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Digital innovation in healthcare: Quantifying the impact of digital sepsis screening tools on patient outcomes, a multisite natural experiment.

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Abstract

The NHS ‘move to digital’ incorporating electronic patient record systems (EPR) facilitates the translation of paper-based screening tools into digital systems, including digital sepsis alerts. We evaluated the impact of sepsis screening tools on in-patient 30-day mortality across four multi-hospital NHS Trusts, each using a different algorithm for early detection of sepsis.

Using quasi-experimental methods, we investigated the impact of the screening tools. Individual level EPR data for 718,000 patients between 2010 to 2020 was extracted to assess the impact on a target cohort and control cohort using interrupted time series (ITS) analysis, based on a binomial regression model. We included one Trust which uses a paper-based screening tool to compare the impact of digital and paper-based interventions, and one Trust which did not introduce a sepsis screening tool, but did introduce an EPR.

All Trusts had lower odds of mortality, between 5 and 12%, after the introduction of the sepsis screening tool, before adjustment for pre-existing trends or patient case-mix. After adjustment for existing trends, there was a significant reduction in mortality in two of the three Trusts which introduced sepsis screening tools. We also observed age-specific effects across Trusts.

Our findings confirm that patients with similar profiles have a lower mortality risk, consistent with our previous work. This study, conducted across multiple NHS Trusts, suggests that alerts could be tailored to specific patient groups based on age-related effects. Different Trusts may require unique indicators, thresholds, actions, and treatments. Including additional EPR information could further enhance personalised care.

What is already known on this topic

A systematic review in 2019 found that the implementation of digital sepsis screening tools was linked to improved patient outcomes, including reductions in length of stay, but there was no evidence of associations with mortality or time to antibiotics.

What this study adds

This is the first evaluation of digital sepsis screening tools across multiple NHS hospitals in England. The results show that implementation of these digital screening tools is associated with a reduction in mortality associated with sepsis. The results also show that there are differential effects of these tools in different age groups.

How this study might affect research, practice or policy

We have shown that the picture is complex; adjusting for patient mix and pre-existing trends, the impact of sepsis screening tools differs for specific patient groups. Recent guidance from the UK NICE calls for tailored approaches to screening for sepsis and our findings support these calls. We propose that incorporating further information from the EPR could facilitate tailoring of these digital tools for specific patient populations.

Additional information

Contributor statement
CEC, KH, GC and the DiAlS co-investigators conceived this study. AT and KH analysed the data. CEC, KH and AT developed the early drafts of the paper. JW, AJB, AK, ACG and SP gave insights on their specific Trusts. All authors, including RL and PG, reviewed and edited early drafts of the manuscript. All authors contributed to the article and approved the submitted version. CEC is the guarantor for this study.

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Data availability statement: The data that support the findings of this study are available via the authors of this study. Restrictions apply to the availability of these data, which were used under license for this study. Data are available via the authors in conjunction with NIHR Health Informatics Collaborative, BRIDgE and iCARE if full permissions are obtained.

Introduction

Sepsis is an international public health problem. Screening for sepsis is widely implemented across countries as an essential approach to facilitate prompt treatment and improve patient outcomes in hospital settings, and protocols to support early identification and standardised treatment of sepsis have been developed all over the world, but vary in their approach..[1] The National Health Service (NHS) in England has introduced various incentives to improve sepsis screening in UK hospitals.[2] Many screening tools which are used to support early identification of patients with infection and at risk of developing organ failure were originally designed as diagnostics criteria.[3] In England, all healthcare organisations are expected to use the National Early Warning Score (version 2) (NEWS2), a generic screening tool indicating deterioration and hence the possibility of sepsis. There is a clear advantage of a common language being used across all organisations; Inada-Kim[4] warns against 'blinkered condition specific approaches' particularly when patients are admitted as emergencies.

