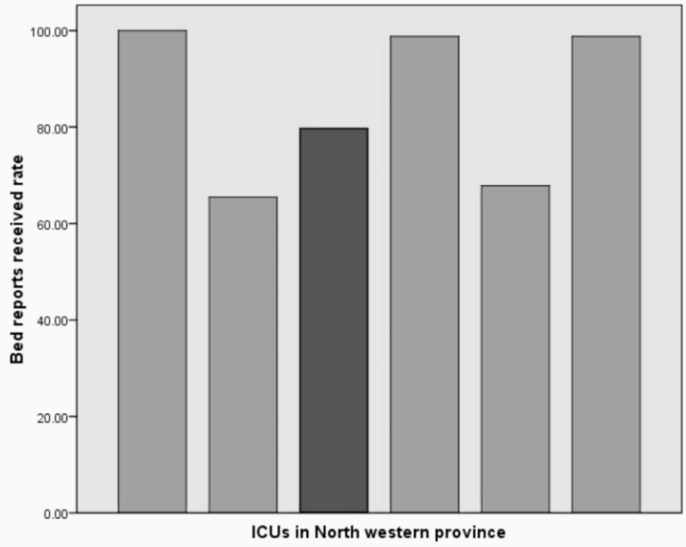

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Figure 3: Bed reports received rate compared with other NICS ICUs in Sri Lanka

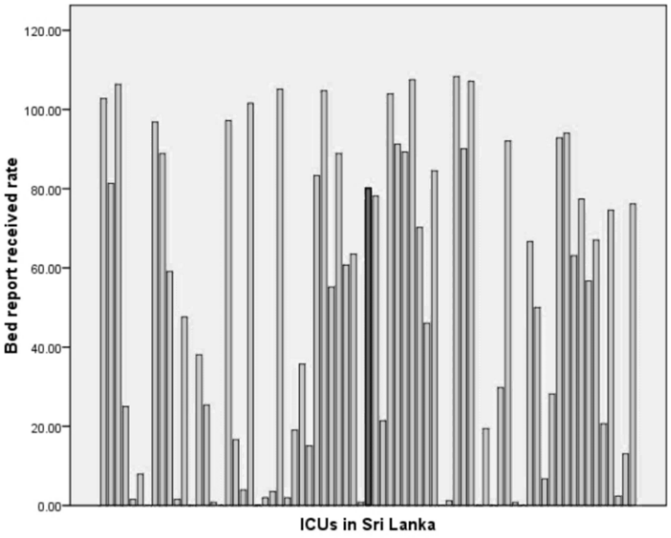

Figure 4: Admissions reporting rate in percentage compared with other NICSICUs in Kurunegala district

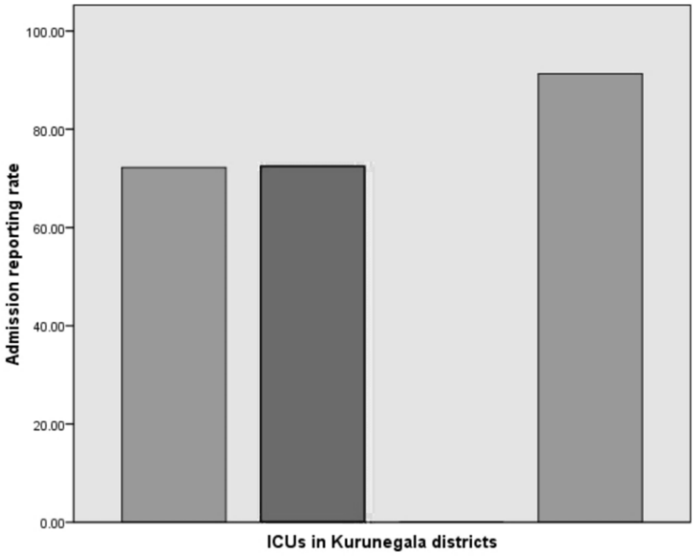

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Figure 5: Admissions reporting rate in percentage compared with other ICUs in North western province

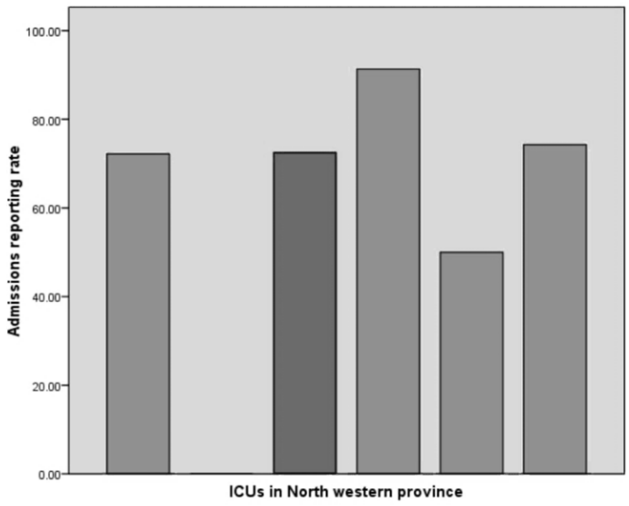

Figure 6: Admission reporting rate of the unit compared with other ICUs in Sri Lanka

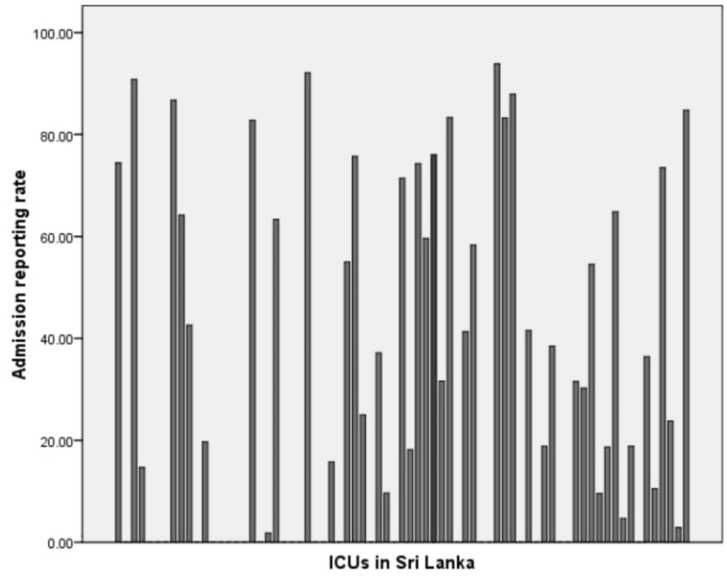

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Table 1 : Effectiveness of filling daily reports

Number of due daily reports for the data entered	569
Number of filled daily reports	0
Effectiveness of filling daily report	0%

Table 2: Effectiveness of filling bed reports

Number of due bed reports	252
Number of bed reports received	206
Effectiveness of filling bed reports	82%

Table 3: Effectiveness of filling admission reports

Number of due admission reports	123
Number of reported admission reports	117
Effectiveness of filling admission report	95%

Table 4: Effectiveness of filling 24 hour reports

Number of due 24 hour reports	124
Number of reported 24 hour reports	102
Effectiveness of filling 24 hour reports	82%

Table 5: Effectiveness of filling discharge reports

Number of due discharge reports	123
Number of reported discharge reports	105
Effectiveness of filling discharge report	85%

Table 6: Quality of reported data

	Number of patients	Percentage
ICU admission time 00:00:00	1	0.9
Discharge time 00:00:00	0	0

Table 7 : Telephone numbers of the patients

Telephone Numbers	Number of patients	Percentage
Invalid numbers	107	91.3
Valid numbers	10	9
Total	117	100.3

Bed reports are to be submitted to NICS 3 times a day

SECTION B: BED UTILIZATION

Out of 252 bed reports 206 bed reports were received.

Table 8 : Total beds reported by the unit

Total Number of beds	Number of bed reports	Percentage
8	206	100

Three bed reports per day as part of NICS

Table 9: No. of occupied ICU beds

Occupied beds in the ICU	Number of bed reports	Percentage
0	12	5.8
1	1	0.5
3	1	0.5
4	10	4.9
5	19	9.2
6	50	24.3
7	37	18
8	76	36.9
Total	206	100

Table 10 : ICU bed occupancy rate

Average bed occupancy rate	
Mean	79%
Median	88%
Std. Deviation	25%
Minimum	0%
Maximum	100%
100% bed occupancy rate	76 bed reports (37 %)

Bed occupancy rate per bed report = Number of occupied beds /Number of total beds*100
Average bed occupancy rate= Average of bed occupancy rates in all bed reports within the time duration

