Review

Disseminating technology in global surgery

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Background: **Effective dissemination of technology in global surgery is vital to realize universal health coverage by 2030. Challenges include a lack of human resource, infrastructure and finance. Understanding these challenges, and exploring opportunities and solutions to overcome them, are essential to improve global surgical care.**

Methods: **This review focuses on technologies and medical devices aimed at improving surgical care and training in low- and middle-income countries. The key considerations in the development of new technologies are described, along with strategies for evaluation and wider dissemination. Notable examples of where the dissemination of a new surgical technology has achieved impact are included.**

Results: **Employing the principles of frugal and responsible innovation, and aligning evaluation and development to high scientific standards help overcome some of the challenges in disseminating technology in global surgery. Exemplars of effective dissemination include low-cost laparoscopes, gasless laparoscopic techniques and innovative training programmes for laparoscopic surgery; low-cost and versatile external fixation devices for fractures; the LifeBox pulse oximeter project; and the use of immersive technologies in simulation, training and surgical care delivery.**

Conclusion: **Core strategies to facilitate technology dissemination in global surgery include leveraging international funding, interdisciplinary collaboration involving all key stakeholders, and frugal scientific design, development and evaluation.**

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Introduction

Technology plays an increasing role in the delivery of healthcare, with particular impact on the delivery of surgical and perioperative care[1–3]. Healthcare in low- and middle-income countries (LMICs) suffers from a lack of technological development and adoption, which needs to be addressed if the World Health Organization's (WHO) ambition of universal health coverage is to be realized by 2030[4–6]. This presents many challenges above those frequently encountered in high-income countries (HICs). Understanding these challenges, and exploring opportunities and solutions to overcome them, are essential to improving global surgical care.

Technology dissemination is a complex process involving needs assessment, conception, innovative research, development and evaluation, and wider implementation and adoption[7]. Challenges include a lack of human resource, infrastructure and finance. Additionally, country-specific healthcare system factors, regulatory factors and local environmental factors all make technology dissemination more difficult. Understanding the specific clinical and healthcare system needs and generating an evidence base to address these, which includes cost-effectiveness within low-resource settings, are essential to inform wider dissemination and adoption. In addition, the appropriate system and process infrastructure is required to ensure effective implementation.

The Lancet Commission on Global Surgery recognized that novel technologies are key enabling factors in the realization of the goal to scale up and strengthen surgical care worldwide by 2030[8]. Specifically, it is necessary to reduce costs, optimize healthcare system and resource use, and improve the delivery of surgical and anaesthesia care and training[8].

Healthcare technologies and technology for health are broad terms that include examples ranging from automobile seatbelts to vaccinations. This review focuses on technologies and medical devices aimed at improving surgical care and training in LMICs. The key considerations in the development of new technologies, along with strategies for evaluation and wider dissemination, are described, illustrated using notable examples of where the dissemination of a new surgical technology has been successful and achieved impact.

Innovation and development

Innovation of novel technology spans the identification of unmet clinical needs, innovation in design and manufacture, through to early-stage evaluation. Within the low-resource setting, two important concepts underlie this process: frugal innovation and responsible innovation. Frugal innovation refers to the concept of doing better with less. By concentrating on user-centred design, core functionalities and reducing cost and waste, frugal innovation can produce elegant, context-specific solutions[7,9]. An example of this is MittiCool® (Wankaner, India), a low-cost, environmentally friendly refrigerator made from locally available materials including clay, which requires no electricity and elegantly addresses the unmet public health need of keeping food fresh in low-resource environments[10]. To complement frugal innovation, responsible innovation focuses on working sustainably and ethically, embedding innovation and research within the society, environment and context locally[11,12]. Responsible innovation in medical device sectors has helped foster effective partnerships between industry, clinicians, researchers and policymakers, and this may be especially important for improving innovation in LMIC contexts[13–16].