The NHS 'move to digital' through the incorporation of electronic patient record systems (EPR) facilitates the translation of paper-based sepsis screening tools into digital systems, including digital sepsis alerts (DSAs). To improve care for patients with sepsis, comply with national financial incentive programmes, and make best use of the introduction of EPR, hospitals in England have introduced digital sepsis alerts. A variety of algorithms are in use, with different workflows and different implementation strategies. A recent survey of NHS Trusts in England suggests that EPR systems have been adopted by 89% of trusts, an increase from 77% in 2018.[2] It is not known whether the translation of traditional paper-based screening tools into digital systems improves patient outcomes.

Digital alerts have generally been introduced across hospitals without randomisation or in a phased approach which would have supported rigorous evaluation of their impact. A systematic review in 2019 found that the implementation of digital sepsis screening tools were linked to improved patient outcomes, including reductions in length of stay, but no evidence of associations with mortality or time to antibiotics.[5] A London based study in 2020 examined the impact of sepsis alerts introduced in a phased approach, and was evaluated using inverse probability of treatment weighting, common in the analysis of natural experiments to emulate a RCT using real world healthcare data. This showed the introduction of digital sepsis alerts was associated with a 23% lower risk of death within 30 days.[6] Alkurti et al (2022)[7] found similar reductions in hospital mortality in children. It is not clear that current sepsis screening tools and treatments are equally effective in all patient groups. Some evidence suggests that sepsis is an end-of-life condition and rapid treatment may be more important for younger patients.[8] Recently a large study has shown that patients from deprived backgrounds are more likely to have sepsis and more likely to die from sepsis.[9]

In this multi-site study, we aimed to determine the impact of the introduction of sepsis screening tools on in-patient 30-day mortality. To determine whether any impact on patient outcomes is associated with the digital nature of some sepsis screening tools we included a Trust which introduced a paper-based alert. To further understand whether changes in patient outcomes associated with the introduction of digital sepsis alerts we included a fourth Trust and considered the impact of the introduction of electronic health records as a sensitivity analysis. We considered whether screening tools have a different impact on younger patients or people from more deprived backgrounds.

Methods

This was a retrospective study to analyse the impact of the introduction of different sepsis screening tools in three NHS Trusts, with a fourth Trust acting as a control. The interventions in each Trust are shown in Table 1 and summarised by Lazzarino et al (2024).[10]

TRUST	SEPSIS SCREENING TOOL		DATE OF INTRODUCTION	PERIOD OF INCLUSION
A	Paper based	Based on 'Red Flad Sepsis'[1]	April 2016	March 2010 to February 2020
B	Digital	Based on 'Red Flag Sepsis'[1], locally adapted. Calculated whenever clinical observations are entered into the EPR.	May 2016	February 2013 to February 2020
C	Digital	Alert packaged as part of Cerner's EPR - the St John Sepsis Algorithm[2]. Calculated whenever clinical observations are entered into the EPR.	April 2017	April 2010 to February 2020
D	None – EPR introduction is intervention of interest		March 2019	April 2016 to February 2020

Table 1: The interventions and key dates for four NHS Trusts included in the study.

[1]Red flag sepsis includes clinical observations and lactate levels. See Table 1 Supplementary materials in Kopcynska (2018) for further details.

[2]St John's Sepsis Algorithm is based on clinical observations and blood test results. See Honeyford (2020) for further details

Timeline

Trusts provided data from as early as 01/04/2010; we included data from the first day of the month where data for the full month was available. The period of study ended on 31/01/2020 to account for the potential impact of COVID-19. In order to use all available data we but to account for different timings of the introductions of sepsis screening tools, we do not have identical periods of data for all Trusts.

The periods of study and the date of introduction sepsis tools is shown in Table 1.

Study design and population

Data for all adult (18+) inpatients admitted between 01/04/10 and 31/01/2020 were initially eligible for inclusion in the study.

We identified two cohorts of patients using ICD-10 codes in the patients' record:

Suspicion of Sepsis (SoS) Cohort: Patients we expected to be impacted by the introduction of a sepsis screening tool. We used published ICD-10 codes associated with bacterial infections that can cause sepsis.[7] This group is thought to mitigate against bias introduced through changes in coding practices. See Box 1 for more details.