Figure 7: Mean bed occupancy rate compared with other NICS ICUs in Sri Lanka

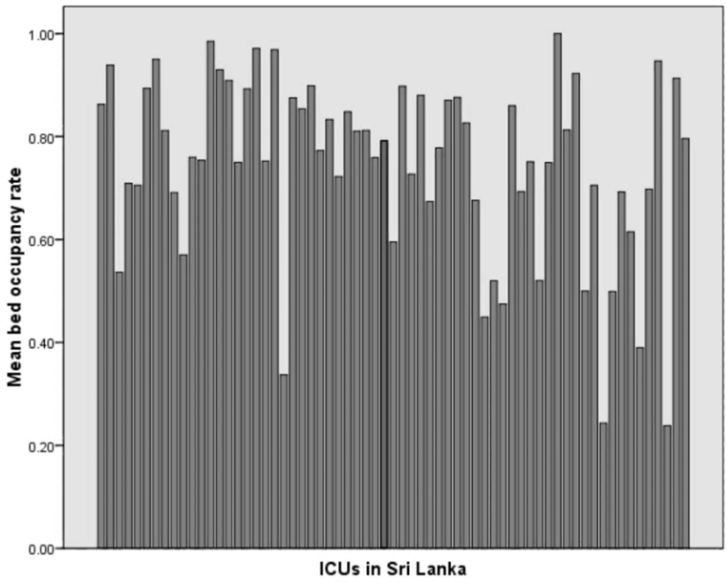

Figure 8: The trend of occupied beds over the year

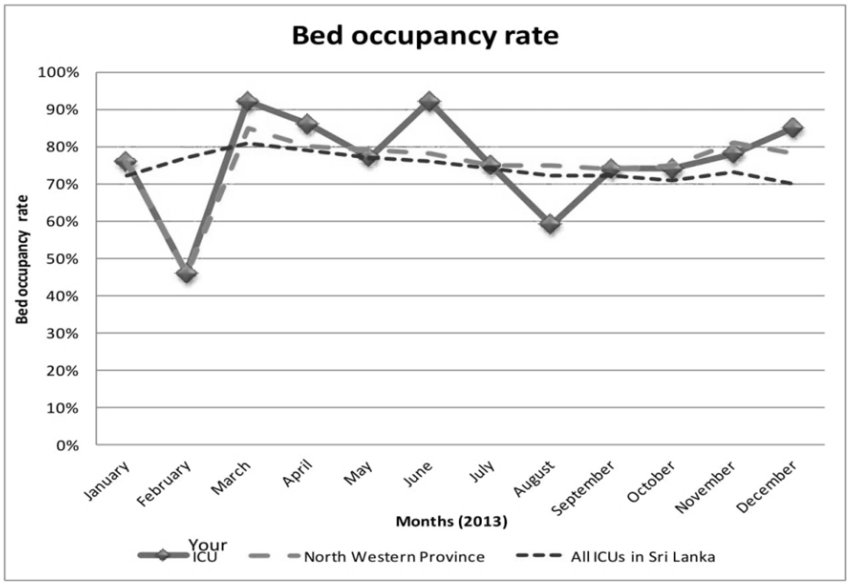

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Table 11 : Number of closed beds in the ICU

Closed beds in the ICU	Number of bed reports	Percentage
0	202	98
3	1	0
6	2	1
8	1	0
Total	206	100

Table 12 : Closed bed rate

Average closed bed rate	
Mean	1%
Median	0%
Std. Deviation	10%
Minimum	0%
Maximum	100%

Closed bed rate per bed report = Number of closed beds /Number of total beds*100
Average closed bed rate= Average of closed bed rates in all bed reports within the time duration

Table 13 : Number of reserved beds in the ICU

Reserved beds in the ICU	Number	Percentage
0	181	88
1	17	8
2	6	3
8	2	1
Total	206	100

Table 14 : ICU bed reserving rate

Reserved bed occupancy rate	
Mean	3%
Median	0%
Std. Deviation	11%
Minimum	0%
Maximum	100%

Reserved bed rate per bed report = Number of reserved beds /Number of total beds*100
Average reserved bed rate= Average of reserved bed rates in all bed reports within the time duration

Table 15: Number of available beds in the ICU

Available beds in the ICU	Number of bed reports	Percentage
0	91	44
1	38	18
2	40	19
3	18	9
4	10	5
5	2	1
7	4	2
8	3	1
Total	206	100

Figure 9: Bed availability of the ICU

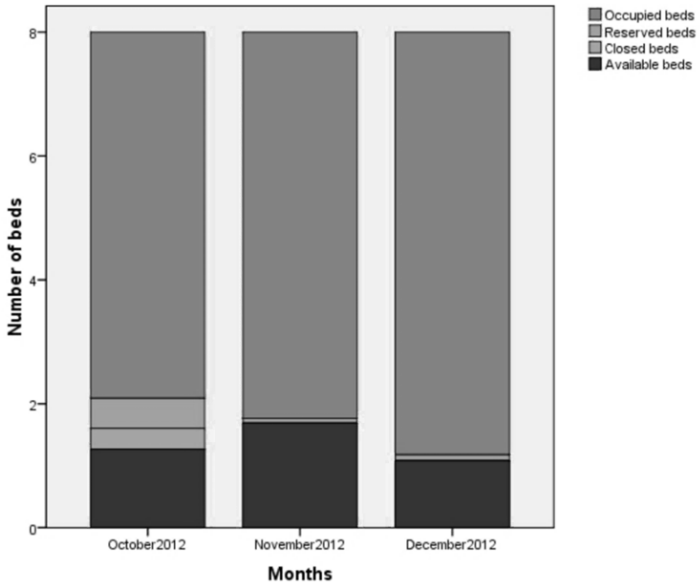

Figure 10: Number of admissions compared with other ICUs in Sri Lanka

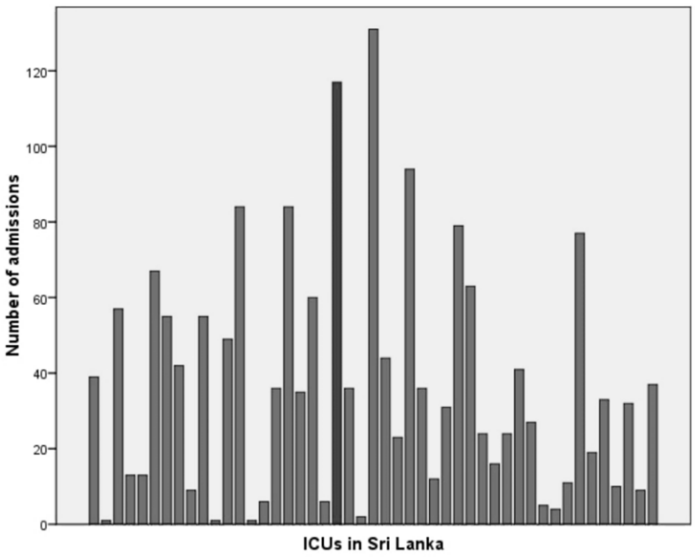

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Table 16: Reported ICU admissions in separate months

Month	Number of patients	Percentage
October 2013	42	35.9
November 2013	43	36.8
December 2013	32	27.4
Total	117	100

Figure 11 : Reported ICU admission in separate months

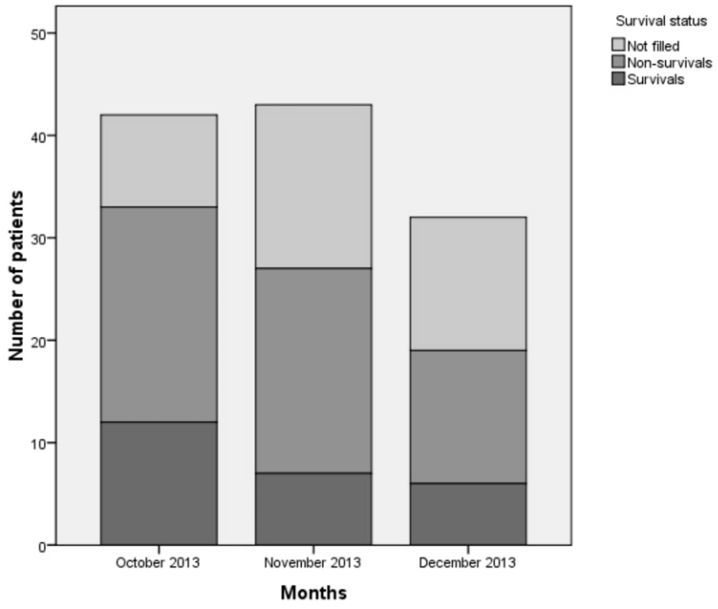

Figure 12 : Admissions in day and night time

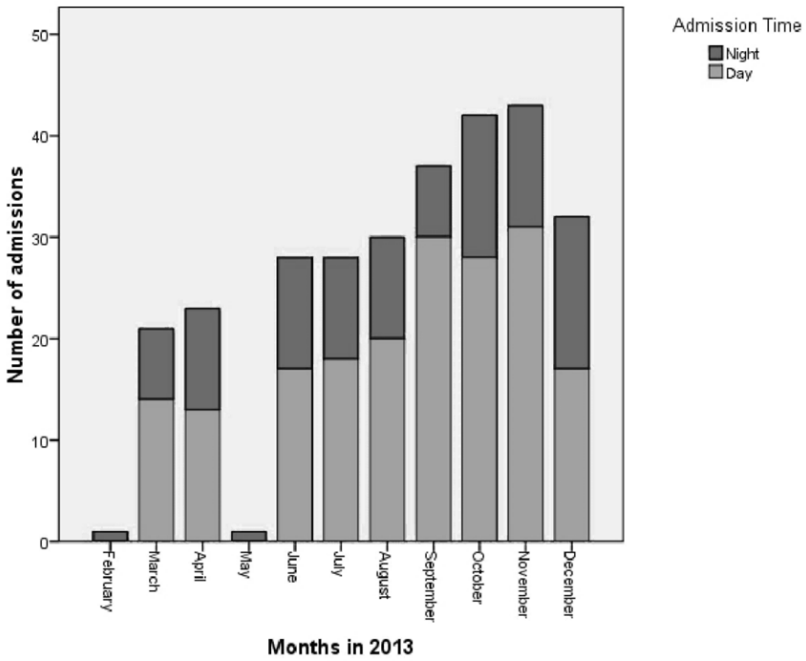

Table 17 : Admissions in day and night time in the quarter

	Number of patients	Percentage
Day time admissions	76	65.0
Night time admissions	41	35.0
Total	117	100

Figure 13 : Discharges in day and night time

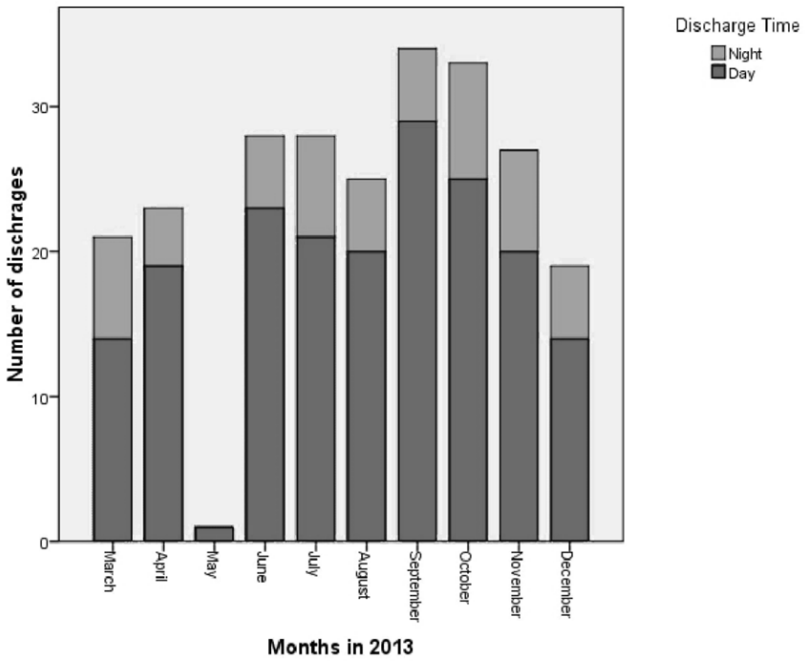

Table 18 : Discharges in day and night time in the quarter

	Number of patients	Percentage
Day time discharges	59	50.4
Night time discharges	20	17.1
Not entered	38	32.5
Total	117	100

SECTION C: ICU WORKLOAD & STAFF

Table 19 : ICU workload

Nursing workload = NA

Unable to calculate nursing workload as no daily reports filled.

