Systematic Review of the Use of 3-Dimensional Printing in Surgical Teaching and Assessment

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OBJECTIVE: The use of 3-dimensional (3D) printing in medicine has rapidly expanded in recent years as the technology has developed. The potential uses of 3D printing are manifold. This article provides a systematic review of the uses of 3D printing within surgical training and assessment.

METHODS: A structured literature search of the major literature databases was performed in adherence to PRISMA guidelines. Articles that met predefined inclusion and exclusion criteria were appraised with respect to the key objectives of the review and sources of bias were analysed.

RESULTS: Overall, 49 studies were identified for inclusion in the qualitative analysis. Heterogeneity in study design and outcome measures used prohibited meaningful meta-analysis. 3D printing has been used in surgical training across a broad range of specialities but most commonly in neurosurgery and otorhinolaryngology. Both objective and subjective outcome measures have been studied, demonstrating the usage of 3D printed models in training and education. 3D printing has also been used in anatomical education and preoperative planning, demonstrating improved outcomes when compared to traditional educational methods and improved patient outcomes, respectively.

CONCLUSIONS: 3D printing technology has a broad range of potential applications within surgical education and training. Although the field is still in its relative infancy, several studies have already demonstrated its usage both instead of and in addition to traditional educational methods. (J Surg Ed ▮:▮▮▮-▮▮▮. © 2017 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: 3-dimensional printing, surgery, training, education, teaching, assessment

COMPETENCIES: Medical Knowledge, Practice-Based Learning and Improvement

INTRODUCTION

Additive manufacturing, more commonly known as 3-dimensional (3D) printing, is a process that permits the rapid manufacturing of high-fidelity 3D models using a specially designed printer. The technology has seen a huge diversity of applications both within and outside of medicine and these continue to increase as printers and the associated software are improved, and the materials that can be used diversify.

The interpretation of medical images has historically been limited to 2D media such as textbooks and computer screens. 3D printers allow medical images, such as from computed tomography (CT), to be converted into 3D structures.[1,2] This ability is now being used within the education of health care professionals to supplant or complement traditional methods of education.[2-4]

Surgery remains a profession, which demands high-quality procedural outcomes in combination with optimal safety outcomes, similar in some respects to airline pilots. Indeed, the airline industry has inspired the growing integration of simulation in surgical training. This is

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recognised as a safe and effective method of training, particularly in a climate of reduced theatre hours.[5] 3D printed models are a continuation of this trend, offering realistic haptic feedback, which may facilitate surgical skills acquisition.

The adoption of 3D printed models into surgery is still at an early stage, but several studies have reported favourable results. In 2 separate studies of 3D models of temporal bone for dissection simulation, otorhinolaryngology trainees, and consultants responded almost universally positively to the usefulness of the models and their value as a training tool.[6,7] Furthermore, 1 recent study objectively demonstrated that a model of endoscopic endonasal transsphenoidal surgery accelerated the learning curve for participants, providing further evidence of the benefits of such models.

This article systematically reviews the use of 3D printing within surgical education to synthesise the rapidly expanding literature within this field and to provide recommendations on how it might develop in future.

Published studies were reviewed to determine the following: (1) the use of 3D printing in surgical training, (2) the use of 3D printing in anatomical education, and (3) the use of 3D printed models preoperatively to aid surgical training.

METHODS

A comprehensive, structured literature search of published articles was conducted. This was designed by authors B.L. and M.G. and performed in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-analyses Guidelines.[8]

Data Sources

A literature search was performed using the electronic databases PubMed, SCOPUS, and The Cochrane foundation. The keywords used were selected from key articles to create a broad search as described in Table 1. Search strings 1 and 2 were combined using the Boolean term AND, then the following limits were applied: (1) Publication date: before September 28, 2016 and (2) English. The final search was conducted on September 28, 2016. In addition, the reference lists of included articles were searched.

TABLE 1. Literature search strategy. Search Strings 1 and 2 Were Combined Using the Boolean Term AND, Then the Limits Were Applied

Search Strategy
1 = "Training" OR "Education" OR "Teaching" OR "Assessment" OR "Skills"
2 = "3D printing" OR "three-dimensional printing" OR "additive manufacturing" OR "3d printed"
Limits
Publication date before September 28, 2016; English

Study Selection and Analysis

A broad search strategy was employed to capture all studies in which 3D printing was used to assist surgical education. Electronic citations, including available abstracts, were screened by the primary reviewer (B.L.). Prespecified limits for study inclusion were that the study be a primary empirical article and include the use of 3D printing in surgical education.

Articles were excluded if they were individual opinions, such as presidential addresses, commentaries, or letters. Literature reviews were also excluded because of the secondary nature of this research.

Selected Articles

The search strategy (Table 1) identified 566 articles, which were reduced to 480 after excluding duplicates. After title and abstract review, the number of relevant articles was reduced to 76. Following full-text review a further 27 articles were excluded, leaving 49 articles for detailed inclusion (Fig. 1).

Data Extraction and Analysis

Articles were appraised and data extracted using a structured, predetermined pro forma to ensure reviewed articles were appraised in a consistent manner.

Bias

Review of the articles included analysis of study design to ascertain quality of evidence and risk of bias. Extent of discussion of individual articles is weighted by the quality of evidence and sources of bias are discussed collectively for each objective of the review.

RESULTS

The Use of 3D Printing in Surgical Training

The literature review identified 27 articles relevant to surgical training. All but 4 of the papers were cross-sectional studies assessing participants' feedback on specific 3D models using Likert questionnaires or a predefined rating scale, thus providing Level IV evidence. The questionnaires assessed a wide variety of domains including accuracy of simulation, anatomical similarity, value as a training tool, usefulness and whether such models should be included in surgical training programs. Reporting on aspects of model fidelity, such as accuracy of a 3D printed (3DP) model to actual patient anatomy, will not be discussed here except where this pertains to the educational benefit received by the participants. Comparatively, 4 studies[9-12] were prospective cohort studies with objective scoring measures, giving Level II evidence. These will be discussed