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Crisis Management Simulation: Review of Current Experience

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Abstract

Crisis management simulation is important in training the next generation of surgeons. In this review, we highlight our experiences with the cavernous carotid injury model. We then delve into other crisis simulation models available for the neurosurgical specialty. The discussion focuses upon how these trainings can continue to evolve. Much work is yet to be done in this exciting arena and we present several avenues for future discovery. Simulation continues to be an important training tool for the surgical learner.

Keywords: Crisis management; Neurosurgical simulation; Current models; Future discovery

Background

The complexity of modern surgical techniques and the development of new technologies make risks unavoidable in the operating room. In fact, errors in the operating room can cause irreparable harm to patients or death [1,2]. Therefore, it is incumbent on surgeons to preoperatively plan their cases by running simulations that target emergent crises. Simulations have been extensively utilized by other professions prior to its implementation in medicine. For example, the performance of a pianist is easily distinguishable if the pianist spends a greater amount of time in solitary practice separate from the required time spent in training by the musical ensemble [3]. Likewise, simulated scenarios in aviation can be used to train flight crews to manage and prepare for unexpected situations [4,5]. Extrapolating these examples to the surgical realm, it becomes clear that repetitive simulated exercises that rely on prior knowledge and informative feedback improves performance in the operating room [1]. Also, simulation models are incorporated into surgical trainee programs to mitigate the current landscape of work hour restrictions on surgical residents so as to ensure that surgical residents attain proficiency on complex technical skills and develop the level of operative experience needed to work independently [6-9].

Simulation models provide a practical experience guided by reflection in a risk-free and low stress environment; hence, it becomes evident why a majority of surgical subspecialties implement simulation models as part of residency training [10-12]. Simulation strategies can be divided into: 1) interdisciplinary (single specialty) simulation which focuses on technical skill acquisition and 2) multidisciplinary (multiple specialties) simulation which focuses on improving communication errors, decision making, and teamwork dynamics (e.g. non-technical skills) [13-14]. The multidisciplinary approach recognizes that the technically skilled surgeon does not work alone in the operating room and must communicate effectively with the surgical team to ensure patient safety and reduce clinical errors [16]. Team members participating in multidisciplinary simulations are debriefed following the simulation on a one-on-one basis or with the whole team. Furthermore, the multidisciplinary approach encourages the participant to comment on their own performance using team-based assessment tools or performance surveys [17-19]. Findings from several studies have demonstrated that participation in medical team training exercises improved team confidence, patient outcome and lowered surgical mortality [14-21]. The multidisciplinary approach is gaining recognition in several surgical subspecialties though still in its infancy.

Surgical simulation models are broadly categorized into four distinct classes, which include: 1) animal models, 2) human cadaveric models, 3) synthetic models, and 4) virtual or robot-assisted models [10,21-24]. Each model can be further categorized into low-fidelity or high fidelity, which describes the closeness of the model to reality. Low-fidelity models such as suturing or knot-tying are often suited for the early career surgeon, while high-fidelity models which replicate an entire surgical operation with high realism are best suited for the intermediate or advanced surgeon [15]. The use of human cadavers as a model of simulation is often regarded to as the gold standard of simulation due to its approximation to human living tissue, realistic anatomy, and the appreciation of anatomic variations which may be present in live patients [24,25]. Despite human cadaveric models providing an adequate representation of human anatomy they fail to emulate physiological conditions or tissue bleeding compared to live animal models [23]. Human cadaveric and animal models often require regular maintenance, storage, and ethical approval which may delay their implementation into the surgical trainee curricula [22,23]. Synthetic models are often used to circumvent the limitations of utilizing human cadaveric and animal models. Synthetic models are able to recapitulate realistic anatomic consistencies but fail to replicate soft tissue consistency [22-26]. In comparison to the aforementioned models, virtual simulators have only been developed in recent decades, and are yet to be fully implemented in the surgical trainee curricula [27]. A unique advantage of the virtual model is the ability to recreate rare surgical cases that the surgical trainee may not otherwise encounter [28]. Despite the preference for human cadaveric, animal, and synthetic models over virtual simulators, there is a growing expansion and shift towards virtual and robot-assisted simulators due to their versatility and considerable evidence demonstrating that virtual simulators improve operative time and surgical performance [10, 29-31]. A major drawback towards the implementation of simulation models is – cost [32,33]. Nevertheless, it is evident that the benefit of utilizing surgical simulators clearly outweighs the prohibitive cost since several studies have demonstrated that modelling operative experience improved familiarity with equipment, effective communication, trainee confidence, and most importantly patient outcome [15,22-26]. Recent technological advancements like 3D printing introduce a cost-effective approach that enables the rapid development of surgical simulators that aid surgical planning and crises management [34-36]. Injury to the cavernous part of the carotid artery is a challenging scenario for any surgical team. The high pressure and high risk environment following a cavernous carotid injury can prove difficult even for the most experienced neurosurgeons [37]. In the present review, we provide a critical overview of crisis management simulation for a cavernous carotid injury. Finally, we discuss other modalities of crises management in neurosurgery practice.