NEMS (Nine Equivalents of nursing Manpower use Score) is used to calculate ICU workload.
ICU workload as percentage per patient per day = score of NEMS per patient per day/ total NEMS score*100
Average ICU workload as percentage = Average of ICU workload as percentage in all patients in all days within the time period

Analysis was not actually done in this case due to unfilled daily report.

Table 20 : Distribution of ICU workload in months

Months	Nursing workload
October 2013	NA
November 2013	NA
December 2013	NA
Total	NA

Table 21: Number of nurses per shift

Mean	9
Median	9
Std. Deviation	2
Minimum	3
Maximum	12

Table 22 : Distribution of number of nurses per shift

Total number of nurses	Number of reports	Percentage
3	1	0
5	1	0
6	1	0
7	3	1
8	77	37
9	47	23
10	2	1
11	38	18
12	36	17
Total	206	100

Table 23: Number of nurses in each shift (median)

Number of nurses in morning	Number of nurses in afternoon	Number of nurses in evening
11	9	8

Table 24: Shift pattern in the ICU

Shift pattern in Morning: Evening : Night	
Nurses (median)	11:9:8
Health Care Assistants (median)	4:3:2
Nurse : patient ratio (mean)	1.5 : 1

Figure 14: Nursing staff (mean)

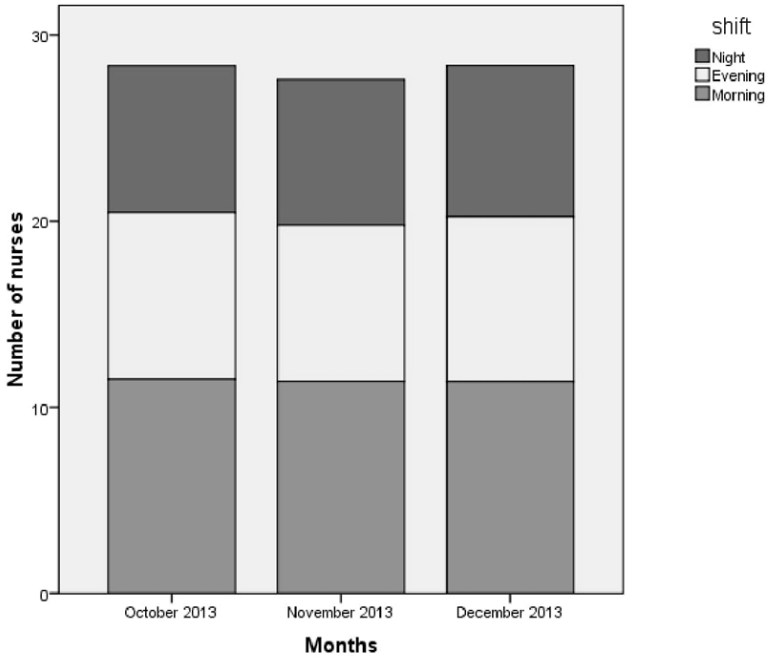

Figure 15: Nurse patient ratio per shift comparison with other ICUs in Sri Lanka (mean)

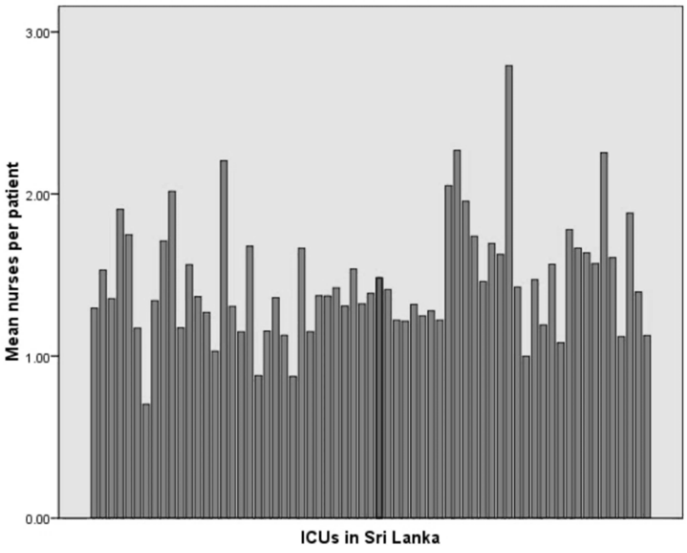

Figure 16: Nurses per patients per shift

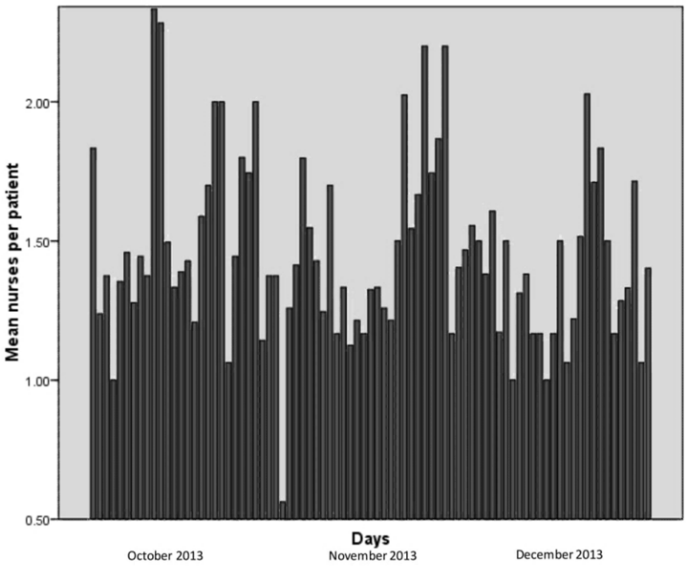

Figure 17: Nurses per patients in each shift

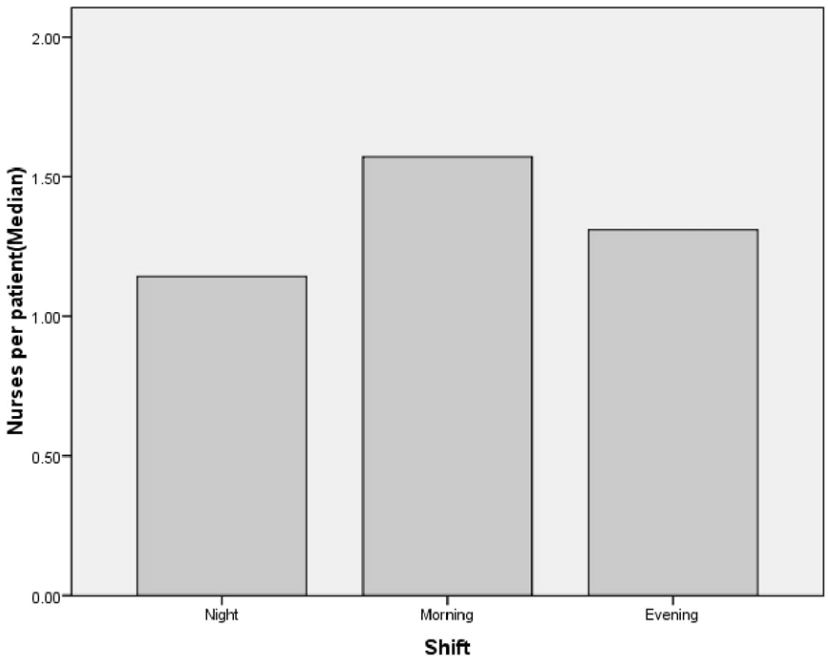

Table 25: Nurse: Patient ratio

Nurse : Patient ratio in the morning = Average staff in the morning/ Average bed occupancy in the day

11:06.8

1.6 :1

Nurse : Patient ratio in the evening = Average staff in the evening/ Average bed occupancy in the day

9/6.8

1.3:1

Nurse : Patient ratio in the night = Average staff in the night/ Average bed occupancy in the day

8/6.8

1.2:1

Table 26 : Number of Health Care Assistants

Mean	3.24
Median	3
Std. Deviation	1.39
Minimum	0
Maximum	10

Table 27 : Distribution of total Health Care Assistants

Number of Heath Care Assistants	Number of reports	Percentage
0	4	2
1	4	2
2	72	35
3	35	17
4	50	24
5	35	17
6	5	2
10	1	0
Total	206	100

Table 28: Number of HCA in each shift

Number of HCA in morning (median)	Number of HCA in after-noon	Number of HCA in evening
4	3	2

