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Research review

Three-dimensional printing in surgery: a review of current surgical applications

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ABSTRACT

Background: Three-dimensional printing (3DP) is gaining increasing recognition as a technique that will transform the landscape of surgical practice. It allows for the rapid conversion of anatomic images into physical objects, which are being used across a variety of surgical specialties. It has been unclear which groups are leading the way in coming up with novel ways of using the technology and what specifically the technology is being used for. The aim of this article was to review the current applications of 3DP in modern surgical practice.

Materials and methods: An electronic search was carried out in MEDLINE, EMBASE, and PsycINFO for terms related to 3DP. These were then screened for relevance and practical applications of the technology in surgery.

Results: Four hundred eighty-eight articles were initially found, and these were eventually narrowed down to 93 full-text articles. It was determined that there were three main areas in which the technology is being used to print: (1) anatomic models, (2) surgical instruments, and (3) implants and prostheses.

Conclusions: Different specialties are at different stages in the use of the technology. The costs involved with implementing the technology and time taken for printing are important factors to consider before widespread use. For the foreseeable future, this is an

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exciting and interesting technology with the capacity to radically change health care and revolutionize modern surgery.

1. Introduction

The last 30 y have seen great advances in medical technology: from open operations to minimally invasive surgery; from the development of advanced prostheses to use of high-tech simulators in training; the modern surgeon has an array of new innovations at his fingertips. The latest innovation has been the advent of three-dimensional printing (3DP), with its technology becoming revolutionary in engineering and product design and now becoming part of surgical practice. Three-dimensional printing allows anyone to rapidly convert digital three-dimensional (3D) models into physical components (Fig. 1).

Outside of the world of medicine, the uses of 3DP have varied enormously. Three-dimensional printing has uses in all areas of industry and benefits from the rapid production of bespoke physical objects. Examples of early adopters include the aeronautic and automotive engineering industry, as well as product design and engineering [1,2]. Parts can be made as pure prototypes or with the intention for actual use and uses range from printing personal objects, such as toys or ornaments by hobbyists, to large-scale industrial applications [3]. With an expanding range of materials to print from, including plastics, metals, and even biodegradable materials or scaffolds for cells, this technology now has the potential to rapidly change the surgical landscape.

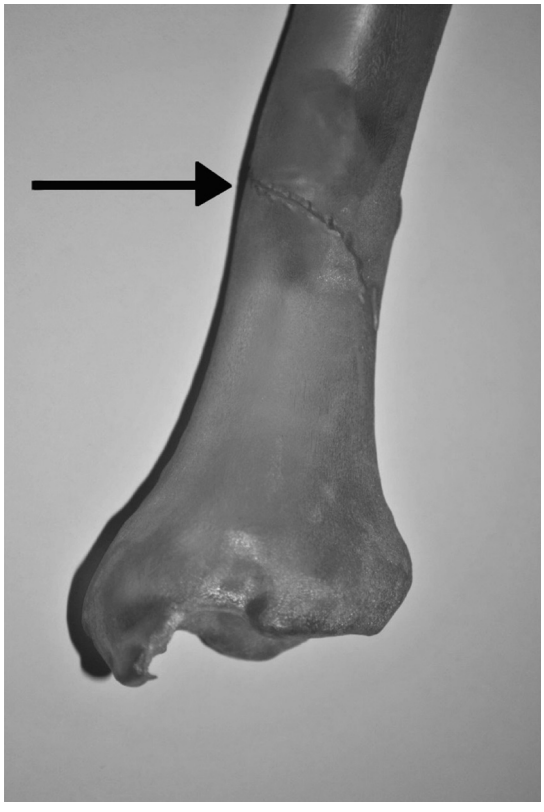

Fig. 1 – A 3D printed model of a distal tibia demonstrating a fracture line (arrow) to facilitate preoperative planning.

In writing this review, the authors sought to conduct a literature search and capture the uses of 3DP across the surgical specialties. The emphasis of this article is on practical and innovative uses, which will educate and spark interest in the surgical community, so as to stimulate further growth of ideas and advancement of the technology.

1.1. *Background to the technology*

It is worth understanding how a printed item is generated, before exploring its uses. In general, 3DP refers to an "additive manufacturing process" that is, new material is added to the surface of existing material to build up a physical 3D model.

At the design stage, a digital 3D model is "sliced" into many two-dimensional (2D) sections in a similar manner to the common anatomic sectional views rendered when viewing computerized tomography (CT) and magnetic resonance imaging (MRI) data. To create anatomic models, data from CT or MRI scans are commonly used to create an initial digital model of patient anatomy. For a bespoke three-dimensional printed item, a novel digital model can be created from scratch (Fig. 2). Each 2D digital slice is then physically recreated, by material laid down layer by layer using various methods, eventually building up a solid model when enough "slices" have been created by the printer. There are three commonly used methods of adding the material in layers:

1. Fused deposition modeling (FDM) is where layers are created by the deposition of a heat-softened polymer with the use of a computer-controlled extrusion nozzle. This technique is used in most economical consumer printers and only occasionally in medical applications.
2. Selective laser sintering (SLS) involves a fine powder bed of varied materials such as nylon or metals—titanium and stainless steel. A focused energy source (laser or electron beam) is used to sweep the powder bed, tracing out the shape of a 2D slice, thus melting and fusing areas of the powder to form the geometry of each layer. A new layer of fresh powder is then added and the process is repeated.
3. Stereolithography (SLA) uses an optical light energy source to scan over a vat of light curable resin, solidifying specific areas on the surface of the liquid. The floor of the fluid container gradually descends, which increases the depth of the material as the model grows and successive layers of resin are cured on top of each other.

There are further 3DP techniques in use and creating tissues or "living" organs is more complex. This review does not discuss organ printing in detail, as this is already well described elsewhere and still in its infancy with regard to surgical application [4–7].