Cavernous Carotid Injury Model

In a previous pilot study, we established an endoscopic endonasal simulation for the management of intraoperative cavernous carotid injury [38]. The endoscopic endonasal approach is commonly used by neurosurgeons for pituitary and skull base surgeries [39,40]. Some studies suggest the incidence of carotid artery injury to be as high as 9% during endonasal surgery [37]. Given the devastating nature of carotid injuries, it is critical that both surgeons and anaesthesiologists are prepared to address this occurrence efficiently and effectively. Simulation has been shown to be an effective method to prepare for crisis clinical scenarios in a safe learning environment [41].

Our vascular perfusion model uses adult cadaveric heads as previously described [38]. Briefly, adult cadaveric heads were prepared by washing out the great vessels of the neck with anticoagulant citrate dextrose. The heads were then stored at 5°C overnight, embalmed, and stored in formalin fixative solution. The heads were then dissected using an endoscope connected to a fibrotic camera. A standard endoscopic endonasal approach to visualize the sella, tuberculum, clivus, optico-carotid recesses, and cavernous carotid arteries was performed. A Kerrison rongeur was used to remove the bone overlying the cavernous carotid artery and a 3mm incision was made in the right internal carotid artery. The common carotid artery was then cannulized and artificial blood was perfused using a perfusion pump. An arterial line was also set up to measure and control mean arterial pressure. Learners were tasked with using a muscle graft from the temporalis muscle to control the bleeding. A variety of clinical scenarios can be simulated by altering factors such as mean arterial pressure and duration of time in which vascular control must be obtained. The simulation included an anaesthesia team equipped with a Laerdal SimMan patient simulator, anaesthesia drug cart, and anaesthesia machine. Surgical emergencies, such as carotid injuries, are best managed with an interdisciplinary approach involving anaesthesiology and the surgical team. As endoscopic endonasal approaches are employed by both otolaryngologists (ENT) and neurosurgeons, we performed this simulation with both ENT/anaesthesiology teams and neurosurgery/anaesthesiology teams [18,42]. Learners were able to develop algorithms that can be implemented in future crisis scenarios [42]. During the simulation experience, learners became more effective and efficient at minimizing blood loss with each subsequent simulation scenario [18]. Additionally, both neurosurgical and ENT learners improved their understanding of relevant surgical anatomy and increased their familiarity with use of endoscopic instruments. An independent cohort of faculty members evaluated both surgical and anaesthesia participants with regards to situational awareness, decision-making abilities, communication/teamwork, and leadership skills. Results demonstrated that with each subsequent scenario, learners received higher scores in each of these domains [18]. In post-simulation surveys, both surgical and anaesthesia learners expressed that they found the simulation to be useful and would be interested in having future simulations incorporated into their educational experience [18,42]. In summary, our interdisciplinary simulation not only allowed learners to develop algorithms for carotid injury management, but also taught transferable skills such as teamwork and effective communication strategies that can be applied to any crisis management situation.

