A Perfusion-based Human Cadaveric Model for Management of Carotid Artery Injury during Endoscopic Endonasal Skull Base Surgery

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Abstract

Objective To create and develop a reproducible and realistic training environment to prepare residents and trainees for arterial catastrophes during endoscopic endonasal surgery.

Design An artificial blood substitute was perfused at systolic blood pressures in eight fresh human cadavers to mimic intraoperative scenarios.

Setting The USC Keck School of Medicine Fresh Tissue Dissection Laboratory was used as the training site.

Participants Trainees were USC neurosurgery residents and junior faculty.

Main Outcome A 5-point questionnaire was used to assess pre- and posttraining confidence scores.

Results High-pressure extravasation at normal arterial blood pressure mimicked real intraoperative internal carotid artery (ICA) injury. Residents developed psychomotor skills required to achieve hemostasis using suction, cottonoids, and muscle grafts. Questionnaire responses from all trainees reported a realistic experience enhanced by the addition of the perfusion model.

Conclusions The addition of an arterial perfusion system to fresh tissue cadavers is among the most realistic training models available. This enables the simulation of rare intraoperative scenarios such as ICA injury. Strategies for rapid hemostasis and implementation of techniques including endoscope manipulation, suction, and packing can all be rehearsed via this novel paradigm.

Keywords

- internal carotid artery
- endoscopic skull base surgery
- transsphenoidal
- resident training
- simulation

Introduction

The learning curve associated with endoscopic endonasal skull base approaches may be steep for residents and other trainees endeavoring to master the technical skills required to perform these operations safely. Endoscopic endonasal surgery provides a unique set of technical challenges and psychomotor skills that must be overcome while progressing along this learning curve. Particular challenges associated

with endoscopic endonasal surgery often include working with reduced depth perception and lack of stereoscopic vision, operating via minimal-access corridors, interaction with an additional surgeon driving the endoscope, collisions between the endoscope and instruments, and challenges with visualization compromised by bleeding or other causes. For these reasons, several authors have recommended a stepwise approach for endoscopic endonasal skull base cases, with respect to the degree of complexity of cases.¹ Of course,

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the ability to manage acute intraoperative complications must be considered as part of this graduated approach.

One of the most dreaded complications of endonasal skull base approaches is acute injury to the internal carotid artery (ICA) or other major arterial vessels. Although trainees may gradually develop experience as it relates to a variety of intraoperative scenarios, adequate preparation for acute ICA injury is not easily imparted. Although modified animal models have been described as an educational paradigm for resident training, the anatomical accuracy remains somewhat limited.^{2,3} Another training paradigm involves surgical simulation or virtual reality programs designed for this purpose that have been shown to confer some benefit in surgical education, but they remain challenged by their somewhat artificial and unrealistic quality, especially as they relate to a major complication such as injury to the ICA.^{4,5}

A significant deal of interest has recently focused on improving alternative methods and protocols for surgical training in the current era of resident work-hour restrictions and more limited surgical experience during resident training process.^{6–10} To improve trainee education and surgical skills as they pertain to endoscopic skull base surgery, we developed a resident training model to enhance residents' surgical skills and ability to deal with an acute arterial injury to the ICA during endonasal endoscopic approaches, based on a novel perfusion-cadaver model available at the Keck School of Medicine of the University of Southern California (USC).

Materials and Methods

All cadaveric dissections in this feasibility pilot study were performed at the Keck School of Medicine of USC fresh tissue dissection laboratory, based at the Los Angeles County-USC Medical Center. This state-of-the-art dissection laboratory has access to fresh unfixed cadavers available through an unclaimed deceased program sanctioned by the Los Angeles County-USC Medical Center, Department of Pathology, and the Los Angeles County Coroner. The mock operating theater is equipped with many of the features of a standard neurosurgical operating room including a surgical microscope, endoscopy system (Karl Storz, Inc.), a high-speed minimal access drill, suction, irrigation, and a wide array of general surgical, endoscopic skull base, and other microdissection instruments. Notably, the laboratory has a perfusion system capable of pumping a blood substitute (saline colored with red dye) into the cadavers via femoral artery access, at a wide range of programmed physiologic blood pressures (►Fig. 1). No difficulties were encountered perfusing the brain due to thrombosed vasculature. The laboratory is also equipped with a variety of digital video recording equipment for endoscopic and microscopic procedures.

