OPEN LETTER

New technologies to improve healthcare in low- and middle-income countries: Global Grand Challenges satellite event, Oxford University Clinical Research Unit, Ho Chi Minh City, 17th-18th September 2019 [version 1; peer review: 1 approved]

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Abstract
We report the outputs of a satellite event in Ho Chi Minh City, Vietnam, organized as part of the “2nd Global Grand Challenges of Engineering Summit”. The event considered challenges and potential solutions for improving low- and middle-income country (LMIC) healthcare systems, with particular reference to critical care. Participants from key regional and local stakeholders in healthcare and engineering discussed how new advances in technology, especially in the field of Artificial Intelligence, could be of potential benefit. This article summarizes the perspectives and conclusions of a group of key stakeholders from LMICs across South and South East Asia.

Keywords
LMIC, healthcare, machine learning, artificial intelligence, technology, engineering

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Any reports and responses or comments on the article can be found at the end of the article.
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Introduction

In September 2019, The UK, US and Chinese academies of engineering co-hosted the 2nd Global Grand Challenges Summit in London. This event, inspired by the ‘14 Grand Challenges of Engineering’ involved engineers, researchers, innovators, entrepreneurs, and policymakers from around the world to discuss the theme ‘Engineering in an Unpredictable World’. As part of the summit, satellite events were held in India, Kenya, Mexico, Thailand, Uganda and Vietnam to discuss globally relevant topics related to the principle theme. In this report, we summarize the outputs of the Vietnamese event, which brought together key regional and local stakeholders in healthcare and engineering to discuss challenges and potential benefits of introducing new technologies to improve healthcare in low- and middle-income countries (LMICs).

Care quality in low- and middle-income country healthcare systems

Healthcare systems in many LMICs have undoubtedly improved over the last few decades. Areas such as maternal health and preventative medicine have benefited from a sustained drive to implement universal standards of care. Nevertheless, a recent report by the Lancet Global Health Commission estimated that almost 9 million lives and $1.6 trillion in productivity are lost each year as a result of poor quality medical care, the majority of which occurs in LMICs. Important limitations in diagnosis and treatment were identified as causes of this, in addition to systems-level problems with safety, integration and continuity of care. Overall quality of care was worst in vulnerable groups, such as the low-income groups, and those with stigmatized conditions.

The Lancet Commission argues that providing any health system that is not of high quality is unethical. However, in improving care quality, LMIC systems face many challenges, particularly with regard to critical illness, where providing healthcare is most complex, requiring highly-trained staff and expensive equipment for diagnostics and treatment.

This satellite event focused on the provision of high-quality care to critically ill patients and enabled a wide variety of engineering and healthcare stakeholders from the region to share perspectives on the potential for new technologies to improve health care and particularly critical care in LMIC settings.

Challenges to providing high quality care of critically ill patients in South and Southeast Asia

Access to care

In many LMICs, there is wide variation in access to healthcare services, and particularly large differences between care available to urban and rural communities. In critical illness, where rapid assessment and treatment are necessary, ensuring timely access to services for remote communities is a particular challenge. Even if there are rural health stations, staff may often have limited medical training and few options to safely transfer their patients to larger centres.

Appropriate diagnosis and treatment

Timely identification of critical illness and prompt implementation of treatment are vital in improving outcome in seriously ill individuals. Indeed, delayed diagnosis and slow initiation of treatment were both identified as the main reasons for poor quality of care by the Lancet Care Quality Commission. However, there are important contextual differences between LMICs and high-income settings, which necessitate innovative solutions to these challenges. For example, the causes of critical illness themselves are often different. In low-income countries, more than half of all deaths are due to maternal causes, nutritional deficiencies or communicable diseases compared to just 7% in high-income settings. This means diagnosis may often require more highly developed laboratory infrastructure and equipment in LMICs. Performing and evaluating diagnostic tests is time-consuming and requires further expertise. In almost all critical illness, once a diagnosis has been reached, treatment requires expensive equipment and careful monitoring to assess response to treatment and anticipate complications early. Whilst these may be available in LMICs, usually this is only in a limited number of specialist centres.