Figure 18 : Health Care Assistants per shift

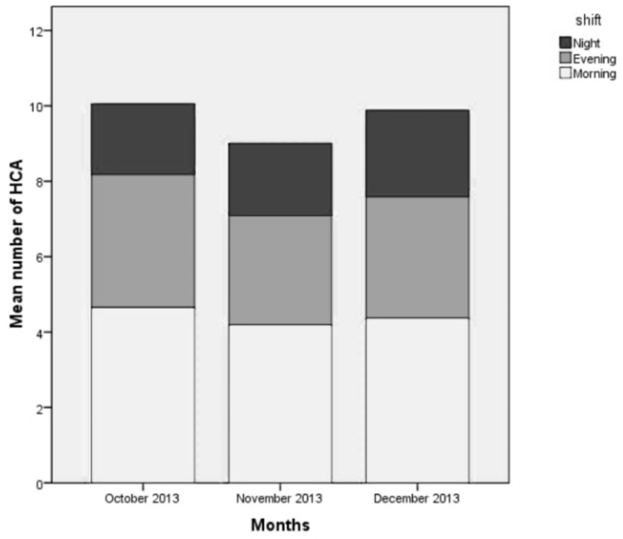

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Figure 19: Health Care Assistants per patient per shift in comparison with other ICUs in Sri Lanka (mean)

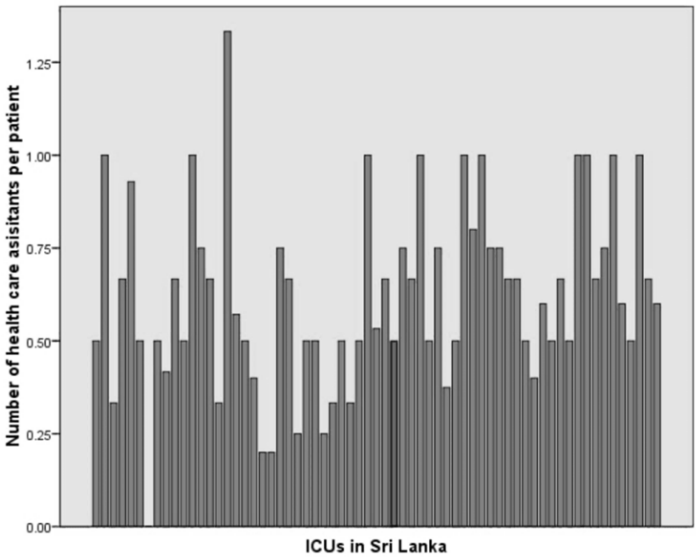

Figure 20: Health Care Assistants per patient per shift

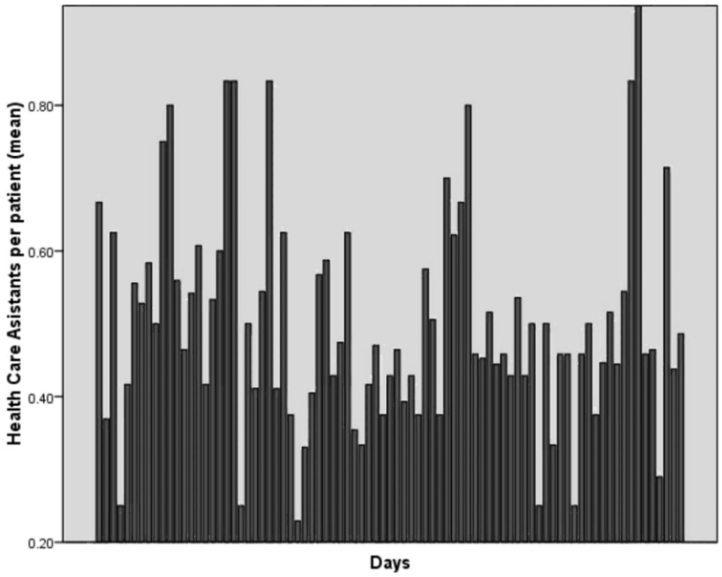

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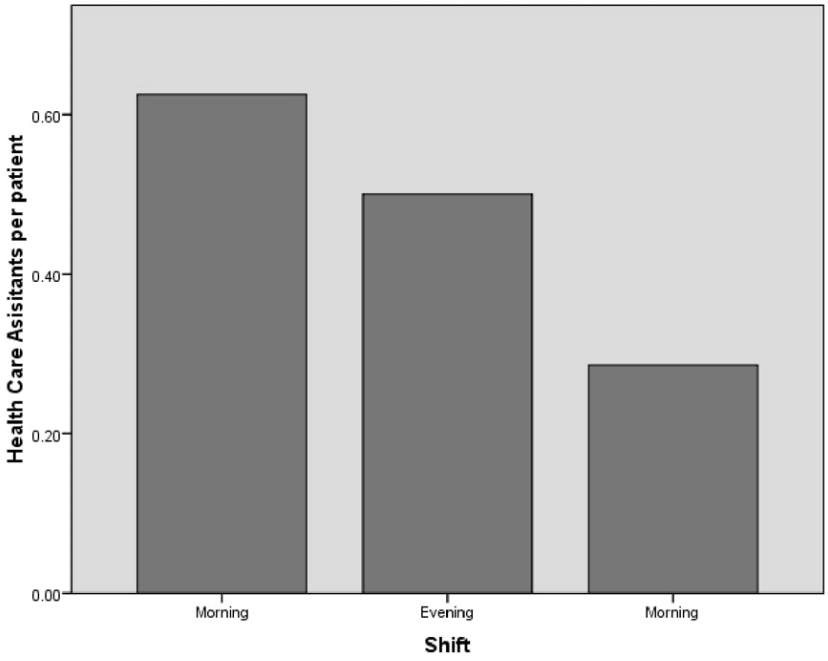
Figure 21: Health Care Assistants per patient in each shift (median)



SECTION D: PATIENT CHARACTERISTICS

Table 29 : Gender distribution in ICU admissions

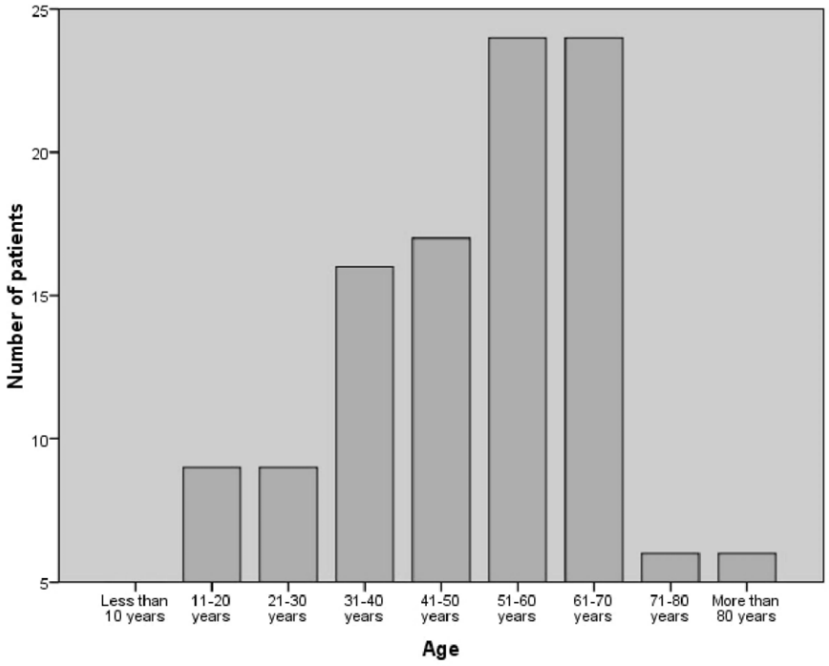
	Number	Percentage
Male	74	63.2
Female	43	36.8
Total	117	100

The ratio of male to female patients was 1.7 :1

Table 30 : Age distribution in ICU admissions

Mean	48.9
Median	53.0
Std. Deviation	20.3
Minimum	1
Maximum	100
Percentiles	
25	35
50	53
75	63

Figure 22: Age distribution as groups



The average age was 49 years

Table 31 : Admission type of the patients

Admission type	Number of patients	Percentage
Emergency surgery	32	27
Medical	42	36
Planned surgery	23	20
NA	20	17
Total	117	100

Figure 23 : Category of patients in separate months

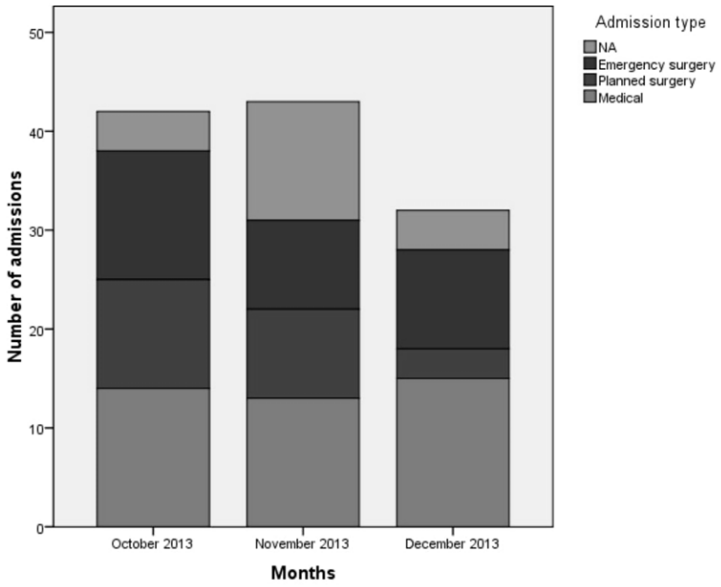


Table 32: In hospital CPR received before ICU admission

		Number of patients with CPR before ICU admission	Total number of patients	Percentage
CPR received before ICU admission in hospital		8	117	7%
Prior CPR grouped by admission type	Emergency surgery	0	32	0%
	Medical	6	42	14%
	Planned surgery	1	23	4%
	NA	1	20	5%
Prior CPR grouped by source of admission	CCU/IC same hospital	1	1	100%
	Emergency room same hospital	1	9	11%
	Emergency room different hospital	1	4	25%
	Nursing ward same hospital	4	54	7%
	Nursing ward different hospital	0	1	0%
	Operating room from nursing ward same hospital	0	29	0%
	Operating room from nursing ward different hospital	0	1	0%
	Operating room from emergency room same hospital	0	2	0%
	Operating room from emergency room different hospital	0	1	0%
	Recovery same hospital (only with unplanned ICU-admission)	0	10	0%
	Recovery different hospital	0	1	0%
	Special/Medium care same hospital	0	1	0%
	CCU/IC different hospital	0	1	0%
	Different	0	1	0%
	Missing	1	1	NA