For the purpose of this study, eight fresh unfixed full cadaveric bodies were prepared, and neurosurgical residents were taught to perform a standard endoscopic endonasal transsphenoidal approach. Residents had familiarity with endoscopic equipment and bimanual operation during endonasal endoscopy from prior experience in live operations with the senior author (G.Z.). Once the sphenoid stage of the

Fig. 1 Cadaveric perfusion setup. (A) Femoral access in the cadaver allows the perfusion system to circulate saline colored with red dye. (B) This system can be programmed to pump the dye at physiologic arterial systolic blood pressures. (C) Trainees using the novel cadaveric model.

procedure was completed, a two-surgeon four-handed approach was utilized, and the floor of the sella turcica was removed widely using a high-speed drill and Kerrison rongeur (►Fig. 2). The bony covering of the cavernous sinus was then drilled and removed, and the parasellar ICA was exposed bilaterally from the level of the opticocarotid recess superiorly to the clivus inferiorly. The entire dissection was performed by the resident with instruction from the supervising staff. Once wide exposure of the ICA was achieved, the perfusion pump

Fig. 2 Exposure of the cadaveric sella turcica. (A) View from the endoscopic transnasal approach to the sella turcica. (B) Using the high-speed drill to subsequently remove the sellar floor. (C) Sellar dura and right internal carotid artery exposed. (D) Closeup of right internal carotid artery exposure.

was initiated and increased to a mean pressure of 80 to 130 mm Hg. At this point, cavernous sinus “bleeding” was typically observed and packed using a cellulose sponge and/or cottonoids.

The resident was then instructed to deliberately injure the ICA using microscissors, and subsequently instructed to manage the brisk arterial extravasation using any combination of suction, packing, and a variety of available products such as cottonoids or gelatin sponges (► **Fig. 3**). Harvesting of a thigh muscle graft was performed once initial hemostasis was achieved to mimic a real intraoperative scenario, and the resident then attempted to exchange the cottonoids with the permanent graft. All residents subsequently filled out questionnaires to assess their experience with the learning model. Questionnaires were distributed to trainees (PGY levels 3–5) following the educational session in nine instances (Supplemental 1). Trainees rated pre- and postsimulation surgical confidence on a 5-point scale following each session.

An annotated video was created for educational purposes and can be found at: <http://www.youtube.com/watch?v=mBljSgYz3E>.

Results

In all cases, brisk extravasation mimicking an acute intraoperative arterial injury was noted (► **Fig. 3**). The resident was faced with many of the same challenges encountered

during a real intraoperative ICA injury, namely diminished visualization caused by high-pressure bleeding, the need for providing effective and direct instruction regarding scope positioning by the assistant, effective suctioning, and obtaining adequate hemostasis with cottonoids and/or a muscle graft. In all cases, hemostasis was ultimately achieved using a variety of packing techniques.

All trainees reported gaining new knowledge, learning new techniques, and felt the pressurized cadaver system was lifelike and simulated a real ICA injury. Confidence in the pretraining session and posttraining session increased in all instances, with a mean increase of 2 points on a 1- to 5-point scale (mean preconfidence score: 2.89; mean postconfidence score: 4.67).

Discussion

Although ICA injury is a fairly uncommon event, its frequency in endonasal transsphenoidal surgery has been well documented. Ciric et al showed in a survey of 3172 neurosurgeons that 52% of surgeons who had performed > 500 endonasal pituitary surgeries had experienced an ICA injury.^{3,11} There was also a reported incidence of ICA injury between 4% and 9% in four different consecutive series of extended endonasal operations.^{3,11–14} With regard to ICA injury specifically during an endoscopic endonasal approach, Frank et al reported one case of carotid injury in 793 endoscopic transsphenoidal procedures; Gardner et al reported 6 injuries

Fig. 3 Inducing and controlling internal carotid artery injury. (A) With the perfusion machine on, the right carotid artery is about to be lacerated with a scissors instrument. (B) Jet of pressurized blood extravasating from the lacerated artery. (C) "Red-out" of the endoscopic field of view with subsequent obstruction of the surgical field. (D) Initial control of bleeding with a cottonoid. (E, F) Exchange of the cottonoid with autografted muscle.

