Viewpoint: digital paediatrics - so close yet so far away

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Abstract

Technology is driving a revolution in health care, but paediatric services have not fully harnessed the potential. Digital health solutions yet to achieve their promise in paediatrics include electronic health records, decision support systems, telemedicine and remote consultations, despite the accelerated uptake during the Covid19 pandemic. There are also significant potential benefits in digitally enabled research, including systems to identify and recruit participants online or through health records, tools to extract data points from routine datasets rather than new data collection, and remote approaches to outcome measurement. Children and their families are increasingly becoming digital health citizens, able to manage their own health and use of health services through mobile apps and wearables such as fitness trackers. Ironically one barrier to the uptake of these technologies is that the fast pace of change in this area means the evidence base behind many of these tools remains underdeveloped. Clinicians are often sceptical of innovations which appear largely driven by enthusiasts rather than science. Rigorous studies are needed to demonstrate safety and effectiveness. Regulators need to be agile and responsive. Implementation needs adequate resource and time, and needs to minimise risks and address concerns, such as worries over losing human contact. Digital health care needs to be embedded in medical education and training so that clinicians are trained in the use of innovations and can understand how to embed within services. In this way, digital paediatrics can deliver benefits to the profession, to services, and to our patients.

The new age: a digital revolution is underway

The non-medical world is already in the middle of a digital revolution. Digital medicine undoubtedly holds great promise, but the *paediatric healthcare service* is mostly falling short of widely benefitting from novel digital technologies. While the healthcare innovation market is booming, a recent study report suggested less than 1% of this investment is on children's digital health ¹. The Digital Medicine Society defines digital medicine as "a field, concerned with the use of technologies as tools for measurement, and intervention in the service of human health". This includes technology supporting administrative functions such as electronic records systems, digital health services such as remote consultations or remote monitoring of sensors or wearables, as well as digital tools (including health apps) that provide diagnosis, treatment or self-management, decision-support tools, and a range of data analytic tools which are increasingly used to derive new knowledge from large, often linked, datasets. Technology has been driving a revolution in health care. Digital health tools have the vast potential to improve our ability to accurately diagnose and treat disease, to harness datasets to increase our understanding of epidemiology and pathogenesis, and to enhance the delivery of health care for the individual.

One key example of a missed chance for *paediatric healthcare* is the electronic medical record (EMR). Even though its utilization is increasing, most paediatricians are either working with suboptimal EMRs or are not using EMRs with even basic paediatric functionality, such as weight-based dosing or preventive care decision support ². A survey addressed to 709 *US American Academy of Pediatrics* members in 2016 revealed that 31% used only basic features and only 16.9% used fully functioning EMRs including paediatric functionality. 41% either used EMRs lacking basic functionality or used no EMRs at all. The risk to child health is that the opportunities of EMRs to reduce medical errors, improve guideline adherence, support decision-making and diagnosis, are not being realised for this population. Paediatric healthcare needs a stronger lobby in the EMR technology design and

production industry. The use of telemedicine for remote consultation and care, although recently accelerated in the context of the Covid19 pandemic, is another example of a largely - as yet – untapped opportunity for child health.

Second, there are missed chances also for *paediatric research*. Patient (and professional) participation in paediatric clinical trials is suboptimal³. Digital solutions could improve this. At a basic level electronic records systems can help identify eligible participants; with more sophistication personal health records allow potential participants (or their parents) to indicate a willingness to take part in a study; *real world evidence* studies can use data points from routine records rather than collecting patient information *de novo*. Health websites and social media can be used to not only advertise research studies, but also to host study recruitment, including taking participants through a process of online consent and screening and baseline measures. But these tools are only being adopted slowly and in ad hoc fashion. A more systematic and connected approach is needed to fully harness digital platforms for all research, and in paediatric in particular this can help provide a broader representation of children in clinical trials, and allow more flexible and convenient participation (for example remote outcome measurement reduces potential disruption to education and home life by avoiding the need to travel to a healthcare site).

Third, as individuals increasingly become digital health citizens, using the internet and consumer tools such as mobile phones or fitness trackers to manage their own health and health care, health services need to understand how to harness the willingness and ability of patients and families to engage with and use such technologies. These may (for example) be wearables which track physiological function, patient-facing health apps or websites providing information or self-management tools, or health portals with access to health records and data such as test results or appointments. However, children and their families may have privacy, security and trust concerns

regarding digital tools.⁴ There is a need to help patients and families navigate these technologies, understand issues of safety and effectiveness as well as trust and data security, and support their use for maximum benefit. Initiatives such as consumer app evaluation platforms may support this, alongside approaches which provide end users (children and families) with the skills to make their own judgments. Healthcare professionals also have a role as advocates, and can share information and encourage use of appropriate tools.