Figure 24: Number of patients who received CPR before admission to the ICU compared with other ICUs in Sri Lanka

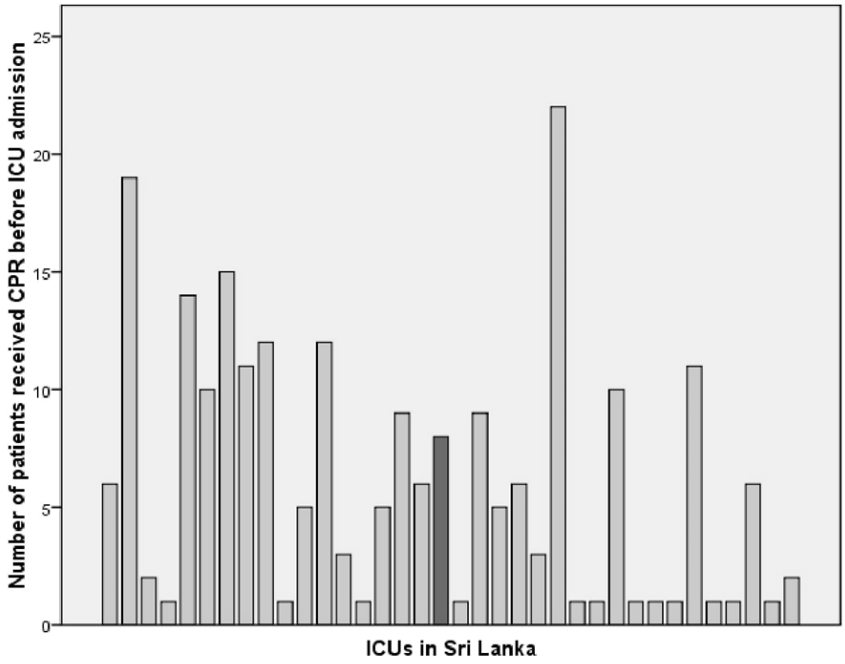


Table 33 : Most common APACHE IV diagnostic categories

Type of admission	System	APACHE IV diagnostic category
Post-Operative	Gastrointestinal	Gastro Intestinal surgery
Non-Operative	Neurologic	Neurologic medical conditions
Non-Operative	Respiratory	Respiratory Arrest
Non-Operative	Respiratory	Asthma
Post-Operative	Gastrointestinal	Surgery for esophageal cancer
Post-Operative	Genitourinary	Cesarean section
Non-Operative	Genitourinary	Genitourinary medical conditions
Post-Operative	Genitourinary	Genitourinary surgical condition
Post-Operative	Gastrointestinal	Surgery for GI perforation/rupture
Non-Operative	Trauma	Head injury

Figure 25: Most common conditions in ICUs

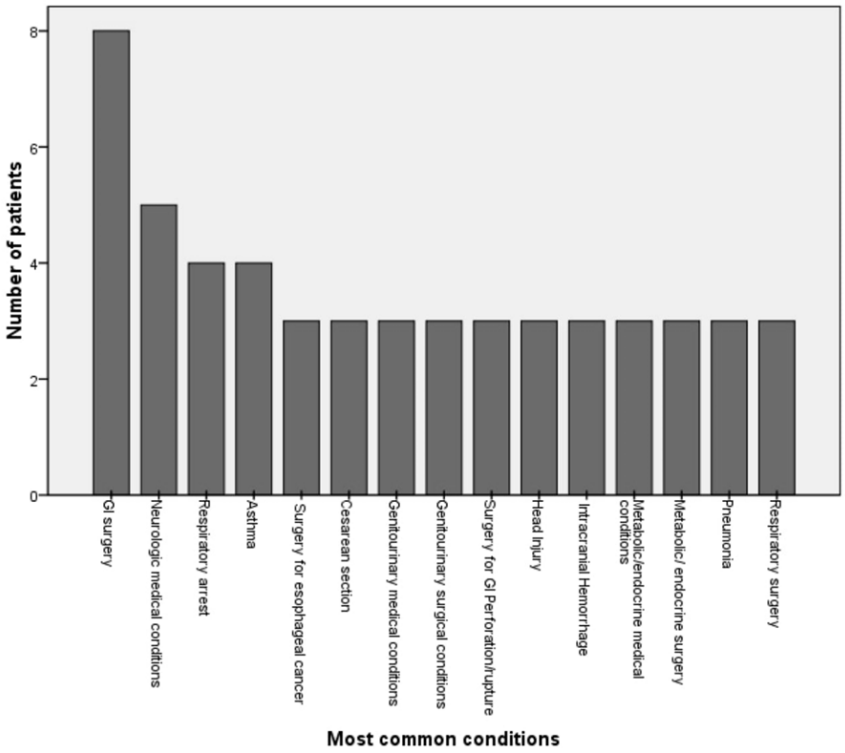


Table 34 : Referring specialty

Referring specialty	Number of patients	Percentage	ICU stay in days	Number of actual deaths	ICU mortality
Gastro-enterology	21	18	4.5	5	24%
Surgery	21	18	3.7	3	14%
Gynecology & obstetrics	10	9	1.4	0	0%
Neurology	9	8	6.5	1	11%
Unknown specialism	9	8	4.4	1	11%
Lung diseases	7	6	3.3	4	57%
Orthopedic	7	6	3.2	2	29%
Cardiology	5	4	3.8	2	40%
Medical microbiology	3	3	5.6	1	33%
Nephrology	3	3	2.1	2	67%
Ear-nose-throat surgery	2	2	4.7	1	50%
Internal medicine	2	2	3.2	0	0%
Allergology	1	1	12.9	0	0%
Anesthesiology	1	1	33.4	1	100%
Clinical chemistry	1	1	1.9	0	0%
Clinical genetics	1	1	4.3	1	100%
Dento-maxillaire orthopedics (orthodontics)	1	1		0	0%
Endocrinology	1	1	3.1	0	0%
Immunology	1	1		0	0%
Mouth diseases & jaw surgery	1	1		0	0%
Neurosurgery	1	1	3.8	0	0%
Oncology	1	1		0	0%
Pediatrics	1	1		0	0%
Pathological	1	1		0	0%
Psychiatry	1	1		0	0%
Rheumatology	1	1	2.4	1	100%
Urology	1	1		0	0%
Missed	3	3		0	0%

Empty slots for ICU length stay in some referring categories due to absence of discharge reports of those admitted patients.

Figure 26 : Location before ICU admission in separate months

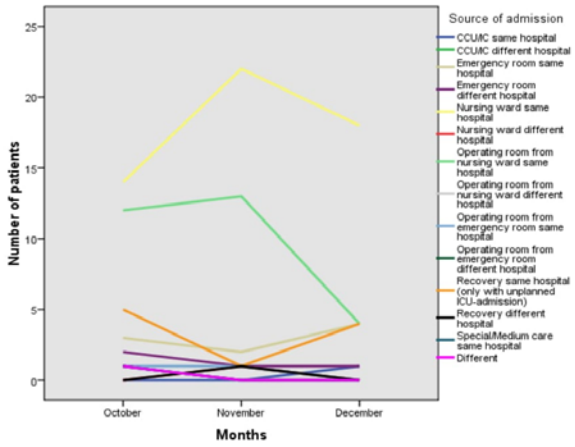


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Figure 27 :Number of patients with measurements and investigations done in the first 24 hours in ICU

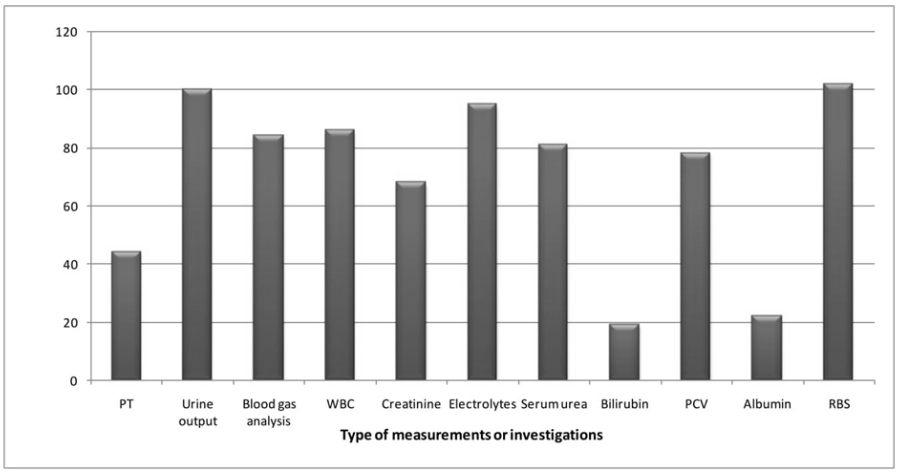

Figure 28 : Percentage of patients with measurements and investigations done in the first 24 hours