Frugal innovation often results in disruptive technologies, technologies that fundamentally alter existing systems, providing a much higher value, often delivered via frugal thinking[17,18]. Reverse innovation refers to the flow of innovations from low- to high-income countries; several technologies have influenced healthcare systems across the world in this way[19,20]. One striking example is the use of mosquito netting in place of commercially produced mesh for abdominal wall hernia repair[21]. Key to the success of this innovation was a drastic reduction in costs and rigorous non-inferiority safety and efficacy evaluation, resulting in the technology having a powerful disruptive potential[21,22]. Reverse innovation implies a unilateral flow of ideas from LMICs to HICs; perhaps a more helpful notion is that of sharing innovation globally and adopting best practice wherever it originates[7].

Central to the tenets of both frugal and responsible innovation is the need for user-centred design, which might involve patients and public, local surgeons, allied healthcare professionals, industry, academic institutes, governments and Ministries of Health[23,24]. Ensuring that all key stakeholders provide critical feedback throughout the evolution of a technology is essential for its ultimate acceptance and adoption. International and local partnerships with academia and industry are key to technology development in global surgery. Although large multinational companies have been reluctant to target LMICs in the past, this might change in the future, driven by the potential market size. In the UK, academic involvement in technological development in LMICs has recently been fuelled by large funding programmes from national organizations such as the National Institute for Health Research (NIHR)[25] and Research Councils UK[26].

Evaluation and adoption

The evaluation of surgical and perioperative care interventions is methodologically challenging even in HICs, involving many inter-related variables including the surgical setting and quality of care[27]. The IDEAL Framework (Idea, Development, Exploration, Assessment, Long-term Follow-up) was conceived to facilitate the translation of new technologies into clinical practice through a structured framework that lends itself to scientific evaluation[27–30]. This includes the rigorous collection of safety and efficacy data before a technology is adopted widely. Obtaining such data in LMIC settings is no less important, but much more challenging given financial and resource restraints. Within the LMIC setting, additional considerations include: interplay between HIC and LMIC partners, including researchers, healthcare professionals and policymakers, to ensure responsible innovation, design and implementation; patient and user acceptability assessment and outcome measurement, to ensure that local contexts, environmental and cultural factors are considered; and rigorous process evaluations of research and technology implementation to ensure quality assessment and sustainable, wider adoption.

Conducting evaluation studies of new technologies in low-resource settings poses unique challenges. A priority setting study undertaken by Rosala-Hallas and colleagues[31] identified appropriate outcome measures and training of research staff as the most important issues when considering clinical evaluations within LMICs. Outcome measures should be chosen in collaboration with LMIC partners and include the feasibility of collecting longer-term data, when required. Incorporating existing technologies, such as mobile phones or wearable technologies, may assist in the collection of accurate data[32,33]. Researcher training is critical to conducting high-quality research, and in building research capacity and capability within LMICs. The Special Programme for Research and Training in Tropical Diseases and the Global Health Network have developed the Global Competency Framework for Clinical Research which describes the core competencies for a research team in LMICs[34]. It provides a range of e-learning materials to help researchers achieve these competencies[35]. Other considerations when undertaking clinical evaluations in LMICs include technology usability and specific training needs, research methodology training, local medical device and manufacture regulations, distribution infrastructure, and maintenance and sustainability.

Overcoming challenges and facilitating dissemination

Howitt and co-workers[7] identified three key barriers to technology dissemination in global health: the necessary technologies do not exist; technology exists, but is not accessible; and technology is accessible, but is not adopted.

Some elements are limited by the pace of scientific discovery, which could be expedited by increased research and development funding. If the technology exists but is not accessible, this could be due to high costs, and lack of human resources and infrastructure. Accessibility challenges should be considered at every stage of technology development, evaluation and implementation. Finally, a lack of wider adoption could result from lack of key stakeholder buy-in, such as early involvement of patients and policymakers, or a lack of wider system and process considerations.

Malkin, along with researchers from Engineering World Health, highlighted three principal design-related barriers to healthcare technology dissemination: cost, spare parts and consumables[36,37]. Context-specific design for low-resource settings should attempt to minimize reliance on consumables and the need for maintenance and repair. Collaboration with in-country distributors and industry is important to ensure successful dissemination[38]. Importantly, the lack of technically trained staff is a significant barrier to technology development and adoption. This is often attributed to a brain drain, where technical skills developed to disseminate a technology are lost as people move out of the areas of need to more attractive environments[36,39]. One strategy to overcome this challenge is to develop bilateral international training partnerships, which has been highly effective in building biomedical engineering capacity[40].