Control Cohort: a comparator group of patients whose outcomes we didn't expect to be impacted by the introduction of the sepsis screening tool. These patients had had an upper gastro-intestinal bleed.[11] We excluded patients who had an ICD-10 code included in the SoS list.

Box 1 – Identifying patients with sepsis using routinely collected, structured data.

A key challenge in evaluating interventions to improve outcomes for patients with sepsis is that neither case note review nor administrative records are necessarily reliable for identifying patients with sepsis. The heterogeneric nature of sepsis means diagnosing sepsis involves considerable subjectivity.[12] Studies have found that relying on ICD-10 sepsis specific codes in administrative data can lead to under-estimates of sepsis incidence,[13] particularly

patients with less severe sepsis.[14] In addition, sudden changes in coding practice can have a big impact.[15] Many interventions, which often target sepsis awareness, can also lead to increases in the recording of sepsis. Digital interventions, such as the ones studied in this paper, often automate the coding of sepsis based on clinician responses, so may also increase the recording of ICD-10 sepsis codes. An additional challenge, which is less discussed, involves the definition of sepsis as an infection which leads to organ dysfunction, Rhee et al[12] have pointed out that it is not always clear whether the organ dysfunction is a result of the infection, but in addition, a strong sepsis intervention may reduce the opportunity of infection resulting in organ dysfunction, if the infection is identified and treated earlier. This may lead to a decrease in patients with sepsis, but may not improve more severe outcomes such as mortality.

These many challenges mean that when studying interventions to improve outcomes for patients with sepsis, focussing only on patients with an ICD-10 code for sepsis is likely to be biased, and the cause of that bias is multifactorial, and is likely to be influenced by the intervention.

In this study, we use an established list of infection codes to define the denominator, these codes have been shown to be more resistant to bias, and in this study, we include sensitivity analysis to determine if this is the case in the Trusts we have included in our analysis.

The list was developed by Inada-Kim et al[16] and is known as the Suspicion of Sepsis code list; a list of codes which 'identifies patients with a bacterial infection serious enough to warrant admission'[17] and considered to be as inclusive as possible.

Data

Electronic patient record (EPR) data were provided by NHS Trusts. Data used in this study were routinely collected, processed by Trusts to comply with NHS requirements for Secondary Uses Service.[17] These data are quality checked by individual Trusts before being submitted to the NHS, and are compiled into Hospital Episode Statistics which have been widely used for research in the UK.[18] Data are stored by Trusts and were made accessible to us via secure data environments, with appropriate data sharing and access government arrangements. See Box 2 for additional information. No verbal or written informed consent from individual patients was required for data set generation. This study was approved by the Health Regulatory Authority (288328).

Box 2 – Data Sharing

A key strength of this study was the collaboration between four NHS Trusts providing data in sharing, analysing and interpreting data. The NIHR-Health Informatics Collaborative facilitated data sharing agreements between the NHS Trusts. We worked with clinicians and health informatics specialists to develop a data dictionary enabling a wide range of research projects. Health Informatics managers at each NHS trust quality checked and processed the data according to the data dictionary, before subsequent transfer to either Imperial Clinical Analytics, Research and Evaluation (iCARE)[19] or Biomedical Research Informatics Digital Environment (BRIDgE)[20] secure data environments.

Data processing

Each patient admission was treated as a separate event with a binary outcome: in-hospital mortality within 30 days of admission. Patient demographic information was linked to hospital admissions through unique patient IDs, Patients were excluded if their age or gender was missing or if their patient id was missing. Less than 15 hospital admissions were excluded in each Trust.

Statistical analysis

Main analysis

Descriptive statistics were used to summarise in the patient cohorts over time and between Trusts.