Health systems

LMIC health systems themselves are often different from those in high income settings and vary widely between countries. Increasingly, private providers provide critical illness care in LMICs, but standards are variable, and lack of comprehensive regulatory systems are a further challenge to implementation of high-quality care. Corruption within some healthcare systems has been cited as a major barrier to advancement and sustainability of quality care. An estimated 10–25% of global health spending is lost to corruption with unquantifiable impact on lives, communicable disease control or antimicrobial resistance. In most healthcare systems, about 70% of recurrent healthcare resources are spent on people, thus improving management, distribution and training can have a huge impact on healthcare quality and outcomes. As lack of knowledge amongst healthcare providers has been identified as a factor in itself preventing further development, improving training and knowledge should be a priority.

Cost of care

Critical care is costly due to the expensive treatments, sophisticated equipment and labour-intensive care required. Although healthcare coverage is increasing, in LMICs, many of these expenses are still passed directly as out-of-pocket costs to patients and their families. Currently about 100 million people are pushed into extreme poverty every year as a result of out-of-pocket medical costs. Additionally, many survivors are left with long-term disability which, in addition to costs of hospitalization, puts huge economic strain on families and communities.

Until now, intensive care units (ICUs) in LMICs have adopted similar models of care used in high income settings. However, the associated requirement for staff, equipment and
training is limiting if not prohibitive in most LMICs. Recent advances in engineering and technology, however, offer disruptive and novel alternatives to conventional care approaches.

**Recent advances in engineering and technology in the healthcare context**

Artificial Intelligence and Machine Learning: definitions and applications in healthcare

“Artificial Intelligence” (AI) refers to a field of computer science that accentuates the creation of intelligent machines that operate and react like humans. Such intelligence can be measured as how a machine produces responses that are indistinguishable from those of a human, as defined in the famous Turing Test (Figure 1). Early applications of AI in healthcare included expert systems, such as MYCIN\(^9\), which assisted physicians in diagnosing blood infections, and DENDRAL\(^11\), which aided chemists in determining the structure of organic molecules. Unfortunately, these expert systems, which relied on static sets of predefined rules, failed to address the dynamic and the probabilistic nature of medical phenomenon and human activities.

Recently, Machine Learning (ML) and Deep Learning (DL) have gained more attention as principled frameworks to implement AI in the age of Big Data\(^12\). ML focuses more on improving the learning and the adaptation capability of machines and computer systems, given the continuing changes in its operational context, while DL introduces the neural network-based methodology where the learning process loosely emulates the information processing and distributed communication nodes in biological systems. Figure 2 puts AI, ML and DL into perspective, in which ML is a subfield of AI and DL is a specific methodology to improve the machine’s capacity to learn. ML is seeing gradual acceptance in the healthcare industry thanks to the capacity to analyze large sets of medical data in order to provide timely risk scores, precise resource allocation, and illness diagnosis. We review some major applications of AI and ML in improving the state-of-the-art in healthcare.

**Enhanced diagnosis.** AI, and DL in particular, are well-suited to pattern recognition and consequently are increasingly being used in interpretation of medical imaging\(^14\). AI has been applied to MRI or CT imaging to look for early signs of cancer. For example, DL systems improved accuracy of lung cancer detection from low-dose CT and a ML system for MR breast cancer detection has received FDA approval\(^15\)–\(^17\). An important advantage of such systems is that, even if they perform similarly to an experienced radiologist, AI systems do not suffer from human fatigue – a potential cause of significant error in busy real-life situations. Figure 3 shows an example of a decision tree for diagnosing dengue.

**Decision support.** ML offers a framework for analysis of high-dimensional multimodal data, which is of particular advantage in examining complex biomedical data, and shows promise in improving detection, diagnosis, and monitoring of disease. Examples include startups such as Face2Gene, which combines facial recognition software with ML to help clinicians detect phenotypes that correlate with rare genetic diseases diagnose, and PathAI, which develops solution to help pathologists to make quicker and more accurate diagnoses and to help guide the right treatment for patients\(^18\). With

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**Figure 1. The Turing Test.**
Figure 2. From Artificial Intelligence to Deep Learning.

Figure 3. A decision tree for dengue diagnostics\textsuperscript{19}. Reproduced under a Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.
To aid healthcare management, ML applications can be developed to better identify and track chronic disease states and high-risk patients, design appropriate interventions, and reduce the number of hospital (re)admissions and claims. For example, BERG’s Interrogative Biology platform uses ML to identify the molecular basis of efficacy and adverse events in order to map disease with and treatments in oncology, neurology and other rare conditions. Such technology allows healthcare providers to take a more predictive approach rather than relying on trial-and-error.