Several tools have been developed to facilitate medical technology development and dissemination in LMICs. The WHO Medical Device Technical Series provides researchers and technologists with guidelines for each stage of development and evaluation, including device regulations, needs assessment, human resources, procurement and maintenance. The WHO Health Technology Assessment (HTA) of Medical Devices guidelines provide practical advice around adaptive global healthcare considerations[41,42]. Within the LMIC setting, a priority HTA strategy is to include health economics evaluation using cost-effectiveness and quality-adjusted life-years to inform wider adoption and healthcare budgets[43,44].

Important steps to improving technology dissemination in global surgery include the effective use of low-resource specific surgical technology innovation, design, development and evaluation guidelines. Existing literature is often not suited to practical use in low-resource environments, or is prohibitively and unnecessarily complex. Future efforts will do well to offer versatile, context-specific and applied practical guidance to contribute to the dissemination of novel surgical technologies in LMICs. Shelton[45] offers 20 criteria to consider when disseminating interventions and technologies, including employing user-centred design, scalability and sustainability; these should be reflected in future studies. Keown and co-workers[46] offer lessons on disseminating innovation in healthcare from eight countries, highlighting the need to foster an organizational culture of innovation and adoption in health systems. Moreover, Howitt *et al.*[7] offer recommendations to different organizations such as Ministries of Health, industry, academic institutes and healthcare organizations, and such guidelines should aim to facilitate interorganizational collaboration.

Ethical practices are essential in healthcare and these should be employed throughout the processes of technology dissemination in global surgery[47,48]. Development and evaluation of technologies should be held to the same ethical and legal standards globally. Of particular importance is the subject of medical device and technology donation from HICs to LMICs. This process is often counterproductive and ignores many of the principles of design, development and evaluation discussed in this review. Donation of HIC technology with little situational awareness can have a negative impact on innovation and dissemination[49]. It is estimated that around 40 per cent of donated medical equipment in LMICs is out of service[50]. However, a subsequent survey found that the majority of broken instruments could be repaired cost-effectively, without the need to import spare parts, by investing in human resource capability[51]. The WHO[52] and Tropical Health and Education Trust[53] provide guidance on responsible and ethical practices in equipment donations to LMICs.

There is also a critical role for strong advocacy programmes to demonstrate the value of low-cost technologies, influence industry, and lobby global organizations. Organizations such as the International Federation of Surgical Colleges[54] and the G4 Alliance for Surgical, Obstetric, Trauma, and Anaesthesia Care[55] play a valuable role in showcasing successes to government organizations and policymakers, disseminating information to wider audiences, and ensuring that technology research and innovation in global surgery remain high on the international healthcare agenda.

Exemplars

Laparoscopic surgery

Laparoscopic surgery is the preferred technique for many general surgical and gynaecological conditions owing to improved short-term clinical outcomes[56,57]. These benefits are even more pronounced in LMICs where access to follow-up care is limited and there is a greater urgency to return to work to prevent spiralling poverty[58]. Laparoscopy also provides a cost-effective diagnostic tool where radiological facilities are limited, and may reduce negative laparotomy rates[59,60]. Laparoscopic surgery requires advanced equipment and infrastructure, including laparoscopes, laparoscopic instruments and piped carbon dioxide, and trained surgical providers. It is usually performed under general anaesthesia, requiring the presence of a trained anaesthetist with appropriate equipment and drugs.