We assessed the impact of the introduction of digital sepsis alerts, paper-sepsis-screening tools and the introduction of an EHR on in-hospital mortality in the SoS cohort and separately on the control cohort using an interrupted time series (ITS) study design, based on a segmented binomial regression model, including a time index and an intervention

variable to indicate whether the time variable is before or after the intervention as independent variables.[21] This design means trends before the intervention are included in the model, allowing us to compare the actual mortality rate after the intervention with the counterfactual, i.e., the predicted mortality if there had been no intervention.[22]

To reduce potential bias introduced by differences in the pre- and post- intervention cohorts, we adjusted for patient case-mix; including age, ethnicity, gender, and comorbidities using the weighted Elixhauser score. We also adjusted for hour of admission and seasonality.

A priori we considered whether sepsis alerts might have an impact on different patient groups; we hypothesised that sepsis screening tools might have different effects on older, frailer patients and patients with a higher level of comorbidities. We therefore modelled two interaction terms: age and comorbidities in separate models.

Sensitivity analyses

Sepsis incidence:. To confirm our hypothesis that studying patients coded as having sepsis can be impacted by coding practice, as described in Box 1, we plotted the incidence and mortality in patients with an SoS code and a sepsis code over time.

Additional adjustment for deprivation: We modelled the impact of the introduction of a sepsis screening tool adjusted for deprivation for these Trusts for the two Trusts were able to supply data on deprivation, based on the Index of Multiple Deprivation(IMD) score.[23]

RESULTS

In total, we examined mortality patterns in 607,980 SoS patients across three Trusts. In Trust A we included 156,387 patients who were admitted over 119 months, in Trust B 248,301 patients over 85 months, in Trust C 203,212 over 118 months and Trust D 110,110 over 46 months.

In all Trusts, the SoS cohort had more females than males, with a high proportion aged 65 and over, and the majority exhibiting at least one comorbidity. Admission rates were lowest between 20:00 and 07:00. The admission rate was similar in the winter and non-winter months. Approximately 40% of SoS patients at Trusts A, C and D are coded as white British and Irish, compared to nearly 80% in Trust B. We included all patients, even those with missing ethnicity; ethnicity was not known (either not stated or missing) for approximately one sixth of patients. See Table 2 for more details.

Trusts A, B and C had significantly lower mortality after the introduction of the sepsis screening tool before adjustment for pre-existing trends or patient case-mix. After adjusting for pre-existing trends, there was a significant reduction in mortality in Trusts A and C, as shown in Figures 1 and 2.

Table 2: Summary of patients admitted with the SoS before and after the introduction of a sepsis screening tool. Counts and % of all admissions in brackets.

