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Simulation in cardiothoracic surgical training: Where do we stand?

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Objectives: Simulation may reduce the risks associated with the complex operations of cardiothoracic surgery and help create a more efficient, thorough, and uniform curriculum for cardiothoracic surgery fellowship. Here, we review the current status of simulation in cardiothoracic surgical training and provide an overview of all simulation models applicable to cardiothoracic surgery that have been published to date.

Methods: We completed a comprehensive search of all publications pertaining to simulation of cardiothoracic surgical procedures by using PubMed.

Results: Numerous cardiothoracic surgical simulators at various stages of development, assessment, and commercial manufacturing have been published to date. There is currently a predominance of models simulating coronary artery bypass grafting and bronchoscopy and a relative paucity of simulators of open pulmonary and esophageal procedures. Despite the wide range of simulators available, few models have been formally assessed for validity and educational value.

Conclusions: Surgical simulation is becoming an increasingly important educational tool in training cardiothoracic surgeons. Our next steps forward will be to develop an objective, standardized way to assess surgical simulation training compared with the current apprenticeship model. (J Thorac Cardiovasc Surg 2014;147:18-24)

Supplemental material is available online.

Seven years ago, the Thoracic Surgery Foundation for Research and Education held the Visioning Simulation Conference (VSC) to accelerate the implementation of simulation in cardiothoracic (CT) surgery.[1] Discussion about technologic, financial, and political barriers to the implementation of simulation in CT surgery led to numerous advances, and this report summarizes much of the published data on simulation in cardiac, general thoracic, and endovascular surgery to date.

HISTORY OF SIMULATION IN SURGICAL TRAINING

Modern surgical simulation dates back to the 1800s when surgeons practiced procedures on cadavers and animals.[2] Today, the scarce resources, ethical questions, and anatomic inaccuracy of this approach leave us in search of better options. Surgeons began using the first artificial simulators only a few decades ago, and within the last several years the Accreditation Council for Graduate Medical Education and the American College of Surgeons have declared strong support for the use of simulation in surgical training, and such programs as the Fundamentals of Laparoscopic Surgery are now mandated for general surgeons to obtain board certification.[3] These events mark the beginning of a potential revolution in surgical education.

VALUE OF SIMULATION IN CARDIOTHORACIC SURGERY

CT surgery training can benefit greatly from simulation considering the high risks and broad range of open, minimally invasive, and endovascular techniques that trainees are expected to learn.[4] Moreover, as the incidence of cardiovascular and thoracic disease grows, the CT surgical workforce is projected to decline by 50% over the next 10 years, creating a tremendous demand for well-trained CT surgeons.[5] Simulation may help by increasing learning opportunities for residents, eliminating costs of cadaver and animal use, decreasing the use of operating room (OR) time at teaching institutions, and integrating new technologies into patient care more smoothly.[6] Simulation also may lay the foundations for uniform certification and assessment standards for graduating CT fellows.[1] The 2007 VSC and the establishment of the Thoracic Surgery Directors Association Boot Camp in 2008 have been important recent events to spur advancement of CT surgery simulation.[7] In addition, the Joint Council for Thoracic Surgery Education is currently developing a simulation curriculum with specified modules and assessment tools specific for training programs.[8]

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Disclosures: Authors have nothing to disclose with regard to commercial support.

Received for publication Feb 11, 2013; revisions received April 22, 2013; accepted for publication Sept 24, 2013.

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0022-5223/$36.00

http://dx.doi.org/10.1016/j.jtcvs.2013.09.007

Abbreviations and Acronyms

CAB = coronary artery bypass
CPB = cardiopulmonary bypass
CT = cardiothoracic
HPS = human performance simulator
OR = operating room
SBM = simple bench model
VATS = video-assisted thoracoscopic surgery
VRS = virtual reality simulator
VSC = Visioning Simulation Conference