### HealthCare Systems

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**AI healthcare potential for critical care in LMICs.** The above mentioned AI systems have potential for significant impact in LMICs and address many of the barriers to providing high quality ICU care as identified by the event participants. Reducing the cost and expertise needed to monitor and treat critically ill patients is an important step not only in improving patient outcomes *per se*, but also in reducing inequalities in service provision. For example, the requirement for highly trained radiology staff can be reduced with DL systems. Busy and less well-trained staff can be supported by ML clinical decision support systems trained or optimized on relevant contextualized data. Furthermore, as more countries embrace electronic health records, data from these could be used either for clinical decision support or healthcare service optimization.

There are already examples from event participants of initiatives towards using these technologies in LMICs. In Vietnam, ML-based clinical decision support tools for tetanus and dengue are being developed as well as DL image-analysis in tuberculous meningitis and dengue as part of the VITAL (Vietnam ICU Technology Applications Laboratory) project.

Nevertheless, despite these potential advantages there remain several challenges and limitations to the adoption of AI technologies.

**Other emerging technologies in healthcare**

A new generation of information technologies including internet of things (IoTs), big data, cloud computing, and crowdsourcing, has transformed healthcare to become not only more efficient and more convenient, but also more personalized, yet deliverable at low-costs. For example, patients can be equipped with wearable devices to monitor their health constantly. Another example is that of low-cost mobile devices can be used as live source of data for monitoring spread of diseases. We identify several trends in which healthcare systems, and in particular critical care, in LMICs can benefit.

**Smart healthcare.** The smart healthcare model focuses on enabling real-time monitoring and immediate feedback of health data in order to deliver timely intervention of medical behavior. This model drives on the emergence of implantable/wearable devices, and smart health information platforms, which are connected by IoT technology. In particular, by integrating advanced sensors with high-performance microprocessors, wearable/implantable devices can continuously sense and monitor various physiological indicators of patients in an intelligent manner. The primary challenges for such systems are the limited battery life and maintaining a wireless network connection. Nevertheless, these technologies have shown to be improving comfort, while allowing sensed data to be combined with health information for better and more timely medical intervention.

Such technologies are particularly attractive in LMIC critical care settings where wearable monitoring systems may be much cheaper and even allow remote monitoring and clinical decision tools to support patient care in isolated communities. There are many other uses beyond the ICU. For example, the HCMC University of Technology and Education, Vietnam, demonstrated IoTs-based fall detection system, in which data collected from tri-axial accelerometer sensors and/or Kinect camera systems are transferred continuously to a cloud server for processing and detecting fall states. Fall detection and alerts can be sent to relatives or healthcare personnel for immediate medical assistance.

**Crowdsourcing and Big Data.** The concept of Crowdsourcing is to utilize the vast wealth of the public data to address social challenges including healthcare. For example, collecting and analyzing geolocation data from sensor-based and mobile devices allows monitoring the spread of diseases or levels of air pollution. Such capacity provides data to better understand causes of disease or can enable prevention and control. Other uses of crowdsourcing data with geolocation technologies include measuring and predicting network performance and coverage, monitoring emergency responders’ locations, tracking and backtracking disease carriers, and determining the effectiveness of quarantine and isolation.

In the critical care setting, large amounts of data are already routinely collected. In high income countries, national-level datasets are routinely gathered and are an invaluable resource for improving care quality and patient outcomes. Improving the quality of these data in LMICs would facilitate similar improvements in these countries. One example of a successful platform is in Sri Lanka where an ICU registry provides accurate real-time data for network partners using a cloud-based platform. This platform has been expanded and adopted by 9 countries as part of the CRIT CARE Asia network and adopted in over 44 sites across the region. Data from the registry allows quality improvement initiatives and audit, with demonstrable benefits in ICU patient outcomes.

**mHealth and telemedicine.** To date, smartphone ownership worldwide surpasses three billion and continues to grow in the next few years. In 2018, 48% of the global population were connected to the internet, and in LMICs mobile phones were the primary medium for this. South and Southeast Asia notably have amongst the world’s most affordable mobile internet.
making these countries ideal sites for telemedicine services. In Vietnam, 40% of the population are expected to have a smartphone by 2021. Such uptakes introduce the opportunity for mHealth, which focuses on improving the quality, efficiency and cost of healthcare via mobile platforms (see Figure 4). For example, a Cloud Telemedicine Information system, which consists of 100 devices to measure blood pressures and heart rate, can obtain live patient data to enable physicians to monitor patient’s blood pressures online. This pilot cyber medical system, developed by the School of Biomedical Engineering of International University - Vietnam National Universities in Ho Chi Minh City, was successfully implemented in Binh Duong province (Vietnam) to test its efficacy. At the University of Medicine and Pharmacy Ho Chi Minh City, the Department of Family Medicine leads a project connecting family doctors and patients through telemedicine. Whilst currently these projects mainly focus on non-acute care, there is potential for similar technologies to be used to support ICU care in remote sites, or for patients after discharge from hospital.

