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Systematic Review of Patient-Specific Surgical Simulation: Toward Advancing Medical Education☆

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OBJECTIVE: Simulation-based education has been shown to be an effective tool to teach foundational technical skills in various surgical specialties. However, most of the current simulations are limited to generic scenarios and do not allow continuation of the learning curve beyond basic technical skills to prepare for more advanced expertise, such as patient-specific surgical planning. The objective of this study was to evaluate the current medical literature with respect to the utilization and educational value of patient-specific simulations for surgical training.

METHODS: We performed a systematic review of the literature using Pubmed, Embase, and Scopus focusing on themes of simulation, patient-specific, surgical procedure, and education. The study included randomized controlled trials, cohort studies, and case-control studies published between 2005 and 2016. Two independent reviewers (W.H.R. and N.D) conducted the study appraisal, data abstraction, and quality assessment of the studies.

RESULTS: The search identified 13 studies that met the inclusion criteria; 7 studies employed computer simulations and 6 studies used 3-dimensional (3D) synthetic models. A number of surgical specialties evaluated patient-specific simulation, including neurosurgery, vascular surgery, orthopedic surgery, and interventional radiology. However, most studies were small in size and primarily aimed at feasibility assessments and early validation.

CONCLUSIONS: Early evidence has shown feasibility and utility of patient-specific simulation for surgical education. With further development of this technology, simulation-based education may be able to support training of higher-level competencies outside the clinical settingto aid learners in their development of surgical skills. (J Surg Ed ■:■■■-■■■. © 2017 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: patient-specific simulation, medical education, systematic review, surgical simulation

COMPETENCIES: Medical knowledge, Practice based learning and improvement

INTRODUCTION

A growing body of evidence has supported the use of simulation-based education as an effective tool to teach foundational technical skills in various surgical specialties.[1-3] An increasing focus on patient safety along with concerns over resident work-hour restrictions leading to reduced operative exposure have highlighted the importance of continuing the development of effective educational modalities to supplement the traditional apprentice model.[4-6] One of the concerns of surgical simulation is the potential plateau effect of these educational tools. For example, a survey of general surgery residents by Wehbe-Janek et al.[7] identified concerns regarding the ability of the simulator to teach beyond simple technical skills. This has also been seen in neurosurgery where the educational benefits of available simulation-based training was significantly lower for senior

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residents compared with junior residents.[8] One potential factor leading to this plateau effect may be related to the fact that most current simulations are limited to generic scenarios that focus on basic skill acquisition.

Along with proficiency in basic procedural techniques, preparation for independent practice requires development of higher-level competencies such as integration of individual context by applying fundamental surgical techniques to patient-specific pathology and anatomical variability. With advances in modern imaging, computation and rapid prototyping, the use of 3-dimensional (3D) reconstruction of patient imaging has become valuable in the clinical setting in terms of preoperative planning and image-guided surgery. What remains uncertain is whether utilizing these technologic innovations to incorporate patient-specific simulation into training will lead to additional educational benefits. The objective of this study was to evaluate the current medical literature with respect to the current utilization and educational value of patient-specific simulations for surgical training.

METHODS

Search Strategy and Study Selection

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines and registered at the International Prospective Register of Systematic Reviews (PROSPERO; CRD42016037148).[9]

We searched the current body of literature through Pubmed, Embase, and Scopus using a search strategy that was developed in collaboration with a medical librarian with expertise in systematic reviews. We employed a broad scope of search terms and related medical subject headings (MeSH) under the themes of simulation, patient-specific, surgical procedure, and education (Supplementary Material). An additional search was completed using references from identified reports, published literature reviews, and key terms in Google Scholar.

We included randomized controlled trials, cohort studies, and case-control studies published between January 1, 2005 and January 1, 2016 if they involved patient-specific simulation for educational purpose. For the purposes of this review, patient-specific simulation refers to the development of 3D reconstruction based on patient imaging data allowing incorporation of individual anatomical variabilities and pathologies in a surgical simulator. Studies from any surgical specialty involving procedural skill training for learners (students, residents, or fellows) were included in the review. Publications categorized as non-English publication, editorials, technical reports, conference abstracts, and case reports were excluded. Following title and abstract review, studies that met the above inclusion criteria were reviewed in full by 2 independent reviewers (W.H.R and N.D).

Data Extraction, Synthesis, and Analysis

The primary reviewer (W.H.R.) extracted the study data using a standardized abstraction form developed a priori. Data fields included author, year of publication, journal of publication, study design, primary objective, simulation device name, sample size, medical or surgical specialty, participants' educational level, pathology of interest, simulated task, image source, 3D reconstruction software, primary outcome, performance metrics, study results, and funding source.

Given that this review involved a broad scope of surgical specialties with differing simulation tasks, the primary outcome was left open to any performance metrics for surgical competence including technical proficiency and surgical knowledge. Furthermore, based on the heterogeneity of study methodology and study outcome, data analysis was performed in a descriptive manner to identify potential educational benefit of the simulators and organized based on surgical specialty.

Quality assessment (QA) was based on National Institute of Health guidelines on systematic review using standardized National Institute of Health Study Quality Assessment Tools.[10] Based on the questions of the Quality Assessment Tools, 2 independent reviewers (W.H.R. and N.D.) judged the overall quality of the study as "good," "fair," or "poor."

RESULTS

The literature search identified 3863 articles with 652 duplicates, resulting in 3211 unique publications (Fig.). After reviewing titles and abstracts of the citations, 32 studies were selected based on the predefined inclusion criteria. Full texts of these studies were reviewed, resulting in the exclusion of 19 additional articles. In total, 13 studies were selected for data extraction, analyses, and QA.[11-23]

Study Characteristics

The number of studies utilizing patient-specific simulators was balanced between 3D model and computer simulations (Table 1). The range of surgical specialties was broad including cardiology, interventional radiology, spinal surgery, neurosurgery, plastic surgery, and vascular surgery. Patient-specific simulation models universally employed patient imaging data in Digital Imaging and Communications in Medicine (DICOM) format that were then reconstructed into a 3D model using various computer software (Table 2). The most common procedures were spine related (e.g., pedicle screw insertion) followed by endovascular procedures (e.g., aortic aneurysm repair and carotid artery stenting) (Table 2). Eight of the 13 studies were composed exclusively of resident physicians whereas 4 studies recruited volunteers of varying medical training