Although these are formidable challenges, laparoscopic surgery has been implemented successfully in low-resource settings with complication rates similar to those in HICs[61]. In a recent systematic review, Chao and colleagues[58] described several adaptive strategies to enhance the adoption of laparoscopic surgery in LMICs. These included infrastructure and system innovations, such as soft drink companies providing carbon dioxide, sunlight as a light source, and low-cost box trainers for surgical training[62–64]. Price *et al.*[63] successfully introduced laparoscopic surgery in Mongolia by building high-volume, bilateral training teams and adapting to local community needs to build sustainable laparoscopic services. The availability of low-cost, high-quality equipment, with minimal maintenance requirements, is key to successful implementation. An example is the Xenoscope™ (Xenocor, Salt Lake City, Utah, USA), a laparoscope that provides high-resolution images at an affordable cost[65] (*Fig. 1*). To avoid the need for carbon dioxide insufflation, abdominal wall lift devices have been developed to facilitate gas insufflation less laparoscopic surgery (GILLS). Using this technique, a range of laparoscopic abdominal and gynaecological procedures can be performed safely under spinal anaesthesia, which is readily available through trained healthcare workers even in the most remote environments[66] (*Fig. 2*). GILLS also negates the need for specialist laparoscopic instruments and trocars; modified open instruments can be used to perform single-incision surgery in rural settings[66,67].

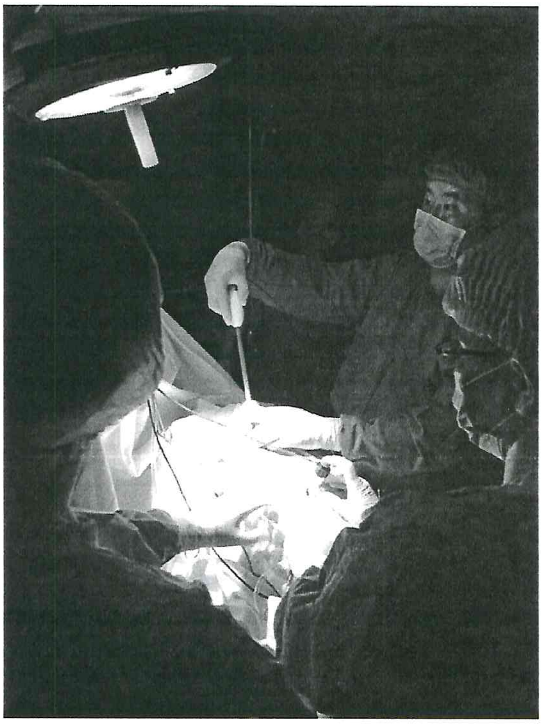
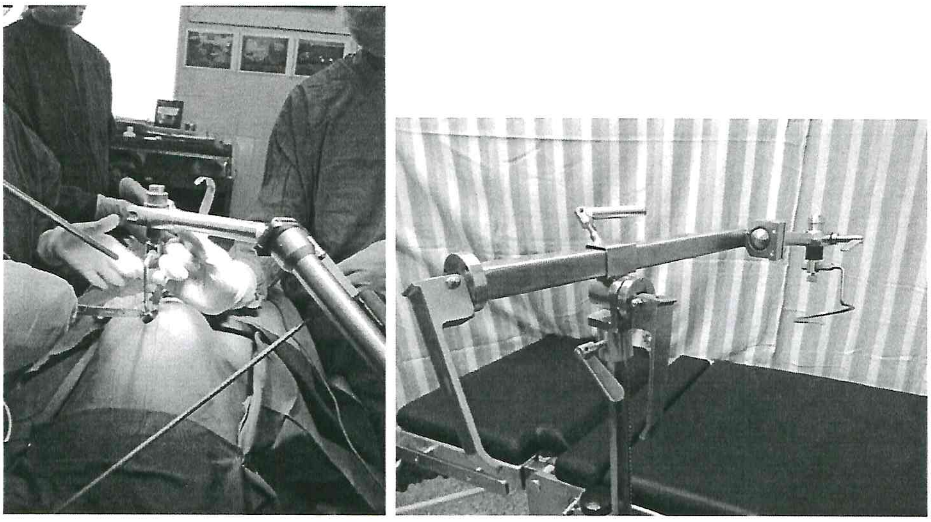


Fig. 1 Xenoscope™ being used to perform laparoscopic surgery in rural areas of Mongolia. Reproduced with permission from Xenocor

