Injury of the Carotid Artery during Endoscopic Endonasal Surgery: Surveys of Skull Base Surgeons

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Abstract

Objectives This study aimed to review endoscopic skull base surgeon experience with internal carotid artery (ICA) injuries during endoscopic endonasal surgery (EES) to provide an estimate of the incidence of ICA injury, the associated factors and identify the best training modalities for the management of this complication.

Design Anonymous electronic survey of past participants at a well-established endoscopic skull base surgery course and a global online community of skull base surgeons.

Main Outcome Measures Relative incidence of ICA injuries during EES, associated anatomic and intraoperative factors, and surgeon experience.

Results At least 20% of surgeons in each surveyed population experienced a carotid artery injury. Reported carotid artery injuries were most common during tumor exposure and removal (48%). The parasellar carotid artery was the most commonly injured segment (39%). Carotid artery injuries were more common in high-volume surgeons, but only statistically significant in one of the two populations. Attendance at a skull base course or courses did not change the incidence of carotid artery injury in either surveyed population. In both surveys, respondents preferred live surgeries or active (not computer simulated) training models.

Conclusions ICA injury is underreported and most common when manipulating the parasellar carotid artery for exposure and tumor dissection. Given the high morbidity and mortality associated with these injuries, vascular injury management should be prioritized and taught in a graduated approach by modern endoscopic skull base courses.

Keywords

- skull base surgery
- carotid artery
- internal
- carotid artery injuries
- vascular system injuries

Introduction

The shift from traditional open skull base surgery to the endoscopic endonasal surgery (EES) for pituitary and skull base pathologies caused a shift in the surgical complication profile and management. Iatrogenic injury of the internal carotid artery (ICA) is one of the most feared and potentially devastating complications of skull base surgery, which requires a unique skill set to manage endoscopically. Fortunately, the incidence is rare, approximately 1.1% for endoscopic

transsphenoidal hypophysectomy, but as high as 9% for extended EES of the clivus and petrous apex.¹ In 2013, our group reported a lower incidence of ICA injury: 0.3% for pituitary adenoma resections, and 2% for chondroid neoplasms requiring extended transpterygoid or transclival approaches.² However, the rarity of ICA injury in skull base surgery has limited research on management and outcomes of ICA injury to case series and reports. A recent systematic review of the published literature included 25 studies; there were 50 cases of ICA

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injury during EES, of which 34 cases were for tumors, and the vast majority of these were transsphenoidal approaches. This review found that the cavernous segment of the ICA is most often injured and the mortality rate due to ICA injury is currently 10%.³

Despite the relatively low reported rates of ICA injury during EES, a survey of experienced neurosurgeons from 1997 found that 50% of those surveyed had experienced an ICA injury during endoscopic transsphenoidal approaches for pituitary pathology.⁴ Though rates of carotid injury are likely lower in modern skull base surgery, they are almost certainly underreported. As EES become more accepted for ventral skull base procedures, the risk of vascular injury may become more significant. Indeed, there appears to be a greater risk of ICA injury earlier in the learning curve as surgical teams adopt these techniques.⁵ As EES continues to gain popularity, more groups are attempting extended approaches, which both extends the learning curve and exposes more segments of the ICA to injury.^{2,6} Acknowledging this, several groups are developing vascular injury models for appropriate training.^{7–11} Despite their success, we suspect that current skull base courses may not adequately prepare surgeons to manage this complication and may foster interest in attempting extended approaches, which may inadvertently lead to increased incidence of vascular injury.

It is essential for the modern skull base surgeon to understand the circumstances under which carotid injuries are encountered and how they are managed. In this study, we aim to provide a realistic estimate of the incidence of ICA injury during EES, identify factors that may be associated with carotid artery injury, and identify the best training modalities for the management of this complication.

Methods

This study was approved by the University of Pittsburgh Institutional Review Board and involved electronic surveys that were distributed to (1) past participants of a well-established endoscopic skull base surgery course that employs a cadaveric high-flow vascular model to simulate intraoperative ICA injury; and (2) an online global community of skull base surgeons (available at: <http://www.skullbasecongress.com>). Questions surveyed recipients' experiences with carotid artery injuries and their perspectives regarding vascular injury training. Survey questions were posited and reviewed by all authors before survey release. Survey domains included: surgeon demographics, the incidence of ICA injury, operative details, outcomes, course efficacy, and preferred method of vascular injury training (►Table 1). Participation in the survey was anonymous, voluntary, and was solicited via e-mail between July 2016 and November 2016.