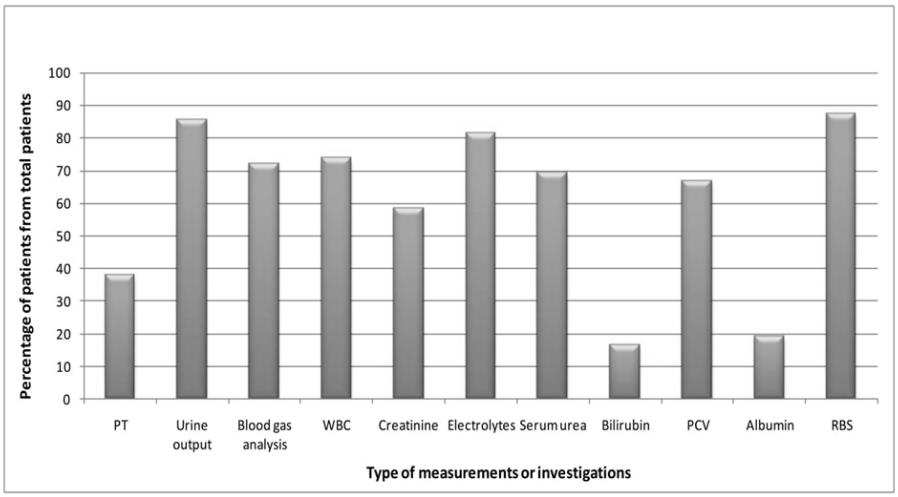

Table 35 : Medical conditions on admission

	Number of patients	Percentage
Chronic Cardiovascular Insufficiencies	14	12
Chronic Respiratory Insufficiencies	4	3.4
Chronic Renal Insufficiencies	9	7.7
COPD	5	4.3
Cirrhosis	2	1.7
Hematological Malignancy	4	3.4
Metastatic Neoplasm	3	2.6
Snake bite	2	1.7
Poisoning	5	4.3
Cardiac Dysarrythmias	12	10.3
Gastrointestinal bleeding	2	1.7
CVA	5	4.3
Chronic dialysis	3	2.6
AIDS	0	0
Burns	1	0.9
Cardiovascular accidents	5	4.3
Intracranial mass effect	1	0.9
Cerebrovascular incident	6	5.1
Diabetics	13	11.1
CABG	0	0

Table 36 :Length of hospital stay prior to ICU admission

		Lead time in hours
Mean		97
Median		23
Std. Deviation		157
Minimum		0
Maximum		887
Percentiles	25	6
	50	23
	75	127

Table 37 : Distribution of length of hospital stay prior to ICU admission

	Number of patients	Percentage
lead time less than 1 day	61	52
lead time between 1 to 5 days	25	21
lead time 5-10 days	13	11
lead time more than 10 days	18	15
Total	117	100

Table 38 : GCS on admission

Mean	8.7
Mean excluding those who were sedated on admission	11.6
Median	9.0
Median excluding those who were sedated on admission	14.0
Std. Deviation	5.4
Minimum	0
Maximum	15
Percentiles-25	3
50	9
75	15

Table 39: Distribution of GCS on admission

GCS on admission	Number of patients	Percentage
3	49	41.9
3 excluding those who were sedated on admission	9	15.3
4 -7	5	4.3
8-12	17	14.5
13-15	46	39.3
Total	117	100.0

Figure 29: Distribution of GCS on admission in survivals & non-survivals

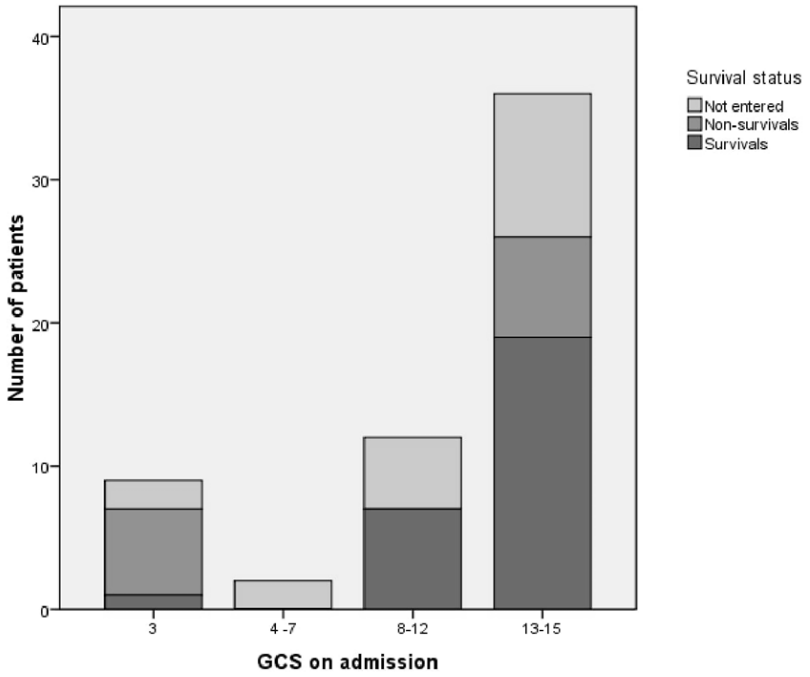

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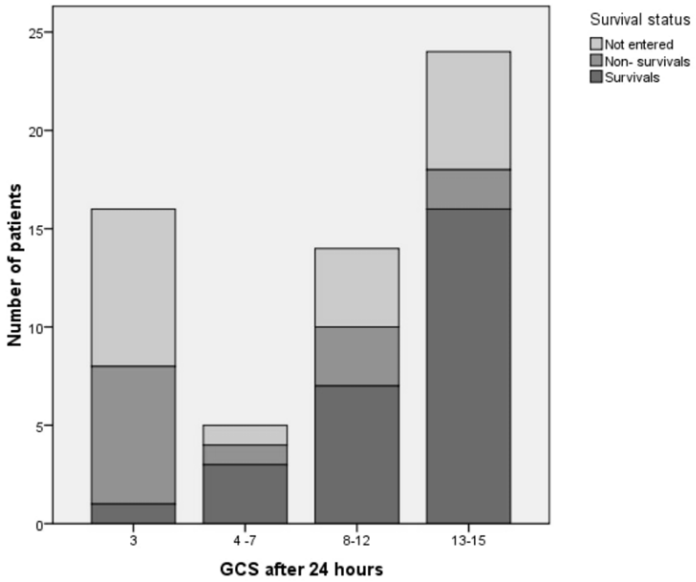
Table 40 : GCS after 24 hours

Mean	8.0
Mean excluding those who were sedated on admission	9.4
Median	8.0
Median excluding those who were sedated on admission	10.0
Std. Deviation	5.6
Minimum	0
Maximum	15
Percentiles-25	3
50	8
75	15

Table 41 : Distribution of GCS after 24 hours

GCS after 24 hours	Number of patients	Percentage
3	45	38
mean excluding those who were sedated on admission	16	27
4 -7	11	9
8-12	25	21
13-15	36	31
Total	117	100

Figure 30: Distribution of GCS after 24 hours in survivals & non-survivals



32

Table 42 : Mechanical ventilation on admission

	Number of patients	Percentage	Non survivals	Crude Mortality
Not ventilated	54	46	6	11.1%
Ventilated	63	54	19	30.2%
Total	117	100	25	21.4%

Figure 31: Percentage of patients ventilated on admission compared with other NICS ICUs in Sri Lanka

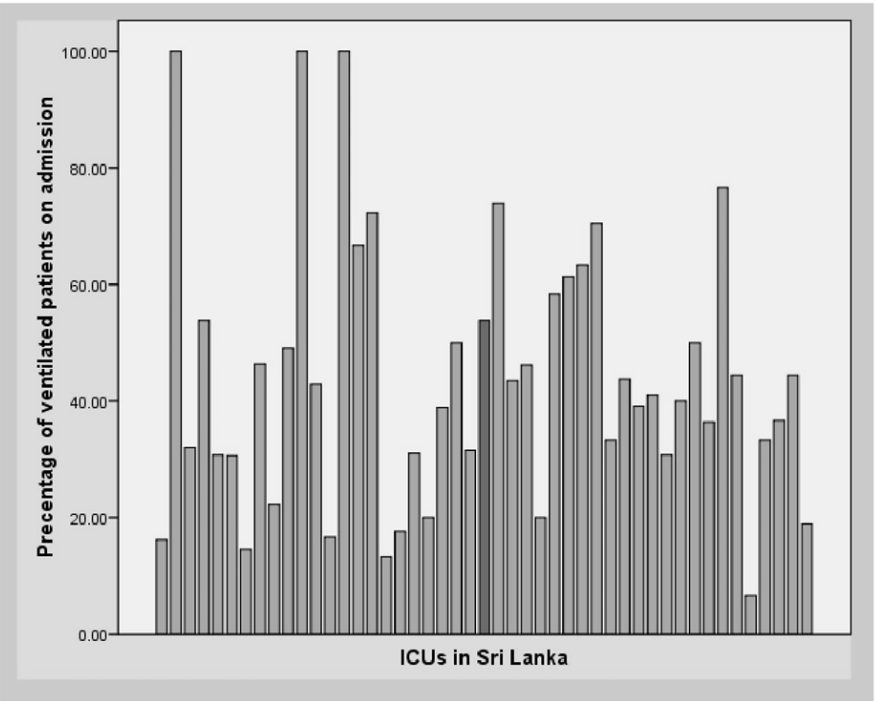


Table 43 : GCS of ventilated patients on admission

GCS on admission in ventilated persons	Number of patients	Percentage
3	43	68
4 -7	3	5
8-12	10	16
13-15	7	11
Total	63	100

SECTION E: PATIENT OUTCOMES

Table 44 : ICU Outcome

	Number of patients	Percentage
Living	54	46
Died	25	21
Missed	38	32
Total	117	100
Crude Mortality	21.4%	

Standarized mortality ratio for ICU = Actual number of deaths/ Sum of "APACHE II" probabilities of deaths
23/28.1
0.8

ICU mortality is taken for calculation of SMR instead of hospital mortality.