(0.3%) in 1643 endoscopic endonasal surgeries.^{13,14} The rarity of this complication during endoscopic skull base approaches highlights the potential challenge presented to an unprepared surgeon, who in the face of a sudden unfamiliar exsanguinating injury must control both visualization down a narrow nasal corridor and pulsatile bleeding of the ICA itself.

Endoscopic endonasal skull base surgery requires a distinct set of psychomotor technical skills from open cranial or microscopic endonasal procedures. It is well known that the learning curve for these surgical skills may be quite steep. Koutourousiou et al demonstrated in their experience of 60 patients with cranial base chordoma resections that their rate

of gross total resections increased from 36.4% to 88.9% over an 8-year period using the endoscopic endonasal approach. They emphasized the significance of this learning curve.¹⁵ Similarly, O'Malley et al showed that the surgical time of a senior neurosurgeon utilizing endoscopic methods for pituitary surgery for the first time decreased by 1 hour over 25 patients, with a trend in reduced cerebrospinal fluid (CSF) leaks as well.¹⁶ On account of the steep learning curve associated with this subset of operations, Snyderman et al recommended a stepwise team approach based on careful selection of pathology to gradually gain the experience required to safely approach and resect skull base lesions via an endoscopic endonasal approach.¹

Aside from actual surgical experience, there are very few models for effectively preparing trainees for the rare, yet potentially catastrophic possibility of ICA injury. This type of high-pressure injury can lead to profuse and life-threatening blood loss that would prove challenging to manage, especially for the novice not yet accustomed to the techniques. Endoscopic endonasal surgery carries with it several distinct and inherent challenges over the microscopic approach that may make this dreaded event even more complicated, including diminished depth perception, proximity of the endoscopic lens to the source of bleeding, different instrumentation, a second surgeon driving the endoscope, and restrictions associated with minimal access surgery.

Although simulators and virtual reality applications for resident training in such rare arterial injuries have been designed, the replicability and “lifelike” quality associated with these paradigms are not readily available for the purposes of resident training in ICA injury management. A more effective model was developed by Wormald et al, who skeletonized the cervical carotid artery in live sheep and subsequently placed the pulsating artery within a model designed to represent the human head and paranasal sinuses.^{3,17} Although the anatomical accuracy and tissue quality of this model cannot approach that of fresh human cadavers, Wormald’s model did offer the major benefit of real sheep blood and the ability to eventually achieve true thrombosis and hemostasis.

One of the obvious limitations of our anatomical model is the use of a blood substitute without the potential for true thrombosis, meaning hemostasis can only be achieved with packing and tamponade of cadaveric tissue. Despite this limitation, we noted that the experience of acute arterial injury in trainees was extremely lifelike based on the prior experience of the senior authors in the current study, and it mandated the familiarization and rapid implementation of technical skills to control the bleeding and the surgical field. We did note some expected mild tissue bleeding within the endoscopic field with the perfusion on, but this did not obscure or alter the experience of obtaining control of the carotid laceration. Although the perfusion system in this study was used on full cadaver bodies, it has also been adapted to detached cadaver heads for ease of training multiple personnel as well. Our model replicated the urgency needed to manage a potentially life-threatening high-flow injury via targeted suction, various packing and tamponade strategies, and clear instruction to the co-surgeon for maneuvering the endoscope to maintain visualization. In all cases, a reproducible experience was achieved for trainees. Future directions include further evaluating this model by prospectively tracking improvements in hemostasis time, blood loss, and creating arterial injuries before the carotid is fully exposed.

Conclusion

The addition of a perfusion system to fresh cadaveric specimens greatly enhances the lifelike quality of surgical dissection and surgical preparation for major surgical complications such as acute carotid artery injury.¹⁸ The future potential of this training paradigm remains to be determined, although we are currently

implementing several aspects of surgical education and recreation of various intraoperative scenarios using the mock operating room at our institution. This method may be ideal for replicating the experience of actual hands-on surgical training, both in endoscopic and open neurosurgical cases.

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