	Trust A[4]		**Trust B[5]**		**Trust C[5]**		**Trust D[6]**	
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
No. of patients admitted	**79527**	**76860**	**66419**	**181882**	**116404**	**86888**	**43046**	**67064**
Gender								
Male	34495 (43.4)	33709 (43.9)	31257 (47.1)	86356 (47.6)	52033 (44.7)	39002 (44.9)	19903 (46.2)	32130 (47.9)
Female	45032 (56.6)	43151 (56.1)	35162 (52.9)	95526 (52.4)	64371 (55.3)	47886 (55.1)	23143 (53.8)	34934 (52.1)
Ethnicity								
White British and Irish	34409 (43.3)	31053 (40.4)	53296 (80.2)	136944 (75.3)	51324 (44.1)	30006 (34.5)	19081 (44.3)	27490 (41)
Asian[1]	10217 (12.8)	11253 (14.6)	2313 (3.5)	6219 (3.4)	12540 (10.8)	9298 (10.7)	3615 (8.4)	6342 (9.5)
Black[2]	4160 (5.2)	3554 (4.6)	880 (1.3)	2462 (1.4)	13354 (11.5)	9641 (11.1)	3401 (7.9)	6249 (9.3)
Any other Ethnicity	17108 (21.5)	16582 (21.6)	2741 (4.1)	9998 (5.5)	27813 (23.9)	21707 (25.0)	8482 (19.7)	14476 (21.6)
Not Stated	9662 (12.5)	12913 (16.8)	6920 (10.3)	24861 (13.6)	5309 (4.6)	10584 (12.2)	3791 (8.8)	11171 (16.7)
Not Known or Missing	3971 (5.0)	1505 (2.0)	269 (0.4)	1443 (0.7)	6064 (5.2)	5652 (6.5)	4676 (10.9)	1336 (2)
Age[3]	49 (27, 64)	61 (37, 77)	55 (30, 70)	52 (29, 66)	55 (33, 70)	49 (27, 64)	59 (37, 76)	58 (36, 74)
Elixhauser score[3]	5 (0,12)	3 (0, 8)	3 (0, 8)	4 (0, 10)	4 (0, 10)	5 (0,12)	2 (0, 8)	4 (0, 11)
Season of admission								
Winter (Dec-March)	32720 (37.7)	26767 (34.8)	24852 (37.4)	60158 (33.1)	37442 (32.2)	32720 (37.7)	13536 (31.4)	20736 (30.9)
Spring, Summer, Autumn (April to Nov)	51377 (62.3)	50093 (65.2)	41567 (62.6)	121724 (66.9)	78962 (67.8)	51377 (62.3)	29510 (68.6)	46328 (69.1)
Time of admission								
Morning (7:00-9:00)	10941 (12.6)	8182 (10.6)	9414 (14.2)	31682 (17.4)	14018 (12.0)	10941 (12.6)	8227 (19.1)	13768 (20.5)
Midday (10:00-13:00)	16905 (19.5)	13761 (17.9)	14385 (21.7)	43711 (24.0)	19099 (16.4)	16905 (19.5)	8646 (20.1)	14217 (21.2)
Afternoon (14:00-19:00)	28146 (32.4)	24997 (32.5)	23606 (35.5)	59811 (32.9)	39434 (33.9)	28146 (32.4)	12003 (27.9)	17958 (26.8)
Night (20:00-6:00)	30869 (35.6)	29920 (38.9)	19014 (28.6)	46678 (25.7)	43853 (37.7)	30869 (35.6)	14170 (32.9)	21121 (31.5)
Patients who died	4200 (4.8)	3017 (3.9)	3979 (6.0)	9429 (5.2)	5834 (5.0)	4200 (4.8)	1205 (2.8)	2251 (3.4)

[1]*Asian, Asian British and Mixed Asian*
[2]*Black, Black British and Mixed Black*
[3]*Median and interquartile range*
[4]*Paper based screening tool*
[5]*Digital based screening tool*
[6]*EPR introduced*

Table 3: Interrupted time-series analysis of the impact of sepsis screening tools on mortality outcomes for SoS patients in three NHS Trusts in England.

