PERSPECTIVE

3D printing: can it make surgery more accessible?

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Abstract
The advancement of 3-Dimensional (3D) printing technology has made the design and production of items increasingly ubiquitous amongst the public. This technology is increasingly being used widely in various medical fields. With its increasing cost efficiency and accessibility, it is the author's perspective that 3D technology can improve accessibility to surgical procedures in low- and medium-income countries (LMIC) by providing proceduralists with the basic equipment required to perform routine operations.

Introduction
Surgical services are increasingly recognised as an important component of public health [1]. These services remain widely accessible in developed countries. However, many fail to appreciate the disparity in low and middle-income countries (LMIC), with only 3.5% of operations performed on the poorest one-third of the world's population[2]. With the advent of accessible and high-quality 3-Dimensional (3D) printing that has been used in various medical fields [3], it is our view that 3D design and printing can help mitigate the shortage and cost of surgical resources in these communities.

3D printing technology
3D printing is a manufacturing method that builds objects by the fusion or deposition of materials. The most common and widely used modality of printing available in medicine is Fused Deposition Modeling (FDM), with the cost of consumer-grade models upwards of USD 300 [4]. FDM printing utilises a heated nozzle to melt and release the plastic filament over a bed, building the object in layers as the plastic cools [5]. Most FDM printer models can print a variety of materials, including but not limited to Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS) and Polyethylene Terephthalate Glycol (PETG) [all simples] (Table 1).

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Material	Cost	Strength	Advantages
PLA	USD 10-40/kg	65MPa	Greatest ultimate strength
ABS	USD 10-40/kg	40MPa	Heat resistant Impact resistant Durable
PETG	USD20-60/kg	53MPa	Water resistant Chemical resistant Durable

Table 1. Characteristics of common materials used for 3D printing [6]

Equipment can be printed at approximately one-tenth the cost of their stainless steel equivalent [4].

The initial process of 3D printing requires the design of a Computer-Aided Design (CAD), a 3D rendered model of the object. There are many open-source and easy-to-use 3D software available for the design of CAD. Furthermore, many pre-made CADs are available for free online and require minimal modifications to fulfil a specific surgical need (e.g smaller retractors for paediatric cases). The CAD models are then uploaded into a printing software where it is reformatted and printed on the 3D printer.

3D design and printing of surgical equipment has already been attempted and utilised on cadaveric inguinal hernia repair with success in 2017 [7]. Construction and modification of instruments, including a scalpel handle, haemostat, needle driver, forceps, self-retaining retractor, and Army-Navy retractors were done in a matter of days.

Requirements
Several key factors will facilitate a conducive 3D printing environment.

(A) Environment
A by-product of 3D printing is the aerosolisation of vapours from the printed material [8]. Fume hoods can be used to extricate the toxic fumes produced [8]. Materials for 3D printing should be kept in an airtight container with silica desiccant packets to prevent moisture absorption and material degradation during long term storage [9].

(B) Electronic resources
A reliable internet connection, suitable computer hardware and software are necessities. Adjustments can be made easily to existing models to be printed on-demand [6].

Disadvantages of 3D printing
Some disadvantages include:
(A) Sterilisation
Unlike stainless steel, sterilisation methods for plastic filaments remain limited. Currently, standardized autoclave sterilisation is not a feasible option for sterilisation of filament plastics as it might lead to warping and degradation of the material [10]. Limited research in sterilisation of 3D printing materials has shown that low-temperature hydrogen peroxide sterilisation or FDA approved glutaraldehyde protocol are the best methods, with minimal degradation and warping [10, 11]. However, repeated sterilisation and durability of these materials have not been adequately researched, opening the potential for future development in durable materials.

(B) Regulatory concerns
3D printed medical devices are still subjected to regulatory requirements, with manufacturing regulations and the country's legal requirement being a barrier to production [12]. The FDA has guidelines available online regarding the governance of 3D printed equipment that can help mitigate certain barriers of production [13].

Accessibility in LMIC
Surgical equipment can be costly especially for health systems in LMIC. The start-up cost for 3D printing can range from USD 300 upwards for printers alone, with additional resources required for the purchase of a computer, printing materials and trained personnel. This confers the health institution the ability to customise individual equipment for specific operations and needs [14]. Once established, the actual manufacturing of 3D printed surgical equipment can be much cheaper than their stainless-steel counterparts. Given that the haemostat printed by George et al measures 8cm by 4cm by 0.5cm (16cm3) [7], the cost of a 3D printed haemostat with current material prices (PETG at USD60/kg) can be as low as USD1. This is compared to the commercial price of titanium haemostat which can cost USD10 [15], making a 3D printed version 10 times cheaper than their commercial counterpart. Even factoring in additional costs such as electricity and wages, the manufacturing of a 3D printed device can be more cost-efficient than its branded counterpart. Ulmeanu et al manufactured a tracheostomy tube (factoring in parts and labour) for as low as 70 USD (62 Euros) when branded counterparts would normally cost significantly more [16]. However, this advantage may be diminished by a reduced number of times 3D printed instruments can be sterilised.

This technology is not just limited to the manufacturing of surgical equipment, 3D printing can be applied to other aspects of medicine including prosthetic and anatomic modelling. Hand prosthesis has been modelled for war-wounded children for as low as USD 19 [17]. With technological advancement, the ability to customise individual prosthesis for patients can lead to improved postoperative outcomes and reduced complication rates. This can be seen in neurosurgery, where customised cranial plates can be printed to be fitted perfectly for patients who had a craniotomy [18].

Furthermore, the delivery of surgical instruments is a timely affair and can take months to be distributed to rural or remote hospitals. 3D printed instruments are cheaper and can be printed quickly, making them more accessible as compared to standard surgical equipment. Increased accessibility enables the population in these areas to receive appropriate and timely surgical care at a reduced cost.

Conclusion
The advancement of household 3D printing technology has benefited the medical community in various ways. With more research into materials and design, 3D printed surgical equipment has the potential to bridge the gap in low resource communities and make basic surgical procedures more accessible to these communities.

All authors disclose no conflict of interest. The study was conducted in accordance with the ethical standards of the relevant institutional or national ethics committee and the Helsinki Declaration of 1975, as revised in 2000.

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