Paediatric healthcare providers and biomedical researchers should embrace digital innovations to improve child health

The digital health market is ever-expanding. Digital technologies - from basic decision tools to artificial intelligence 'chatbots' and sophisticated wearables - are readily available. **Table 1** provides an overview of benefits and limitations for key digital technologies and features specific examples of digital medicine solutions in the field of paediatric healthcare. To date, the evidence-base for many of these tools has remained relatively underdeveloped. Digital technologies are often driven by enthusiasts, and not necessarily by unmet medical need, and high quality research studies demonstrating benefit are uncommon⁵. This is an emergent industry dominated by small or medium size enterprises and not by 'big pharma', and long-term research investment is unusual. At the same time, the pace of change in digital health often means that an intervention will have evolved by the time a long-term trial has reported. All of this means that where studies exist, they tend to be small scale and short term, with proxy measures often replacing longer term clinical outcomes. Alongside the usual challenges of acceptability, efficacy and safety, digital tools must also address issues of information security, data privacy and interoperability. It is important to also acknowledge that many clinicians remain sceptical of the benefits of digital tools and successful implementation requires engaging with such stakeholders and demonstrating the benefits to their own work.

A shining example of a medical wearable with undoubted proven clinical benefit is the real-time continuous glucose monitoring device. Multinational, multicentre RCTs have demonstrated reduced exposure to prolonged or severe hyperglycaemia and hypoglycaemia and less severe adverse events, both in adolescents ⁶ as well as in preterm neonates ⁷. Similarly, Palmer et al. recently provided an impressive real-world example for the enormous potential of integrated antenatal care using telehealth ⁸. Analysing > 20 thousand consultations of 2292 women giving birth in an interrupted time-series design demonstrated the successful reduction of in-person consultations by 50% without compromising pregnancy outcomes.

What the field needs now, is to bridge the gap between emerging technologies and shortcomings in health care delivery. The response to the COVID-19 pandemic has demonstrated advantages that these technologies can hold, including the widespread use of remote consultations, the harnessing of mobile health apps for contact tracing and disease surveillance, and rapid studies of linked datasets to derive new knowledge on an emerging issue.

A rocky road ahead? Limitations and barriers, and how to overcome them

These emerging technologies must be evaluated, kept valid, updated, free of bias, and specifically adapted for paediatric and neonatal healthcare. This requires scientific rigor, quality control mechanisms, transparency and essentially a paediatric advocate through each step of the entire process from initial tool design to its widespread clinical implementation. Minimizing patients' risks and adequate handling of personal sensitive data are essential. The feared perceived loss of "*the human touch*" and the black box momentum - the uncertainty regarding specific mechanisms of action - of novel technologies that many digital innovations hold, raise potential safety concerns that ought to be thoroughly addressed to improve security and trust. Regulators were initially slow to

respond to the digital revolution in healthcare but agencies such as the FDA in the US and the MHRA in the UK now have clear guidance on the use of software as a medical device, with a focus on safety and protecting patients from harm. Ethical, regulatory, financial, and legal issues, in general and in relation to children specifically, need to be clarified by the respective authorities, and specialist (paediatric) societies. We also need clinicians to take action. Digital medical technologies should be more embedded within medical education and specialty training. This could include the evidence base for these tools, and the research and implementation issues that clinicians need to consider. Academic clinical fellow pathways, and specialty training days can provide some of the mechanisms for this embedding. Further, continuous professional development of senior medics should encompass novel interventions and the training required for their use, e.g. in form of a virtual digital paediatrics training series, at national paediatrics meetings or in clinical simulation centres. The digital paediatrics revolution needs to come from within the specialty, in other words, be driven by the paediatric healthcare providers. In the 2020s, pen-and-paper medicine (and the associated avoidable errors and handicaps) should be a matter of the past.

There are some blurred regulatory boundaries: devices which claim to support wellness rather than a medical need can sidestep regulation as a medical device; tools which claim to be for information only (rather than to guide treatment) may have reduced scrutiny. But the regulatory landscape is becoming clearer and health technology assessment agencies such as NICE in the UK are now developing programmes of work to appraise the clinical effectiveness and cost-effectiveness of digital tools. Quality assessors such as the Care Quality Commission in the UK are also developing standards for assessing digital services. Paediatric services need to understand the factors that support successful implementation of digital health technologies. These include having sufficient time and resource dedicated to making implementation happen – healthcare innovation rarely occurs by chance and needs to be supported by project management. Ideally end-users (and other stakeholders) need to be involved in the design of tools and throughout the development journey;

these users also need to understand the benefits to their work of adopting the new technology, and be provided with training in how to use any new tools. Implementation approaches should be tailored for local contexts and any local barriers identified early and addressed. Information governance and interoperability issues are key. Initial adoption is not enough, ongoing maintenance is also required and needs to be managed and monitored to support full embedding of innovations. Evidence of real-world effectiveness, using routinely collected data from implementation settings, can support further uptake.