TYPES OF SIMULATION TECHNOLOGIES

Three broad categories of surgical simulators include the simple bench model (SBM), virtual reality simulator (VRS), and human performance simulator (HPS) (Table 1). SBMs are ''partial-task'' tools that simulate a small component of a larger operation. They may be synthetic (eg, rubber vessels to simulate coronary anastomosis) or consist of biological tissue (eg, porcine or bovine organs to practice valve suturing). Use of biological tissues in many of these models decreases cost- and time-efficiency and may not accurately mimic human anatomy; however, SBMs are generally inexpensive and easily available to most centers and trainees. Thus, SBMs are best used as an introduction to an operation before learning in a more realistic environment.[9]

The VRS is computer-based and often lacks a physical component. Thoracoscopic or laparoscopic tools are used to manipulate virtual organs, making virtual reality simulation readily reusable with little maintenance, an advantage that can offset high initial costs. With sophisticated programming, these models can present broad clinical variation, interactively respond to the user, and independently provide performance assessment and feedback. The biggest disadvantage of this technology is the use of a 2-dimensional computer screen that compromises depth perception and tactile sensation of the real 3-dimensional environment; however, because these are also the limitations of video-assisted thoracoscopic surgery (VATS) and laparoscopic surgery, VRS is ideal for learning such procedures.[6]

The HPS is a high-technology system that fuses an elaborate physical component with a computer interface. These systems typically simulate the entire OR environment and are used for both individual and team training of an operation from start to finish.[9] This is particularly useful for simulating CT crisis management, which involves attention to a complex interplay of many real-life details in a high-stakes environment.[10-12] Like VRS, HPS can include patient variation and capabilities for assessment and feedback. However, use of biological tissue and numerous intricate parts increase resource use and maintenance time.

CURRENT SIMULATORS IN CARDIOTHORACIC SURGERY

Discussions at the VSC identified several areas in need of simulation, including cardiopulmonary bypass (CPB), coronary artery bypass (CAB), VATS, open lobectomy, and endovascular procedures. Table 2 contains a comprehensive list of CT surgery simulators published to date.

CARDIOVASCULAR

Cardiopulmonary Bypass

The Orpheus Cardiopulmonary Bypass Simulation System (ULCO Technologies, Marrickville, Australia) trains a team of surgeons, anesthesiologists, perfusionists, and OR nurses together in performing CPB (Figure E1). It includes an entire OR with a heart–lung machine, heater/cooler, patient monitor, anesthetic machine, and artificial patient substitute. The Orpheus can be connected to a monitoring system to display the electrocardiograms, arterial waveform, temperature, blood gas, and coagulation parameters based on pre-programmed patient cases or customized cases designed by an instructor. Simulation of drug administration, as well as equipment malfunctioning, alters patient parameters in real-time.[13] Burkhart and colleagues[14] studied this model as an educational tool and found significant improvement in confidence and knowledge, and participants preferred this learning method over classroom and clinical-based learning. The Turkmen simulator is a similar model designed to train perfusionists in the operation of a heart-lung machine.[15]

A less-expensive simulator for CPB is the Hicks perfused nonbeating heart, composed of a porcine heart with the intact thoracic aorta. The aorta is perfused with a pressurized bag of saline to mimic blood flow and leakage, and the organ bloc is placed in an inexpensive plastic container and draped to mimic the thoracic cavity.[16,17]

Coronary Artery Bypass

The Ramphal Cardiac Surgery Simulator is a perfused, beating heart simulator used most extensively for CAB (Figure E2).[18] It includes a porcine heart with the right and left ventricles filled with balloons that are connected to a computer-controlled pneumatic pump, allowing their inflation to simulate pulsation of the heart. The rate and force of contraction can vary in response to handling through sensors connected to the computer, and blood pressure and core temperature also change in response to stimuli. Artificial blood perfuses the entire system, including the coronary arteries and veins, atria, and ventricles via a perfusion line connected to a roller pump. The heart is placed in a realistically pigmented well in the anterior chest wall of a life-sized mannequin to simulate a standard median sternotomy.

Early beating-heart SBMs, such as the Zurich Heart-Trainer and Izzat off-pump CAB model, paved the way