Other Neurosurgery Crisis Management Models

Several other models have been utilized in neurosurgical training over the years in order to allow neurosurgical trainees opportunities to experience surgical scenarios that they may not otherwise observe in their clinical training and to improve their surgical management in controlled environments. There have been a wide array of model mediums including synthetic, cadaveric, and virtual models, which have been gaining traction in recent years [43]. These models have been used to simulate a multitude of other surgical scenarios with potential crisis management including aneurysmal rupture, cerebrospinal fluid (CSF) leak, tumor removal near critical structures, and spinal fixation accuracy. Arterial perfusion models have been one of the primary modalities for crisis management simulation due to their ability to simulate a multitude of vascular injuries and potential intra-operative emergencies [44]. Internal carotid injury models have been widely used and noted to be effective in crisis management training [45]. Perfused models been especially useful for open cerebrovascular training which has become less prominent in neurosurgical training programs where the management paradigms have shifted towards endovascular intervention [43,45]. Studies have showed that aneurysmal rupture during pre-clipping dissection is reduced with experience in operating room [44]. As a result, realistic simulations of aneurysm clipping approaches have been a critical aid to allow neurosurgical residents extra training where such cases maybe seldom done. A realistic simulation perfused model was developed. for training aneurysm clipping and managing intraoperative bleeding.46 Cadavers were implanted with aortic balloon pumps to mimic pulsatile blood flow and physiologic blood pressures. In this large study, 96% of participants felt that the model simulated the conditions of live surgery [46]. A similar technique for carotid perfused models to perfuse saline in the subarachnoid space of cadavers using Pediatric arterial catheters to simulate endoscopic third ventriculostomy and septum pellucidotomy procedures [47]. Similar models have also been used to simulate CSF leak in spinal procedures to train residents in emergent dural repair [48]. A skull base tumor model was utilized by Gragnaniello et al. where a synthetic polymer was injected into cadaveric perfused heads via endonasal/trans oral route to simulate surgical management of space occupying lesions near critical structures [49]. The polymer, Stratathane resin ST-504, expands as a foam internally and then solidifies, simulating a tumour which distorts normal anatomy. The model was also perfused with blood product with human serum in order to mimic normal blood clotting and consistency. This simulation allowed trainees to explore sixteen different approaches to tumours removal in the setting of tumour distorted anatomy with potential of neurovascular injury through perfused models. Spinal models have also been shown to be very effective in simulating spinal exposure approaches and in pedicle screw placement accuracy. Several studies have noted that errors decrease significantly with repeated model use particularly in screw violations of pedicle walls [44]. In recent years with the development of virtual reality (VR) technology, virtual simulations have been explored as an aid in neurosurgical training [50]. These simulations can be non-immersive, where participants remain as observers in a simulated learning scenario, and immersive, where participants take a direct interaction in a three-dimensional environment with haptic feedback in a simulated scenario [51]. These immersive VRs can range in their graphical and tactile responsiveness and can simulate a wide variety of scenarios that may not be feasible in cadaveric models. Simulators such as vascular intervention simulation trainer (VIST) and ANGIO mentor have been noted as effective simulators for endovascular neurosurgical procedures and scenario [45]. Although these simulators can replicate intraoperative scenarios with such a high accuracy and realism, their cost can be excessive and as a result they have not been widely accepted in neuralgically residency training [51]. As the technology becomes more affordable and as more studies are conducted to assess their effectiveness, VR simulations may become mainstay tool in neurosurgical training in the future to provide residents a low stress environment in which they can develop skills to manage high stake scenarios more effectively [50,51].

Discussion

Future models of neurosurgical simulation are primarily centered on the developing technologies of 3-dimensional (3-D) printing and virtual reality (VR) simulation [52-54]. As simulation-based training becomes more integrated into neurosurgical education, the cost of each simulation becomes a potential limitation [52]. Cadaveric models have multiple cost-based limitations, including availability, tissue preservation, and biohazard safety; however, 3-D printed simulations offer solutions to these problems, while still offering high-fidelity simulation [54]. 2016 study looked at the use of 3-D printing to create personalized models of the brain in 24 hours for a cost basis of $50 [55]. A separate study looked at streamlining the 3-D printing process of the brain and skull to create models a cost basis of $1-5 in fewer than 14 hours [56]. Furthermore, 3-D printed models do not require biohazard considerations and some 3-D printed models have the additional cost-related advantages of being reusable and portable [57]. Although VR simulations may be high-fidelity and offer solutions to availability, they are expensive, due to the inherent complexity of the computer hardware and software required [53]. In a 2013 survey of 99 neurosurgery program directors, only 30% were willing to spend more than $10,000 on procurement of simulation technology for resident education; therefore, price may be a continual barrier to the implementation of VR simulation models. Until the software and hardware necessary for VR technology becomes a lower barrier to entry, its use in surgical residency education may be limited [58].