Fracture fixation

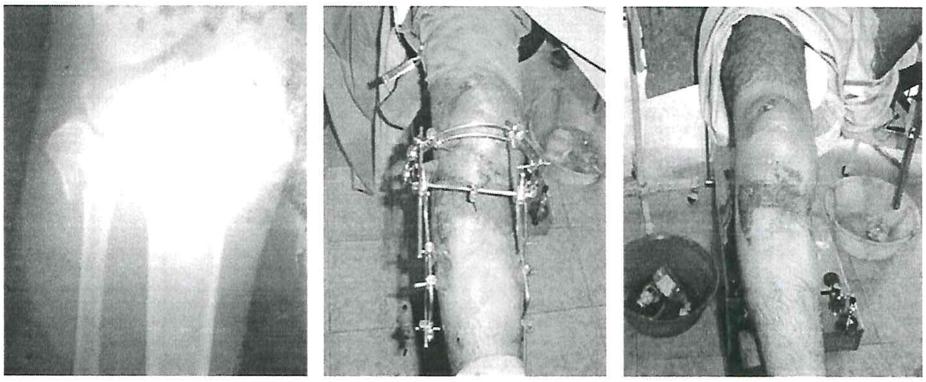
The management of open fractures, along with laparotomy and caesarean section, are the three most essential surgical procedures that all hospitals should be able to perform[68]. In LMICs, the treatment of long bone fractures is frequently limited to skin traction and casting, which ultimately leads to poor functional outcomes and protracted hospital stays[69,70]. The management of severe and open fractures is often limited to amputation[71].

Operative fixation of long bone fractures can reduce hospital stay, provide a quicker return to work, and improve fracture healing[72,73]. External fixation devices, such as



a GILLS device in use **b** Attachment to operating table

Fig. 2 Gas insufflation less laparoscopic surgery (GILLS) abdominal wall lift device facilitating laparoscopic surgery in low-resource settings. **a** Single-incision abdominal surgery under spinal anaesthesia using GILLS device; **b** GILLS device, easily attached to operating tables, with clamps, arms and internal helical retractor. Reproduced with permission from J. Gnanaraj



a Tibial fracture **b** JESS *in situ* **c** Fracture healed

Fig. 3 Joshi's external stabilization system (JESS) stabilizing a tibial fracture. **a** Radiograph of tibial fracture; **b** JESS device *in situ*; **c** JESS removed and fracture healed. Reproduced with permission from J. Gnanaraj; photograph credit to R. Prabhoo

the Ilizarov frame, are favoured in low-resource settings because of their ease of application and low complication rates compared with internal fixation methods[74,75]. Padhi and colleagues[74] and Pulate *et al.*[75] demonstrated the safe and cost-effective application of Ilizarov frame technology in LMICs including India, highlighting the importance of sourcing materials locally, local industry engagement, and reducing waste by resterilization, where safe and feasible. A further example of technology innovation for fracture fixation in LMICs is Joshi's external stabilization system (JESS), again from India[76,77] (*Fig. 3*). This external fixation device was designed to be manufactured locally, versatile and reusable, with many orthopaedic applications spanning age ranges, anatomical areas and mechanisms of injury[78,79].

Safe anaesthesia

The safe delivery of anaesthetic and perioperative care is of paramount importance to improving surgical outcomes. The WHO Safe Surgery Saves Lives programme introduced the WHO Surgical Safety Checklist which has had an impact on surgical safety across the world[80–82]. One of the mandated items on the checklist is a pulse oximeter,

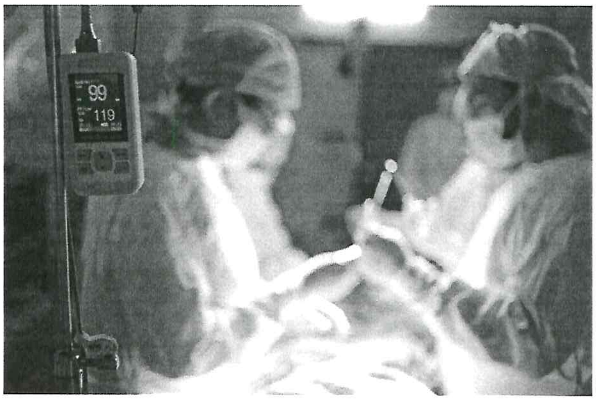


Fig. 4 LifeBox pulse oximeter being used in an operating theatre in India. Reproduced with permission from LifeBox; photograph credit to R. Uttamchandani