A 15-question electronic survey (Qualtrics Survey Service, available at: <http://technology.pitt.edu/service/qualtrics-survey-service>) was sent via e-mail to all prior course participants. Participants had all registered and participated in a 4-day course that included daily lectures, daily cadaveric anatomical dissections of endonasal approaches to the skull base, live surgical demonstrations, and a cadaveric vascular injury model. Meanwhile, a 12-question electronic survey was sent to members of the Skull Base Congress, a global online community of skull base surgeons dedicated to the exchange of educational materials related to skull base surgery (available at: <http://www.skullbasecongress.com>) (►Table 2). Responses were kept in two separate databases. For questions that were not answered, those responses were excluded in the analysis of results. Results are reported as the

Table 1 Electronic survey questions for skull base course participants

Skull base course participant survey
1. What year(s) did you attend the UPMC Skull Base Course?
2. How many skull base courses have you attended (all sites)?
3. On average, how many endoscopic endonasal surgeries do you perform per month?
4. Did you have any carotid injuries prior to taking the UPMC course?
5. Did you have any carotid injuries after taking the UPMC course?
6. How many carotid injuries did you have in the last 12 months?
7. What was the site of your last carotid injury?
8. What was the tumor type of your last carotid injury?
9. What was the mechanism of injury of your last carotid injury?
10. During which phase of surgery did your last carotid injury occur?
11. How did you manage your last carotid injury intraoperatively?
12. How did you manage the injury postoperatively?
13. What was the outcome of your last carotid injury?
14. Have you had any additional training on management of carotid injury outside of the UPMC course?
15. What is the best way to learn management of carotid injuries?

Table 2 Electronic survey questions for Skull Base Congress members

Skull Base Congress survey	
1.	Do you perform endoscopic pituitary surgery?
2.	On average, how many endoscopic pituitary surgeries do you perform per month?
3.	Do you perform endoscopic skull base surgery (outside the sella)?
4.	On average, how many endoscopic endonasal surgeries do you perform per month?
5.	How many years have you been performing endoscopic endonasal surgery?
6.	How many years since you finished residency/fellowship training?
7.	Have you had fellowship training in endoscopic endonasal surgery of the skull base?
8.	How many years since your last skull base course?
9.	Did you have any carotid injuries before taking a course?
10.	Have you had any carotid injuries since your last skull base course?
11.	Have you had any training on management of carotid injury in a course?
12.	What is the best way to learn management of carotid injuries?

number of responses over the total number of surveys. Results were tabulated, and statistical analysis was performed where appropriate; with a *p* value of 0.05 used to determine statistical significance (GraphPad Prism software, version 6 for Macintosh; GraphPad Software Inc., La Jolla, California, United States).

Results

The survey was sent to 974 University OF Pittsburgh Medical Center (UPMC) course participants and 289 Skull Base Congress members. A total of 134 course participants responded for an overall response rate of 14% (134/974). A total of 43 congress members responded for an overall response rate of 15% (43/289). The response rate for individual questions varied as not all respondents answered every question. No attempt was made to determine overlap of respondents due to the anonymous nature of the two surveys.

Table 3 Skull base course survey surgeon demographics

Question	Response	N	Percentage
Number of skull base courses attended	1	34	25.3
	2	33	24.6
	3	26	19.4
	4	17	12.7
	5	22	16.4
Average number of endoscopic endonasal surgeries	<4/mo	60	45.5
	4–8/mo	35	26.5
	>8/mo	37	28.0
Number of carotid artery injuries in last 12 mo	0	49	77.7
	1	13	20.6
	>1	1	1.6

Note: Values in bold signify modal (most frequent) response.

Surgeon demographic information for each survey is depicted in ►**Tables 3** and **4**. The majority of surgeons perform both endoscopic pituitary and skull base surgery. Most surgeons performed less than four EES cases per month (45.5 and 45.7%). Although most surgeons had been out of training for more than 10 years (47.5%), most surgeons performed EES for less than 5 years (48.6%), suggesting that EES was an acquired skill for most surgeons.

Table 4 Skull Base Congress survey surgeon demographics and surgeon experience

Question	Response	N	Percentage
Do you perform endoscopic pituitary surgery?	Yes	37	86.1
	No	6	14.0
Do you perform surgery outside the sella	Yes	35	81.4
	No	8	18.6
Did you do fellowship training in the endoscopic endonasal skull base surgery?	Yes	16	40.0
	No	24	60.0
How many endoscopic pituitary surgeries do you perform per month?	<4	23	62.2
	4–8	11	29.7
	>8	3	8.1
How many endoscopic endonasal surgeries do you perform per month?	<4	16	45.7
	4–8	12	34.3
	>8	7	20.0
How many years have you been performing endoscopic endonasal surgery?	<5	17	48.6
	5–10	10	28.6
	>10	8	22.9
How many years since you have finished residency/fellowship training?	<5	13	32.5
	5–10	8	20.0
	>10	19	47.5
How many years since your last skull base course?	<3	33	86.8
	3–5	3	7.9
	>5	2	5.3

Note: Values in bold signify modal (most frequent) response.