3-D printed models may also be constructed from 2-D images, such as CTs or MRIs [55]. This technology constructs models based directly on patient anatomy, including any pathology; something that is lacking in many cadaveric models [55]. The potential pathology that may be incorporated into the models is broad and includes AVMs, tumors, and hydrocephalus [59,60]. These models enable improved understanding of operative anatomy and an opportunity for neurosurgical residents to rehearse the case [54,55]. Although these models offer potential, they are currently limited by 3-D printing technology because printing soft structures, like the brain, is particularly difficult [61,62]. This is because soft structures deform significantly under their own weight during the printing process [55]. Though materials like silicone or flexible polyurethane have been used, they did not achieve the same mechanical properties as soft, biological tissue, like the brain.62 Potential future materials to create a more realistic model design may be hydrogels [62]. VR is not limited by material design, and, therefore, allows the creation of elaborate models. In addition, future VR models may include tactile feedback in addition to visual feedback [63,64].

Conclusions

Surgical simulation trainings have been widely accepted as an effective teaching method in the recent decades [43,65,66]. Neurosurgical simulation training seems to be a beneficial tool for teaching and reinforcing technical skills, allowing for effective evaluation of resident performances in a risk-free setting of an otherwise highly stressful real-life scenario [43,65-67]. There has also been a favourable surge in adopting patient-specific virtual and 3D printed models in concert with cadaveric simulations to supplement residency surgical learning in hopes of improving efficiency and overall competency [64,65,68-70]. Carotid artery injury is a devastating complication of endoscopic endo-nasal procedure which can result in a high-panic environment for surgical team leading to management paralysis especially due to lack of relevant experience and proper planning [37,38]. Such high-risk emergency scenarios could result in unfavourable outcomes if not prevented through effective and meaningful training of residents to develop algorithms for managing difficult scenarios. As such, crisis management simulations can be a valuable learning tool for the trainees in learning the optimal technique to control the surgical field by practicing adequate contingency planning and establishing a lifesaving surgical plan for the patient.

Simulations have a positive impact on trainees, of all levels, in terms of improvement of accuracy, and time to completion of procedural tasks [43,65]. It is also suggested that real-time tactile feedback, incorporation of personalized improvement strategies along with structured debriefing can improve learning outcomes and have potential for improved patient outcomes [42,54,71] However, there is a need for more validity studies to prove improvement in patient outcomes by further investigating translational outcomes in the operating theatre to resolve the concern of simulation-to-reality disconnect.

The future of simulation holds a lot of potential given the rapidly evolving simulation technological revolution [43,65,66,71]. The focus is towards gathering evidence and implementing training strategies geared towards making these training experiences more engaging and representative of real surgery through using a combination of cadaveric, VR and 3D models [42,66,72]. In particular, there is an increasing interest in developing and implementing reusable, cost-effective and patient-specific models to increase familiarity with the complete operative experience including surgical instrument handling, developing proper coordinative technical skills, and for developing skills necessary to control surgical field during crisis and operational complications [37,38,42,73,74]. With cutting-edge advances in the 3D technology, it is now becoming more accepted to employ patient-specific customized simulators for neurosurgery which have the potential to improve surgical results by providing opportunities for identifying surgical crucial points and practicing best strategies for managing and minimizing complications [35,75-78]. Moreover, pairing 3D simulation with virtual simulations can optimize the pre-operative educational experience by providing anatomically accurate model for systematic understanding of spatial relationships between vital structures and surgical targets [35,79]. As a consequence of current shift towards digital technologies capable of providing haptic feedback with improved photorealistic fidelity, it seems that adaptation of these simulation learning experiences will greatly benefit and aid the learning curves for residents undergoing operative neurosurgical training while also providing numerous prospective standpoints to progress the field through improved pre-operative planning, training and education, developing tissue-engineered implants and innovative surgical devices.

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