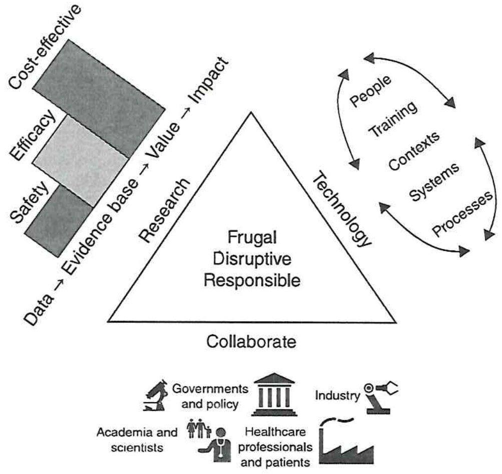


Fig. 5 Key factors driving technology innovation and dissemination in global surgery

which is the only piece of equipment required. Funk and co-workers[83] highlighted the global lack of pulse oximetry as a significant unmet global health need. This need was met by the non-governmental organization LifeBox, an international charitable organization that developed a novel pulse oximeter designed specifically for the needs of low-resource settings[84,85] (*Fig. 4*). The LifeBox pulse oximeter project has provided over 15 000 pulse oximeters to hospitals across 100 countries[86]. Its success is attributed to careful consideration of the design specification, focusing on minimum standards and core functionalities, and building in affordable cost, durability and low-resource environmental factors, such as limited power supply and distribution challenges[87]. Other key disseminating strategies included LMIC user-centred design, effective industry and local partner engagement, and, importantly, rigorous clinical evaluation[88–90].

Surgical training

The WHO acknowledges that significant investment in healthcare professional education is required to realize universal health coverage by 2030. It estimates that globally there is a shortage of over 7·2 million healthcare providers[91,92]. This shortage is particularly acute in LMICs where the lowest workforce densities are found[8,92]. The principles of task shifting or task sharing have been developed as an innovative model of healthcare delivery, addressing the human resource gap by training alternative surgical providers[93]. Training surgeons is expensive, time-consuming and often relies on skill acquisition along a learning curve that involves a high volume of cases with expert supervision[94]. Advances in simulation and immersive technologies may address these challenges by providing a safe and scalable training environment[94]. A study from Rwanda[95] confirmed the feasibility of simulation-based training to improve operative skills when delivered as a brief training intervention in LMICs. LMICs have the same drivers as HICs to the adoption of simulation and immersive technologies as part of surgical training. These technologies may be particularly suited to LMICs owing to the high trainee to trainer ratios, limited number of operating rooms, and reliance on short-term training from visiting international trainers.

Virtual reality has been explored in the teaching of surgeons across the world using live streaming and immersive training modules[96]. Augmented reality has also been explored, allowing surgical trainers to scrub in with an operating LMIC team to teach and deliver surgical care[97]. These technologies have been evaluated in a variety of global surgical training scenarios[98–101]. Their wider use will be determined by infrastructure challenges, such as power supply and internet access, as well as a better understanding of how they might be incorporated into traditional training.

Conclusion

The dissemination of technologies in global surgery faces several challenges unique to working in low-resource environments. Employing the principles of frugal and responsible innovation, and aligning evaluation and development to high scientific standards will help in overcoming some of these challenges. Generating centralized, international technology repositories, such as the WHO compendium of innovative health technologies for low-resource settings, will facilitate the sharing of best practice[102]. In the future, technologies developed for low-resource settings using frugal design will be used to improve health and stem the rising costs of healthcare worldwide.

Capacity and needs assessment are important, but international efforts should now take a step beyond this and begin catalysing technology dissemination to improve outcomes for surgical patients in LMICs. Principal core strategies to achieve this are: leveraging international funding; interdisciplinary collaboration involving all key stakeholders including industry, academics, clinicians and policymakers; and scientific frugal design, development and evaluation (*Fig. 5*). Technology alone is not enough; process and system innovations and evaluations considering the wider context are required. Practical and context-specific guidance in global surgical technologies will catalyse this process to improve outcomes for patients in LMICs.

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