Figure 32: Crude mortality in ICU compared with other NICS ICUs in Sri Lanka

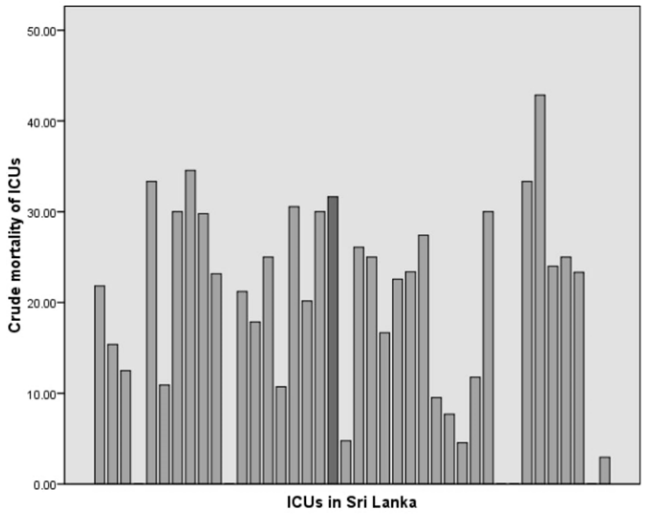


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Table 45 : Average "APACHE II" score

Mean	20.4
Median	18.0
Std. Deviation	10.4
Minimum	1
Maximum	43
Percentiles-25	12
50	18
75	29.75

Figure 33: Median "APACHE II" score compared with other NICS ICUs in Sri Lanka

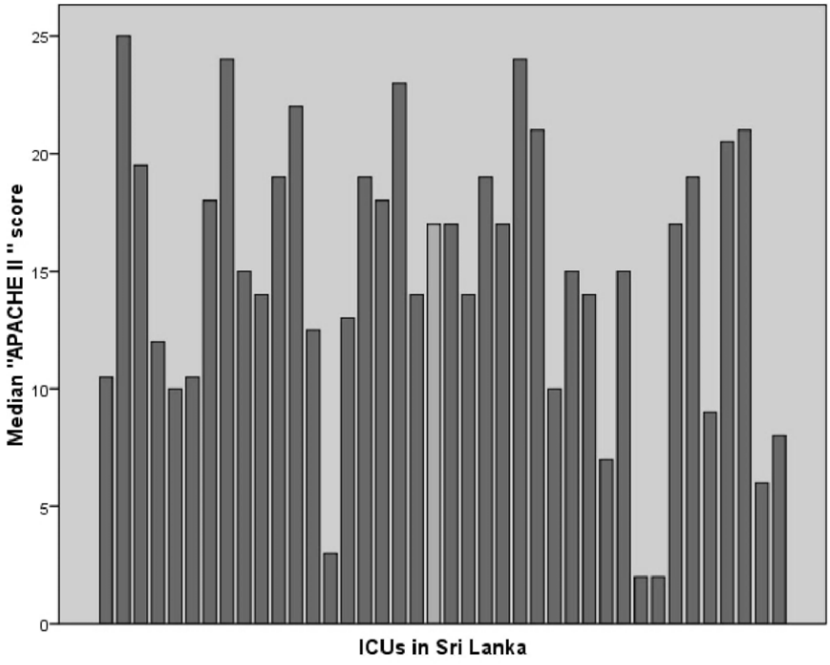

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Figure 34: Mean "APACHE II" score compared with other NICS ICUs in Sri Lanka

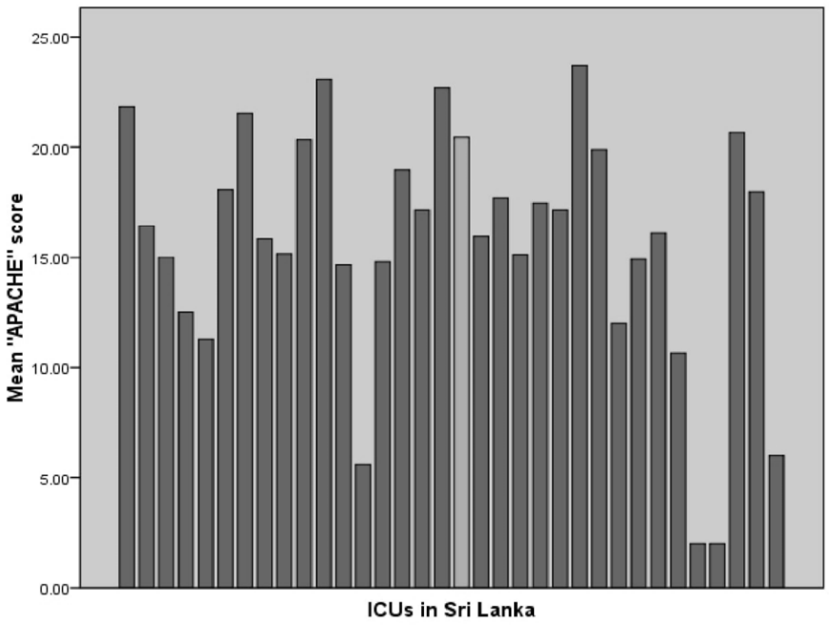

Table 46 - "APACHE II" exclusion criteria

	Number of patients	Percentage
CABG Patients	0	0
Burn-patients	1	0.9
Younger than 16 years	7	6
No ICU discharge	38	32.5
ICU stay < 8hours	1	0.9

Table 47 : Distribution of "APACHE II" score

"APACHE II" Score	Number of patients	Percentage	Number of ICU deaths	ICU Mortality	"APACHE II" probability %	No. expected Hospital deaths
Less than 15	25	35	0	0%	0.12	3.0
15 -19	12	17	3	25%	0.22	2.7
20-24	8	11	2	25%	0.48	3.8
25-29	9	13	4	44%	0.56	5.1
30-34	11	15	7	64%	0.69	7.5
More than 34	7	10	7	100%	0.86	6.0
Total	72	100	23.0	32%	0.49	28.1

Figure 35: Standarized Mortality Ratio compared with other NICS ICUs in Sri Lanka

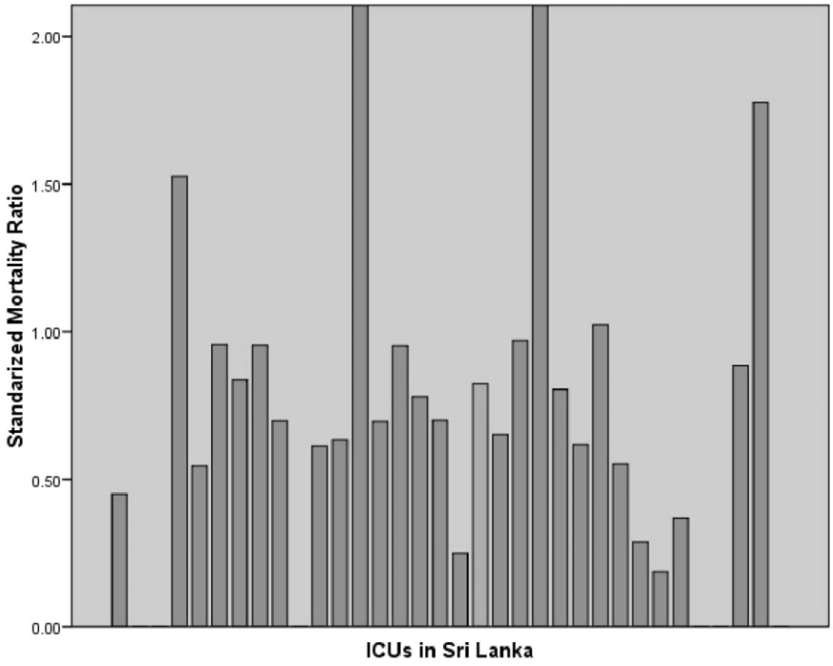

Figure 36 : Distribution of "APACHE II" score

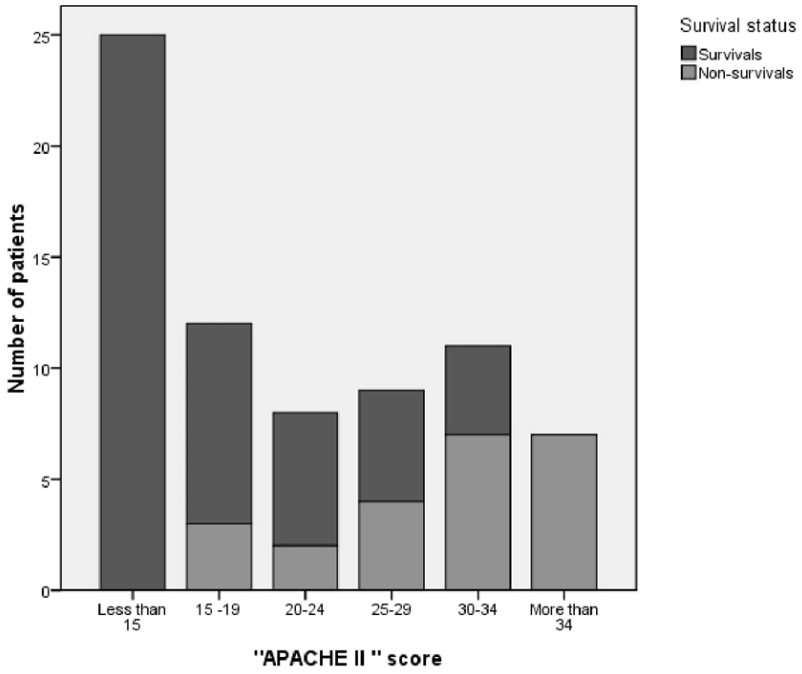

Table 48 : ICU Outcome with "APACHE II" inclusion criteria

	Number of patients	Percentage
Living	49	68
Died	23	32
Total	72	100
Crude Mortality	31.9%	

Table 49 : Comparison of "APACHE II score" in survivals and non-survivals

	Number of patients	Mean	Std. Deviation	p value
Non-survivals	23	30.09	7.64	0.00
Survivals	49	15.92	8.17	

Table 50 : Length of ICU stay

	ICU stay in hours	ICU stay in days
Mean	107.8	4.5
Median	70.5	2.9
Std. Deviation	121.4	5.1
Minimum	8.0	0.3
Maximum	802.0	33.4
Percentiles-25	44.8	1.9
50	70.5	2.9
75	124.5	5.2