A total of 40% of Skull Base Congress respondents have had fellowship training in skull base surgery. Skull base course participants had attended varying numbers of skull base courses, ranging between one and five courses. The majority of respondents (86.8%) attended a course within the last 3 years.

Greater than 20% of the surveyed population had at least one ICA injury in the last 12 months. Most injuries were associated with pituitary pathology (50.9%), with a predominance of nonsecreting tumors (35.1%). The ICA was most commonly injured during tumor exposure and removal (31.6 and 52.6%, respectively) (►Table 5). The parasellar carotid (68.4%) was the most common location of the injury, followed by the paraclival (21.1%) segment. The instrument

Table 5 Characteristics of internal carotid artery injury, skull base course participants (low-volume surgeon represents <4 endoscopic endonasal skull base cases per month, high-volume surgeon represents >4 cases per month)

Question	Response	N	Percentage	p Value
Surgical phase during carotid artery injury	Sinus phase	8	14.0	
	Tumor exposure	18	31.6	
	Tumor removal	30	52.6	
	Reconstruction	1	1.8	–
Location of injury	Intracranial	4	7.0	
	Parasellar	39	68.4	
	Paraclival	12	21.1	
	Horizontal petrous	2	3.5	
	Parapharyngeal	0	0.0	–
Instrumentation used during injury	Rongeur	13	22.8	
	Sharp instrumentation	11	19.3	
	Other dissecting instrument	13	22.8	
	Powered instrument	8	14.0	
	Cautery	2	3.5	
	Other	10	17.5	–
Adverse outcome of carotid artery injury	None	36	60.0	
	Death	8	13.3	
	Stroke	11	18.3	
	Pseudoaneurysm	5	8.3	–
Tumor pathology during injury	Nonfunctioning pituitary tumor	20	35.1	
	Functioning pituitary tumor	9	15.8	
	Other benign	17	29.8	
	Malignant	11	19.3	0.25
Surgeon clinical volume, injury within 12 mo	Low-volume surgeon	3	4.8	
	High-volume surgeon	11	17.7	0.34
Number of courses attended, injury within 12 mo	1–2 courses attended	7	11.3	
	3–5 courses attended	7	11.3	1.00

Note: Values in bold signify modal (most frequent) response.

most commonly associated with injury was a rongeur or another dissecting instrument (22.8% for each). Sharp instruments (scissors or surgical knife) were being used in 19.3% of injuries, while the injury was attributed to electrocautery in 3.5% of patients. A total of 40% of patients with carotid injury experienced major complications including: stroke (18.3%), death (13.3%), and pseudoaneurysm (8.3%).

In skull base course participants, there was no statistical difference in the frequency of reported injuries when comparisons were made between low versus high surgical volume ($p = 0.34$), types of pathology treated ($p = 0.25$), or the number of skull base courses attended ($p = 1.0$) (►Table 5). Meanwhile, in Skull Base Congress respondents, carotid artery injuries were more common in surgeons who perform greater than four cases per month ($p = 0.047$). However, in the same population, there were no statistical differences in the injury rates depending on the number of years performing endoscopic skull base surgery ($p = 1.0$), whether or not surgeons operate outside the sella ($p = 0.597$). The likelihood of ICA injury was not related to fellowship training ($p = 0.094$) (►Table 6).

Respondents were asked to recall the relative timing of their carotid artery injuries with respect to skull base course attendance in both surveys. There was a slight increase in respondents that had experienced at least one carotid injury following their attendance at the UPMC skull base course; however, this difference was not statistically different ($p = 0.21$). Meanwhile, 20% of Skull Base Congress members remembered a carotid artery injury before their first skull base course, and a similar percentage (17.5%) reported an ICA injury since attendance at their most recent skull base course ($p = 1.0$) (►Table 7).

Table 6 Characteristics of internal carotid artery injury, Skull Base Congress members (low-volume surgeon represents <4 endoscopic endonasal skull base cases per month, high-volume surgeon represents >4 cases per month)

Question	Response	N	Percentage	p Value
Cases per month, injury since last skull base course	Low-volume surgeon	1	2.9	0.047
	High-volume surgeon	7	20.0	
Number of years performing endoscopic endonasal surgery, injury since last skull base course	<5 ye	2	5.7	1.000
	>5 y	3	8.6	
Do you perform surgery outside sella? Injury since last skull base course	Yes surgery outside sella	5	11.6	0.597
	No surgery outside sella	2	4.7	
Fellowship trained, injury since last skull base course	Yes fellowship trained	2	5.0	0.094
	Not fellowship trained	6	15.0	

Note: Values in bold signify modal (most frequent) response.