Paediatric medicine is still largely untouched by the digital potential of next generation technical innovations. But digital technologies will become a cornerstone of medical research and everyday health care in the (not so far) future. The time has come to embrace the concept of '*digital paediatrics*' - child-centred digital medicine solutions - so that the profession can grow further in a timely manner and, ultimately, our patients will benefit from the digital boost with sustainably improved outcomes and better overall child health.

Table 1. Synopsis of key digital health technologies – benefits, limitations, and illustrative examples of utilization in paediatric healthcare

Digital technology / entity	Description	Advantages	Limitations	Examples in paediatric medicine/research
Internet Health (ehealth)	Healthcare services provided electronically via the internet	Cost-efficiency; information accessibility; patient empowerment	Time-consuming to learn/apply; IT shortage in low resource countries	In a randomized trial of 152 children with obsessive-compulsive disorders, Aspvall et al. demonstrated internet-delivered CBT ($\pm$ consecutive in-person therapy if necessary) to be noninferior to in-person therapy alone (mean Children's Yale-Brown Obsessive-Compulsive Scale score 11.57 vs. 10.57) ⁹ .
Mobile Health (mhealth)	Smartphone applications supplying information or tools to improve paediatric care ¹⁰	Accessibility; variety in options;	Most apps are not validated; confusing variety of apps / tools	Ybarra et al. conducted an mHealth comprehensive text messaging-based intervention RCT for pregnancy prevention including 799 LGB+ teens that resulted in significantly higher rates of condom-protected sex (aOR = 1.48), use of birth control other than condoms (aOR = 1.60), and intentions to use birth control (aOR = 1.93) ¹¹ .
Telemedicine and telecare	Remote diagnosis and management of patients by means of telecommunications technology	Remote access to (specialized) medical care; on-demand options; cost- and time-efficiency	Cumbersome set-up and maintenance; less personal doctor-patient-relationship	Halterman et al. conducted an RCT using a school-based telemedicine enhanced asthma management strategy to improve symptoms and reduced health care utilization among 400 urban children with persistent asthma. The intervention resulted in more symptom-free days per 2 weeks postintervention (difference, 0.85; 95%CI, 0.10-1.59) and less ED visits or hospitalizations for asthma (7% vs. 15%; OR, 0.52; 95%CI, 0.32-0.84) ¹² .
Electronic medical record	Digital version of a chart with patient information	Accurate, up-to-date, and complete patient information; easy access to / sharing of records; coordinated efficient care	Privacy / cybersecurity concerns.	Breton et al. conducted a quality improvement study using automated technology to assist clinicians in their commitment to provide evidence-based care for 1343 children with inflammatory bowel diseases ¹³ . This resulted in improved rates of iron deficiency screening (from 31.7% to 63.6%), in higher iron deficiency anaemia treatment rates (38.2% vs. 49.9%), and in decreased prevalence of anaemia (35.8% vs. 29.7%).
Sensors and wearable devices	Electronic devices worn close to/on the skin to detect body signals (e.g. vital signs) or ambient data	Convenience; patient empowerment; early disease / harm detection	Data (mis)-interpretation; artefacts; cost; potential distraction; magnitude of unfiltered data; challenging differentiation of pathology and physiological changes as children mature	Chan et al. used smartphones as a low-barrier effective screening tool for detecting the presence of middle ear fluid on 98 patient ears (AUC, 0.898; sensitivity, 85%; specificity, 82%), with parents performing similarly to trained clinicians ¹⁴ .
Digital clinical trial	A trial utilizing digital technologies to improve recruitment / retention, data collection and analytics	Improve participant access / engagement, data measurements, enable concealed	Privacy / data security; data quality; lack of human oversight	The US National Institutes of Health and the National Science Foundation issued a position paper on the current state of the art for digital clinical trials ¹⁵ . Kruijinga et al. reported the tolerability, repeatability and reference values of candidate digital endpoints derived from physical activity, heart rate and sleep in 175 healthy children (median compliance, 94%) ¹⁶ .