**Issues of adopting emerging technologies in healthcare**

Despite much interest and enthusiasm in the technologies described above, the application in patient care has some limitations. Compared to traditional statistical analysis tools, many AI solutions (particularly DL) are considered ‘black boxes’ because outputs from AI models lack transparency and their rationale cannot be clearly explained. Using systems without clear biologically-plausible reasoning concerns many clinicians and regulators, especially if results have direct impact on patient care. There are critical questions around ethics, such as who is responsible for biases produced by AI. Finally, some practitioners consider AI a ‘hype’ because its recent success in other disciplines mainly due to the advent of brute-force computing power and the availability of more data. This sentiment generates caution in adopting AI and ML solutions in patient care and clinical practices. For mHealth and Big Data technologies there are concerns about data privacy and ownership. These issues may be particularly pertinent in LMIC settings where regulation and control may be lacking (Table 1).

**Conclusions and next steps**

Improving the provision and quality of critical care in South and Southeast Asia is a significant step towards achieving sustainable development goals and improving quality of life in the region. Heterogeneity of health systems, remote rural populations and cost of providing critical care are significant barriers to achieving this.

During the satellite event in Vietnam, we identified a range of technology advances that are beneficial to healthcare systems in LMICs. However, these may have significant disruptive potential to conventional models of care provision, but ultimately offers cost-effective solutions for LMICs in the region. This multidisciplinary meeting enabled professionals from relevant backgrounds to discuss key elements of this. Attendees made a firm commitment to maintaining working together in the future. This includes activities such as an international meeting in 2020, shared student projects and new research initiatives.

**Disclaimer**

The views expressed in this article are those of the author(s). Publication in Wellcome Open Research does not imply endorsement by Wellcome.
Table 1. Barriers to adoption of Artificial Intelligence (AI) in low- and middle-income country healthcare settings.

<table>
<thead>
<tr>
<th>Barriers to adoption of Artificial Intelligence (AI) in low- and middle-income country healthcare settings.</th>
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<tbody>
<tr>
<td>Poor quality of data or insufficient volume due to data, especially heath care data, is often in inconsistent formats and consists of a lot of noise and bias</td>
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<tr>
<td>Integration into existing clinical workflows</td>
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<tr>
<td>Lack of skilled staff to lead and use AI because it is challenging to find and employ staffs with both healthcare background and Machine Learning skills</td>
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<tr>
<td>No clear benefits from using AI because medical doctors often found AI outputs lack transparency to support medical decisions</td>
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<td>Regulatory and legal requirements</td>
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Data availability
No data is associated with this article.

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This open letter touches on very important issues in trying to improve healthcare provision and adoption of new technologies in LMIC. It reflects on an international event hosted at the Oxford University Clinical Research Unit in Ho Chi Minh City, Vietnam.

There are many important aspects that they discuss, from the complex (and almost impossible) task of a technology developed for HIC to be adopted by LMICs. The authors explained the different barriers and challenges in providing high-quality care in South and Southeast Asia, which is a complex, multivariate problem.

This letter comments on the importance and relevance of using machine learning and deep learning algorithms in order to help provide the best quality of care for LMICs, whilst not posing an excessive burden on an already tired healthcare system.

I believe, there are a couple of aspects that could be improved:

1. Figure 1 is a bit confusing, maybe the authors can add detail to Figure captions.

2. The authors could invite for further research/action by providing a list of recommendations from the satellite event.

3. The complexity of data protection in adopting cloud data systems was not discussed, this is a crucial aspect of telehealth and should be addressed from the beginning. If there was no discussion around the topic at the satellite event, the authors could perhaps make a note of it for future research on the topic.

Is the rationale for the Open Letter provided in sufficient detail?
Yes

Does the article adequately reference differing views and opinions?
Yes
Are all factual statements correct, and are statements and arguments made adequately supported by citations?
Yes

Is the Open Letter written in accessible language?
Yes

Where applicable, are recommendations and next steps explained clearly for others to follow?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Development of medical technology.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.