Table 7 Carotid artery injury relationship to attendance at a skull base course

Question	Yes, N (%)	No, N (%)	p Value
Carotid artery injury prior to UPMC course attendance?	30 (22.7%)	40 (77.3%)	
Carotid artery injury after UPMC course attendance?	40 (30.3%)	92 (69.7%)	0.21
Skull Base Congress members with carotid injury before first skull base course attendance	8 (20%)	32 (80%)	
Skull Base Congress members with carotid injury after last skull base course attendance	7 (17.5%)	33 (82.5%)	1.0

Table 8 UPMC course participant and Skull Base Congress preferred vascular injury training modality

Modality	UPMC course participants (%)	Skull Base Congress members (%)
Live surgery	36.1	37.5
Animal model	27.9	40.0
Cadaver model	34.4	20.0
Computer simulation	1.6	2.5

In both surveys, respondents were asked to evaluate their learning preferences in the management of carotid artery injury. In each survey, computer simulation models were the least preferred (1.6 and 2.5%) among respondents. Meanwhile, observations of live surgery, as well as animal and cadaveric models of vascular injury, were preferred at similar rates in the UPMC skull base course and Skull Base Congress surveys (► **Table 8**).

Discussion

EES of the skull base offers significant advantages over open skull base surgery including: lack of external incisions, direct access to the tumor without frontal lobe retraction, improved visualization using high-definition endoscopes with dynamic endoscopy, less postoperative pain, and reduced length of hospital stay.^{6,12} Today, high-volume centers with experience in this technique, using vascularized repair of skull base defects, have complication rates similar to centers preferring open approaches: including postoperative cerebrospinal fluid leak rates for large, high-flow defects of less than 5%, and ICA injury rates of < 1%.^{2,3,14} For these reasons, EES is becoming more widely adopted with many surgical groups acquiring these skills outside of residency/fellowship training. Inexperience and extended surgical approaches to parasellar and clival regions may increase the risk of injury to multiple segments of the ICA, such as the parasellar, paraclival, lacerum, and petrous segments.^{2,3,14}

ICA injury is one of the most catastrophic complications of EES. Management requires the skills of an experienced skull base team that is facile with endoscopic hemostatic techniques and familiar with the medical and surgical management of cerebral ischemia including endovascular stenting and revas-

cularization.^{4,15} Risk factors for ICA injury have been identified by numerous groups and include: prior surgery, radiation, prolonged bromocriptine, acromegaly (tortuous arteries), anatomical variations (dehiscent carotid), and invasive tumors.^{5,6,16}

The learning curve for EES has been well-established by early adopting groups. One of the first articles to address the learning curve described an incremental progression through procedure levels of increasing anatomical complexity, technical difficulty, and risk. The best evidence suggests that the team should perform at least 30 to 50 cases before progressing to higher levels to avoid having an increased complication rate.¹⁴

Prevention of ICA injury is the best surgical strategy. This includes proper case selection with appropriate surgical goals, preoperative imaging to identify anatomical variations, image-based navigation using computed tomography (CT) angiography to delineate the course of the ICA, Doppler ultrasound probe, good surgical technique, and wide exposure with dynamic endoscopy.¹⁵ When arterial injury does occur, proper management requires an experienced team. Management of the injury depends on multiple factors including the magnitude and location of the injury, pathology, collateral circulation, experience of the team, and access to resources, such as interventional radiology. Algorithms for management have been proposed that stratify patients based on mechanism (perforator avulsion vs. direct injury) and size of the defect.^{7,17}

Although we have not observed a preponderance of ICA injuries in our early experience, concerns remain that the risk of injury may be increased and surgeons may be unprepared to manage a carotid injury when they are acquiring surgical skills postresidency/fellowship training. Courses, presentations at meetings, and publications may encourage surgeons to attempt higher complexity EES before they have mastered basic techniques and learned to function well as a team. These surveys are an attempt to identify any shortcomings of current postgraduate training practices.