Figure 37: Median ICU stay compared with other NICS ICUs in Sri Lanka

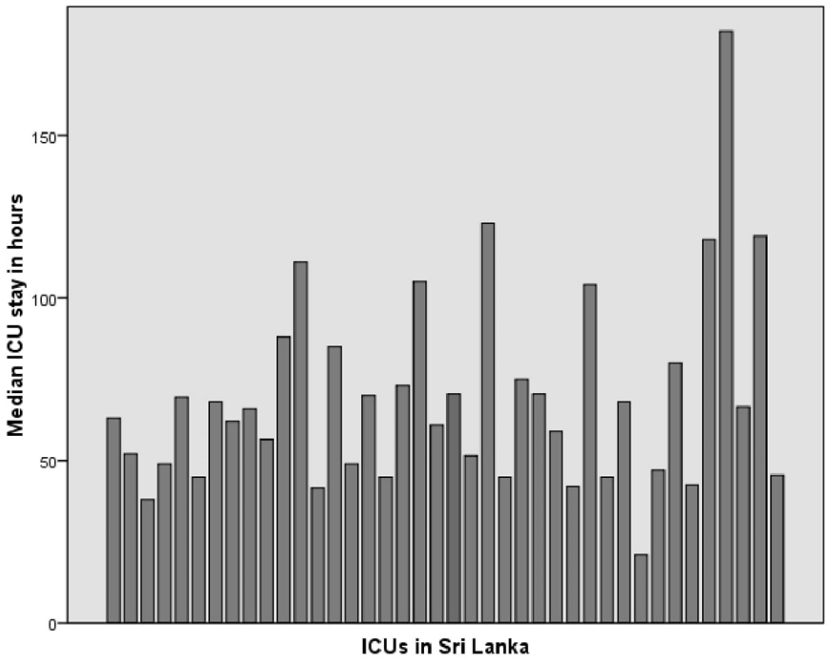

Table 51 : Distribution of Intensive care treatment duration

ICU stay duration	Number of patients	Percentage
ICU stay less than 1 day	8	6.8
ICU stay between 1 to 2 days	19	16.2
ICU stay between 3 to 5 days	19	16.2
ICU stay between 5 to 10 days	12	10.3
ICU stay more than 10 days	8	6.8
Missed	51	43.6
Total	117	100

Table 52 :Decisions to withdraw therapy

Decision to withdrawal	Number of patients	Percentage
Yes	3	3
No	22	19
Unfilled	92	79
Total	117	100

Table 53: Differences of characteristics in survivals and non-survivals

	Survivals	Non-survivals
Median duration of treatment	2.7 days	2.5 days
Mean GCS on admissions	10	8
Mean GCS after 24 hours	11	6
Mean APACHE II score	14	26
CPR on admission	1	6
Diabetes	3	3
Main organ failure on admission		
Cardiovascular	14	16
Renal failure	3	5
Neurological failure	1	1
Respiratory failure	23	19
Median number of organ failure on admission	1	2

Figure 38: Number of organ failures in patients

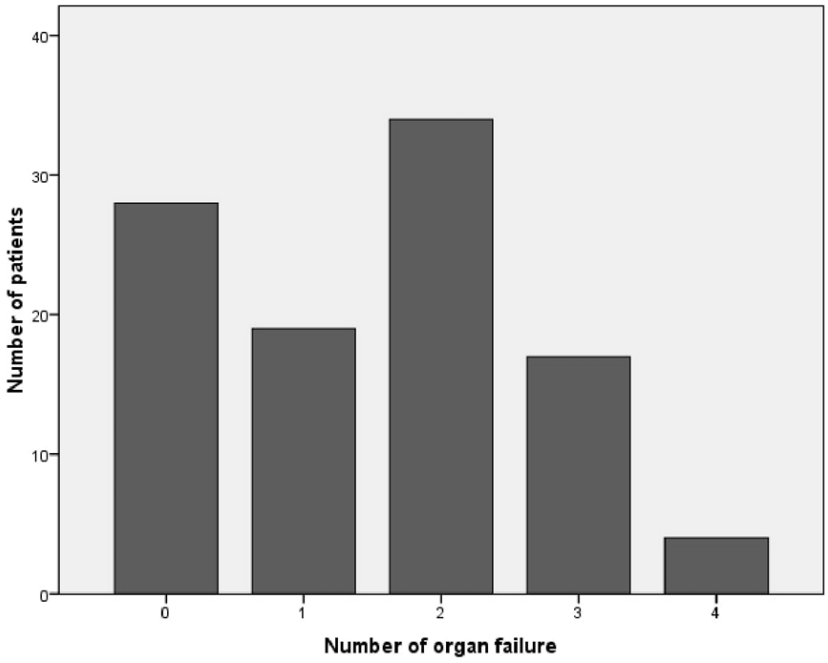

Figure 39: Type of organ failures in patients

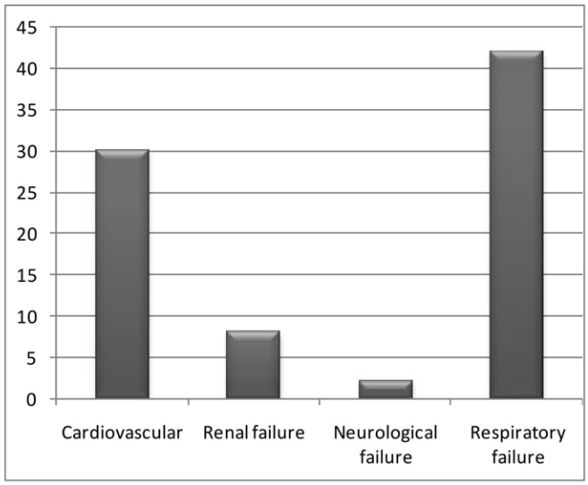

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Table 54: Organ support and ICU stay

Organ failure at admission	Number of patients	% of ICU stay in days
Respiratory failure	63	52
Cardiovascular failure	41	43
Renal failure	11	14
Neurological failure	54	47

% of ICU stay in days = Sum of ICU stay of patient's with particular organ failure at admission in days / Sum of ICU stay of all patient's in days

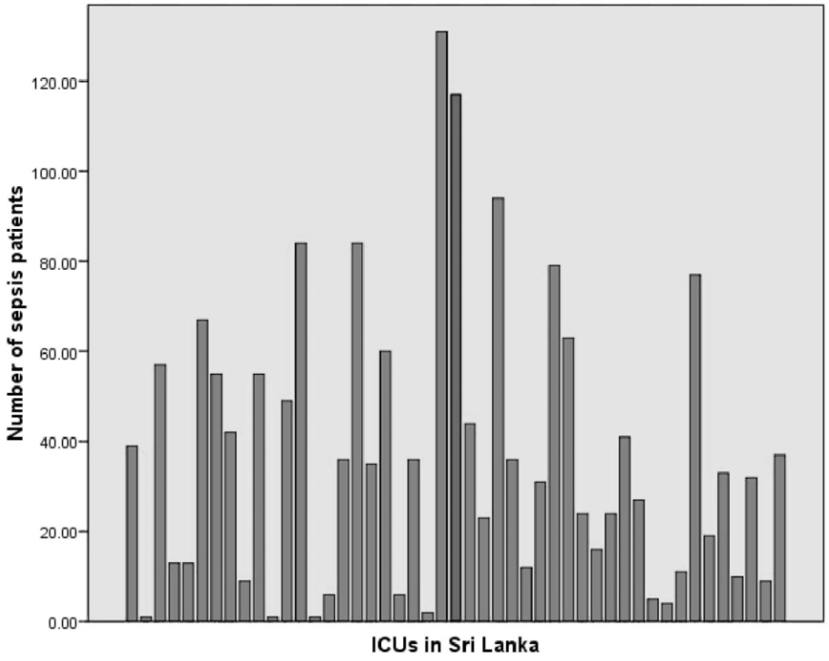
Sepsis patients

Table 55: Number of sepsis patients

	Number of patients	Percentage
Sepsis patients	11	9.4

Please see the definition of sepsis in the glossary.

Figure 40 : Number of sepsis patients in the ICU in comparison with other NICS ICUs in Sri Lanka



SECTION F: FOLLOW UP SERVICES

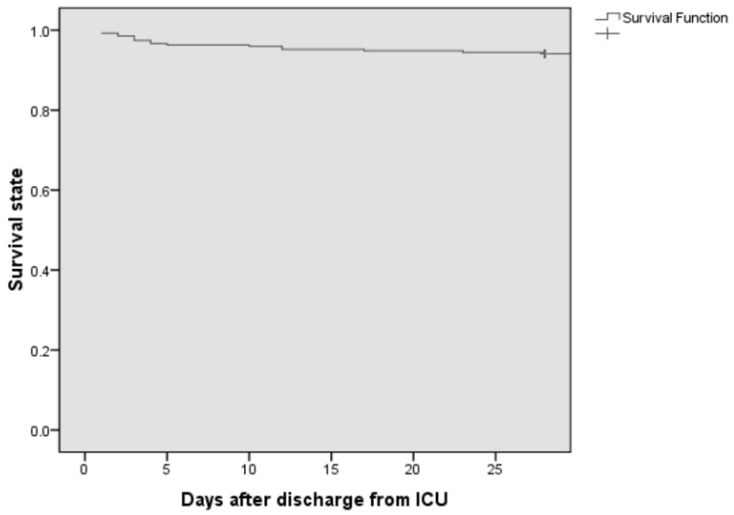
Table 60: Telephone follow up services in the ICU

	Number of patients	Percentage
Patients discharged alive from ICU	NA	NA
Number of patients/relatives contacted	NA	NA
Unreachable contact numbers of survivals	NA	NA
Died after hospital discharge	NA	NA
Survival rate of the patients after discharge from ICU	NA	NA
(Only those are contactable)	NA	NA

Figure 45 : Thirty day Kaplan-Meier survival curve

No follow up services are started in this ICU.

Sample Kaplan –Meier survival curve of all adult ICUs in Sri Lanka.



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