		randomization; cost-effectiveness		
Big data and data mining	Analysis of information from, data sets too complex for traditional data-processing; extracting patterns in large data sets involving methods at the intersection of machine learning, statistics and database systems	Improved decision making; increased productivity; cost-efficiency; identification of best practices; detection of fraud (insurances)	Questionable data quality; security risks; lack of precision; hardware needs; implementation costs	Heude et al. produced calibrated paediatric growth charts by utilizing big-data processing of routinely collected information (>1.4 million height and >1.6 million weight measurements) from 238 102 children ¹⁷ . Based on data mining Rodríguez-Herrera et al. identified optimal timing of follow-up visits to assess gluten-free diet in 188 children with coeliac disease ¹⁸ .
Gamification	To apply game mechanics to non-game contexts to engage children generating motivational and cognitive benefits	Patient engagement; creates enthusiasm; provides instant feedback; social connections	Increased screen-time; cost; equipment availability; narrow margin of age-appropriateness	In a multicentre RCT, Kollins et al. utilized a digital gaming therapeutic to improve objectively measured inattention in 857 children with ADHD (mean compliance, 83%; change from baseline TOVA API, 0.88 (95% CI 0.24–1.49) ¹⁹ .
Machine learning	Computer algorithms that improve automatically through experience / by use of data	Identification of trends / patterns; improves over time; automation	Error Susceptibility; time- and resource-consuming; protracted; automation	In a randomized study, Jia et al. used gamification to improve melanoma visual identification (74.2% vs. 63.5%) among 271 high school students ²⁰ . In a multicentre RCT, Pavel et al. utilized a machine-learning algorithm that was safe and able to accurately detect neonatal seizures in 132 neonates (percentage of seizure hours correctly identified, 66%; 95% CI 53.8–77.3 vs. 45.3%; 34.5–58.3; difference 20.8% (3.6–37.1) ²¹ .
Deep learning	A machine learning method based on artificial neural networks with which multiple layers of processing to extract progressively higher-level features from data	Effective integration of multiple layers of data; incorporating expert knowledge (e.g. PubMed mining); temporal modelling	Requires large data volume; data quality; temporality, interpretability	Mori et al. demonstrated improved diagnostic accuracy realized by incorporating a deep learning model that outperformed paediatric cardiologists in diagnosing atrial septal defect from 1192 ECGs of 728 patients (sensitivity, 76%; specificity, 96%; PPV, 88%) ²² . Arnaout et al. used an ensemble of neural networks to improve the detection of foetal complex congenital heart disease (sensitivity, 95%; specificity, 96%; NPV, 100%) ²³ .
Artificial intelligence	Computer simulation of (imitated) intelligent (human) behaviour	Efficient healthcare delivery; increased accessibility; early diagnosis;	Algorithmic bias (lack of transparency); lack of “human touch”, uncorrected erroneous reasoning	Nimri et al. demonstrated successful insulin dose optimization, non-inferiority regarding percentage of time spent within target glucose range (50.2 ± 11.1% vs. 51.6 ± 11.3%) and improved safety (0 vs. 3 severe adverse events) using an automated AI-based decision support system in 108 youths with type 1 diabetes in a multicentre RCT ⁶ .
Virtual reality	A computer-generated simulation to enable the interaction within an artificial 3D environment (e.g. using special goggles or gloves with sensors)	Enhanced patient and medical training experience; high perceived value	High cost of equipment and set-up; potential nonconformity with reality	Ryu et al. used VR in an RCT to reduce preoperative anxiety (median m-YPAS score, 28.3; IQR, 23.3–36.7 vs. 46.7; 31.7–51.7) and improve compliance during anaesthetic induction in 69 children undergoing elective surgery and general anaesthesia ²⁴ .
Blockchain	A distributed system for recording and storing transactional data	Increased trust / security / transparency /	Privacy concerns; cultural adoption / disruption; complex signature verification	Peng et al. utilized blockchain technology to realize spatiotemporal efficiency supervision of vaccine production ²⁵ .

traceability of shared
data; cost-saving

process; integration
concerns

3D = three-dimensional; ADHD = attention-deficit hyperactivity disorder; AI = artificial intelligence; aOR = adjusted odds ratio; AUC = area under the curve; CBT = cognitive behavioural therapy; ECG = electrocardiogram; ED = emergency department; IQR = interquartile ratio; IT = information technology; LGB = lesbian, gay, bisexual; m-YPAS = modified Yale Preoperative Anxiety Scale; NPV = negative predictive value; OR = odds ratio; PPV = positive predictive value; RCT = randomized controlled trial; TOVA API = test of variables of attention attention performance index; VR = virtual reality

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