	Trust A		Trust B		Trust C		Trust D	
Variable	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Alert/EPR introduction	0.931 (0.822, 1.054)	0.261	0.961 (0.877, 1.053)	0.391	0.826 (0.749, 0.911)	0.0001	1.271 (1.006, 1.605)	0.0442
Time in days since the start of the study period (gradient)	1.000 (1.000, 1.000)	0.003	1.000 (1.000, 1.000)	0.041	1.000 (1.000, 1.000)	0.0003	1.000 (1.000, 1.000)	0.1468
Time in **years** since the start of the study period	1.044 (1.020, 1.068)	0.003	0.963 (0.929, 0.998)	0.041	1.025 (1.012, 1.039)	0.0003	0.999 (0.998, 1.000)	0.2106
Change in gradient[1]	1.000 (1.000, 1.000)	0.133	1.000 (1.000, 1.000)	0.968	1.000 (1.000, 1.000)	<0.0001	1.227 (1.098, 1.372)	0.0003
Season of admission (reference is Feb – Oct) Winter admission	1.174 (1.103, 1.250)	<0.0001	1.112 (1.061, 1.166)	<0.0001	1.097 (1.046, 1.151)	0.0001	1.000 (1.000, 1.000)	0.0000
Time of admission (reference is Morning)								
Afternoon	1.526 (1.318, 1.767)	<0.0001	1.735 (1.583, 1.901)	<0.0001	1.446 (1.313, 1.593)	<0.0001	2.468 (2.001, 3.044)	<0.0001
Midday	1.380 (1.178, 1.618)	0.0001	1.630 (1.479, 1.796)	<0.0001	1.324 (1.190, 1.473)	<0.0001	1.402 (1.098, 1.791)	0.0068
Night	1.562 (1.351, 1.807)	<0.0001	1.856 (1.692, 2.037)	<0.0001	1.565 (1.422, 1.722)	<0.0001	2.837 (2.310, 3.485)	<0.0001
Ethnicity (reference is White British and Irish)								
Ethnicity – Any other	0.658 (0.592, 0.732)	<0.0001	0.968 (0.832, 1.126)	0.675	1.042 (0.982, 1.106)	0.1771	0.815 (0.699, 0.952)	0.0096
Asian[2]	1.203 (1.096, 1.321)	0.0001	0.707 (0.578, 0.866)	0.0008	0.949 (0.875, 1.029)	0.2071	0.960 (0.782, 1.177)	0.6920
Black[3]	0.550 (0.430, 0.703)	<0.0001	0.952 (0.712, 1.273)	0.741	0.820 (0.753, 0.894)	<0.0001	1.173 (0.955, 1.441)	0.1284
Not Known or Missing	1.011 (0.883, 1.157)	0.877	2.765 (2.064, 3.704)	<0.0001	0.905 (0.802, 1.023)	0.1103	1.589 (1.299, 1.944)	<0.0001
Not Stated	0.878 (0.800, 0.964)	0.006	1.426 (1.325, 1.534)	<0.0001	1.309 (1.196, 1.433)	<0.0001	1.339 (1.109, 1.617)	0.0024
Age (in years)	1.051 (1.048, 1.053)	<0.0001	1.046 (1.044, 1.047)	<0.0001	1.040 (1.039, 1.042)	<0.0001	1.032 (1.029, 1.035)	<0.0001
Gender (male is reference) Female	0.878 (0.826, 0.933)	<0.0001	0.892 (0.852, 0.934)	<0.0001	0.932 (0.890, 0.975)	0.0024	0.918 (0.828, 1.017)	0.1026
Elixhauser score	1.112 (1.108, 1.116)	<0.0001	1.114 (1.111, 1.118)	<0.0001	1.111 (1.108, 1.114)	<0.0001	1.116 (1.110, 1.123)	<0.0001

Interrupted time-series data are presented as odds ratios (95% CI), except where specified. Values are given to three decimal places

[1]Interaction between time in days since the start of the study period and the introduction of the alert
[2]Asian, Asian British and Mixed Asian
[3]Black, Black British and Mixed Black

In Trust A, crude analysis indicated that there was reduction in mortality rate following introduction of the screening tool (see Figure 1). After adjusting for time and season of admission; and patient case mix, the screening tool showed no impact on mortality (see Table 3 for more details). We investigated whether the alert had differential impacts on specific patient groups by fitting interaction terms. This suggested that the introduction of the screening tool was significantly associated with a reduction in mortality in older patients, but not younger patients (see Table S2 for details). There was no evidence of a different impact on patients with more comorbidities.

In Trust B, prior to the introduction of a digital sepsis alert there was a decreasing trend in mortality in patients in the SoS cohort and the association of the introduction of the alert with mortality is not significant in both crude and adjusted analyses. However, the interaction between age and the introduction of the alert is significant, suggesting that the alert had a significant impact on reducing mortality in older patients, but not in younger patients.