The literature on ICA injury during endoscopic skull base surgery is limited to systematic reviews that include the totality of case reports and series in the literature. A prior survey suggests that ICA injury is underreported; 52% of respondents who had performed > 500 endonasal approaches to the pituitary have had an ICA injury.⁴ Our survey of the UPMC endoscopic skull base surgery course participants corroborates this; greater than 20% of respondents had an ICA injury within the last 12 months. Our survey response rates (14 and 15%) were consistent with other survey studies in the literature. While respondents experiencing ICA injury may be more likely to respond, the incidence we report is well above the incidence in the literature, and is less than that of neurosurgeons who have self-reported ICA injury rates.

The characteristics of recalled carotid artery injuries in our surveys varied. The most common mechanism of injury was during tumor removal and/or tumor exposure. The most common segment injured among those surveyed was the parasellar segment. We are unable to differentiate between the injury to a branch of the ICA versus direct injury to the wall of the ICA. In each survey, the reported rate of ICA injury was higher with high-volume surgeons (greater than four cases per month) though only statistically significant in the Skull Base Congress

survey. Given that endoscopic transsphenoidal pituitary surgery is the most common endoscopic endonasal skull base surgery, this is not surprising. The more operations one does, the more likely that a complication is to be incurred by any particular surgeon. We suspect that high-volume centers are performing more revision cases and cases of increased complexity. Furthermore, although not statistically significant with a *p* value of 0.09, lack of fellowship training in endoscopic approaches may be another potential risk for carotid artery injury.

These surveys do not answer the concern of whether typical courses adequately prepare surgeons for EES or encourage higher risk surgeries. Given the perils of the learning curve, perhaps courses on extended endonasal approaches (e.g., middle and posterior coronal plane approaches) should be subjects for advanced courses with experienced teams. As EES becomes more established in academic centers with training programs, developing surgeons should have greater exposure with better preparation.

Multiple training models of EES offer varying levels of realistic experiences to improve surgeon knowledge, surgical skills, confidence, and potentially patient outcomes.^{8,10,18,19} Similarly, endovascular vascular injury models have been developed to provide more realistic training. Valentine et al proposed the use of a large animal model that would recreate high-flow, high-pressure injury and allow for objective assessment of the success in management with an evaluation of pre- and post-injury mean arterial pressure, mean resuscitation volume, mean blood loss, and survival time.⁷ While efficacious in its ability to duplicate true carotid injury and allow for objective measures of hemostatic control and patient (animal) outcome, this model does not accurately reproduce the complex and variable anatomy of the human intracranial carotid artery. Pham et al developed a human cadaveric model employing a perfusion system to circulate dyed saline via the femoral artery while drilling the ICA via an endonasal approach.⁸ A more recently developed ICA injury model uses a reusable CT generated model head with a recreation of transsphenoidal anatomy and a perfusion pump to simulate vascular injury.¹¹ This model is purported to be more cost-effective without the ethical, biohazard, religious, and legal concerns associated with cadaveric models. Finally, a group from University of Southern California studied the use of a cadaveric vascular injury model for trainees using pre- and posttraining confidence scores. This group found that their model provided a reproducible, realistic scenario to practice management of this rare complication and that training improved trainee confidence in management of ICA injury.⁸

Overall, it appears that multiple modalities are capable of improving overall surgical skills, especially for novice surgeons. Vascular injury models also provide important team training to develop technical maneuvers, coordination of care, and communication skills. Further investigation into the most efficacious modality is needed. Surgeon preferences will certainly be an important factor. In both of our study surveys, respondents preferred live and hands-on models as compared with computer simulation models of vascular injury.

Our survey is limited in its ability to calculate a true incidence of carotid injury rates among patients undergoing EES because we did not collect data on the total number of carotid injuries or

the total number of cases performed by those surveyed. However, given the current limitations of the literature, these surveys suggest underestimation of ICA injury. Moreover, the relatively low response rate, which is common for survey-based literature, may further add to the underestimation of carotid injury incidence and risks sampling bias in addition to inherent recall bias.^{20–22} These results should prompt further study of instructional methods and use of ICA injury modules to improve patient outcomes. The details presented regarding the characteristics of ICA injury provide potential areas of focus for modern skull base courses, which should prioritize vascular injury management.

Conclusions

ICA injury is a rare complication of EES that is underreported in the literature. In surveys of past skull base course participants and an online community of skull base surgeons, ICA injuries were most common when manipulating the parasellar carotid artery for exposure and tumor dissection. The morbidity and mortality of these injuries are high, and should be an area of focus for modern endoscopic skull base courses. Surgeon comfort and preference should be considered when choosing training modules. Per the results of our survey, active, noncomputer simulated, vascular injury training is preferred. Because we postulate that skull base courses may encourage less experienced surgeons to push the boundaries of their skillset, a graduated approach to teaching increasing surgical complexity should be considered for these courses with the development of basic and advanced skull base courses for teams of varying experience.

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