In Trust C there was an increasing trend in mortality prior to the introduction of a digital sepsis alert, and an increase in odds of mortality of 2.6% (95%CI:1.2% to 4.0%). The introduction of the alert is associated with a decrease in odds of mortality of 14% (21% to 5%). In addition, after the introduction of the alert the trend in mortality rate changes to a decreasing mortality rate. However, there was no significant interaction between the introduction of the alert and age, suggesting the alert does not have a differential impact in patients of different ages.
The introduction of the EPR in Trust D was apparently associated with an increased odds of mortality of 27% (95%CI: 0.6% to 60%), we propose that this is likely to be to do with coding and recording changes as a result of both the introduction of the EHR but also national sepsis coding guidelines in April 2017 and again April 2018, which have been shown to have centre specific impacts on mortality.[24]

While the primary objective of the statistical models is to assess the impact of digital sepsis screening alerts following case-mix adjustment, the significance of various case-mix variables presents intriguing and complex pattern. The risk of mortality rises with age over 18 and higher Elixhauser scores. Being female is associated with a decreased risk of death. Additionally, mortality risk increases when patients are admitted during winter and not in the morning. The influence and significance of ethnicity on the risk of mortality exhibit variations across trusts. For example, being Asian or Asian British was associated with 20% higher odds of death in Trust A (95%CI:10% to 32%), a 29% lower odds of death in Trust B (95%CI:13% to 42%) and no significant association with mortality in Trust C. In addition, nighttime admissions had a higher risk of mortality, across all Trusts.

Control cohort

To determine if any change in mortality rate was specific to patients with an infection rather than patients who are acutely deteriorating, we modelled mortality in patients with a gastric bleed, who didn't also have an SoS diagnosis. There was no statistical evidence ($p>0.05$) that the introduction of sepsis screening tools was associated with a decrease in mortality in this cohort. Both increasing age and Elixhauser score were significantly associated with increased risk of mortality (see Table S3 & 4 in the supplementary materials for more details).

Sensitivity Analyses

Sepsis incidence: We investigated whether our hypothesis that the introduction of DSAs and financial incentives associated with sepsis screening affected the number of people with a sepsis diagnosis; which would justify our approach of using patients with a diagnosis from the Suspicion of Sepsis code list, rather than patients with an ICD-10 code specifically for sepsis. We found that the incidence of sepsis increases when a sepsis screening tool is introduced, and again when the coding policy changed in England. Although the number of patients who died during these times also increases the case fatality is less. See Figure S1 in the supplementary materials.

Additional adjustment for deprivation: Only two trusts provided data on deprivation. Including this in the model had no effect on the overall model interpretation. Patients with no deprivation recorded had the highest odds of death. For patients with a score, there was no significant association with mortality.

DISCUSSION

All Trusts had a lower mortality rate in patients with a serious infection, identified by the SoS code list, after the introduction of a sepsis screening tool. After adjusting for patient case-mix, admission patterns and pre-existing trends, the introduction of a sepsis screening tool was significantly associated with a decrease in mortality rate in one Trust. In the remaining two Trusts, there was evidence that the introduction of a sepsis screening tool was associated with a reduction in mortality rate in older patients.

We have previously shown that patients for whom a digital sepsis alert was active had a lower risk of mortality than for those who had a similar profile.[6] These results confirm these results, across multiple NHS Trusts this lower risk, even when previous trends are considered. Previously, paper-based screening tools have been shown to be associated with a reduced risk of mortality.[25] We found evidence that the introduction of a paper-based screening tool impacted mortality in an older patient cohort only. We have not found previous research which has looked at the differential impact of the sepsis screening tools on different groups of patients. The literature on the effectiveness of digital sepsis screening tools shows that our findings, with different impact in different healthcare organisations, is consistent. Evidence is unclear and the rationale for different impact in different settings is not well understood. Trust C's algorithm includes blood test results, which may be more useful, or perhaps the alert introduced at Trust C was the right alert for the patient population at the right time, and this is why a clear impact was seen. The underlying trend in mortality prior to introduction may also be important.
Crude changes in mortality rates may show that sepsis screening tools reduce mortality, and many NHS Trusts have highlighted the impact of new tools.[26] We have shown that the picture is more complex, and after adjusting for patient mix and pre-existing trends the impact of sepsis screening tools may not be clear.

Across England, digital screening tools in NHS hospitals are based on paper-based screening tools embedded in EPRs;[2] generally they do not exploit the extensive data held in EPRs or utilise machine learning algorithms to personalise alerts. The picture with digital screening tools is complex, for example, evaluations of the Epic Sepsis Model have suggested a reduced risk of mortality[27] but some suggest possible harm due to its poor diagnostic performance.[28] Digital screening tools embedded in EPRs have advantages when compared to paper-based screening systems, they can be linked directly to treatment plans, which has been shown to improve adherence.[29]

A recent national study suggested that people of white ethnicity had the highest sepsis mortality risk.[9] We found different mortality risks for different ethnic groups between Trusts, suggesting that the impact of ethnicity is different in different NHS Trusts. We retained 'not stated' and 'missing' as different ethnic groups, and saw different odds of mortality, suggesting different Trusts may use these codes differently. The groups in use may not best describe ethnic groups in different areas of England, and not be comparable internationally.[30] We explored deprivation in two trusts and did not find poorer outcomes for patients from more deprived areas, but did find having no IMD score was associated with poorer outcomes. This group may be more likely to have no permanent residence, and therefore be representative of the most vulnerable patients.

As with many studies on sepsis, we are limited by the challenges of a gold-standard for sepsis diagnosis. We used the diagnosis list suggested by Inada-Kim et al.[4] We have explored this in Box 1. There was an increasing trend in SoS admissions during the period of study. Possible causes for this include increasing numbers of admissions, or increasing admissions of patients with infections, or less severely ill patients being included in the cohort due to changes in coding. The use of an ITS approach takes into account underlying trends and helps to disentangle these

from the impact of interventions. Despite using this recommended method for determining causal inference[31] we cannot determine that the sepsis screening tools are solely responsible for changing behaviour which leads to reductions in mortality, and other confounders such as changes in staffing, pressures in the hospital, paramedic responses to suspected sepsis and treatment plans may be important factors in the changes we observed. Another factor to consider is the potential overlap between patients with an SoS cohort and those who triggered an alert A further, detailed patient level analysis which considers this in detail is in progress and part of ongoing work for a separate publication. We carried out sensitivity analysis to determine if any changed in the mortality risk in SoS patients were also seen in patients with a non-related condition, and found no evidence of an associated reduction in mortality risk. In addition, we have shown that the introduction of an EPR was not associated with reduced in mortality. In the future, we will look at patient level analysis

Screening tools and digital alerts should be designed with a strong evidence base. Different patient groups within different Trusts may need different indicators, different thresholds for action and/or different actions and treatments. A parallel qualitative study from our team[10] highlights calls from healthcare practitioners, who advise that sepsis screening tools should be more specific, patient-based, target healthcare practitioner teams, be portable and remotely accessible, and integrate community, ambulance, and primary care with secondary care to accelerate ED triaging. A key advantage of EPRs and embedded digital tools is that screening and treatment can be readily personalised, without expecting health care professionals to look up specific guidance. Our results also support recent UK NICE guidelines which highlights that current sepsis screening tools are dependent on use of individual variables informed by low quality evidence.

For evidence-based screening tools, we need to have strong evaluations of interventions in health care, and work collaboratively to share data and research methodology. The rich data from EPRs is a vital resource for identifying the need for digital innovation; developing and validating models; and evaluating interventions. We have shown that with detailed preparation and effective collaboration we can establish results which support a wider understanding of the complex nature of preventing mortality from sepsis.

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Figure Titles

Figure 1 Odds Ratios for impact of the introduction of a sepsis screening tool, adjusted for pre-existing trends, but not for case-mix

Figure 2: 30-day mortality trend in the SoS cohort. Dots represent the actual mortality, dashed line represents the counterfactual if there was no intervention, and the solid line represents the modelled mortality pre the intervention, and post as if there was no intervention..