

Carotid artery injury in endoscopic endonasal surgery: Risk factors, prevention, and management

Rahul K. Sharma^{1,2} | Alexandria L. Irace¹ | Jonathan B. Overdevest¹ | David A. Gudis¹

¹Department of Otolaryngology-Head and Neck Surgery, Columbia University Irving Medical Center, NewYork-Presbyterian Hospital, New York, New York, USA

²Department of Otolaryngology-Head and Neck Surgery, Vanderbilt University Medical Center, Nashville, Tennessee, USA

Correspondence

David A. Gudis, Department of Otolaryngology-Head and Neck Surgery, Columbia University Irving Medical Center, NewYork-Presbyterian Hospital, 180 Ft Washington Ave, HP8/New York, NY 10032, USA.

Email: dag62@cumc.columbia.edu

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Abstract

Objective: Endoscopic approaches for sinus and skull base surgery are increasing in popularity. The objective of this narrative review is to characterize risk factors for internal carotid artery injury in endoscopic endonasal surgery (EES), highlight preventative measures, and illustrate key management principles.

Data Sources: Comprehensive literature review.

Methods: Relevant literature was reviewed using PubMed/MEDLINE.

Results: Carotid artery injury in EES is rare, with most studies reporting an incidence below 0.1%. Anatomic aberrancies, wide dissection margins, as well as specific provider and hospital factors, may increase the risk of injury. Multidisciplinary teams, comprehensive preoperative imaging, patient risk assessment, and formal training in vascular emergencies may reduce the risk. Management protocols should emphasize proper visualization of the injury site, fluid replacement, rapid packing, angiography, and endovascular techniques to achieve hemostasis.

Conclusions: While EES is a relatively safe procedure, carotid artery injury is a devastating complication that warrants full consideration in surgical planning. Important preventative measures include identifying patients with notable risk factors and obtaining preoperative imaging. Multidisciplinary teams and management protocols are ultimately necessary to reduce morbidity and mortality.

KEYWORDS

carotid injury, complications, internal carotid, pituitary, pituitary adenoma, pituitary tumor, skull base surgery, surgical outcomes, transphenoidal

Highlights

- Internal carotid artery (ICA) injury is a rare complication of endoscopic endonasal surgery.
- Risk factors for ICA injury may include vascular anatomic variants, invasive pathology, and prior radiation therapy.
- Surgical team preparation and experience are key to successful management of operative complications.

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INTRODUCTION

Management of paranasal sinus and skull base disease using endoscopic approaches has become increasingly common over the past several decades. With improved visualization of the sino-nasal cavities, endoscopic endonasal surgery (EES) has become the standard of care for refractory chronic rhinosinusitis and has proven useful for the management of other pathologies,^{1,2} including primary malignancies of the paranasal sinuses and skull base.³⁻⁶ Studies have suggested that endoscopic approaches are associated with improved subjective and objective outcomes for these conditions.⁷⁻¹⁰

Complications of EES are generally rare, with some studies reporting major complication rates of 1% and lower.¹¹⁻¹³ However, adverse events have been reported, with one of the most common complications being hemorrhage and hematoma formation.¹⁴ One rare and notably devastating complication in EES is injury to the internal carotid artery (ICA). Injury to the ICA can result in catastrophic ischemic damage to the brain, cranial nerve palsies, and death. The most common site of damage is the cavernous segment of the ICA, although the risk of certain segments can vary based on anatomical differences.^{15,16}

This review will highlight the incidence and risk factors for ICA injury in EES, and emphasize preventative measures as well as management principles that can be utilized in the event of an ICA injury.

INCIDENCE OF ICA INJURY IN EES

Overall, injury of the ICA in endonasal endoscopic surgery is rare. Various studies have illustrated an overall incidence rate of 0–0.1%. One study of approximately 5000 patients only identified one case of ICA injury (0.0002%) intraoperatively, while another study of approximately 16,000 surgeries over 30 years identified only four events (0.0003%).^{17,18} The highest incidence rate reported was approximately 1% in a cohort of 1800 patients undergoing transsphenoidal surgery for pituitary adenomas, although a recent international study demonstrated a 0.20% ICA injury rate among over 2000 patients undergoing a transsphenoidal skull base approach.^{19,20} Finally, a more recent, multi-institutional study identified a 0.004% incidence rate in a cohort of 7160 patients who underwent EES.²¹ Despite the low incidence of this event, understanding and identifying risk factors for ICA injury is imperative given its potential for catastrophic morbidity and death in the context of EES becoming more widespread.

RISK FACTORS FOR CAROTID ARTERY INJURY IN EES

While a number of studies have examined risk factors for ICA injury, the low incidence of this event limits statistical power to establish clear associations. Most published data on ICA injuries are in the form

of case reports or case series, but several meta-analytic and multi-institution studies have been completed in an effort to identify risk factors. In this discussion, we categorize risk factors by subcauses to further differentiate actionable items. Patient-specific factors have been the most commonly identified risk factors for ICA injury in EES. These factors include demographic factors, anatomical variations, diagnosis, pathological characteristics, and previous medical history and treatments. Understanding patient-specific factors are necessary to identify high-risk surgical candidates and consider the risk-benefit analysis of aggressive tumor resections for patients with increased risk for vascular complications. Provider and hospital-specific factors include the surgeon's experience and team, surgical techniques, imaging, and facility volume and ancillary staff.

Patient-specific anatomic factors

Anatomic aberrations may increase the risk of ICA injury during EES. In one multicenter study of ICA injuries during EES, 82% of events involved patients with an anatomic variation of the ICA.²¹ High-risk variations in anatomy can be present in both the ICA itself as well as surrounding structures that affect the surgical field or displace the ICA. A dehiscence ICA canal can be found in up to 22% of anatomic specimens.²² Incomplete or thin bony coverings over the ICA increase the susceptibility to injury and should thus be dissected carefully if identified on preoperative imaging.

Other aberrations include lesions displacing the ICA, as well as vessel wall abnormalities (aneurysm, pseudoaneurysm, carotid-cavernous fistula, etc.). These aberrations are not uncommon, as over 10% of all intracranial aneurysms are localized to the ICA. Aneurysms are notably more common in patients with pituitary adenomas, theoretically due to increased levels of Insulin-like growth factor 1.^{23,24} Bulging of the ICA into the superolateral wall of the posterior part of the sphenoid has been noted to occur in over 70% of patients, which should be considered during operative planning.²⁵ Interestingly, bulging of the ICA has been positively associated with the degree of pneumatization of the sphenoid sinus.²⁶

Sphenoidal septa attaching to the ICA may be associated with the risk of ICA injury.¹⁶ Previous studies have established a relationship between sphenoid sinus septations and the ICA in which many intrasphenoidal septa insert at the parasellar or paraclival carotid prominence.²⁷ During dissection, manipulation of these septa can damage the ICA due to their physical attachment to the vessel wall as well as their overall proximity to these structures. A recent study established that 49% of sphenoid sinuses have at least one septum exhibiting involvement with the ICA protuberance.²⁸ A study utilizing 3D-modeling of the sinuses in 260 patients also established a positive relationship between sphenoid sinus volume and septations with ICA injury in endoscopic surgery.²⁹ Dissecting or twisting such septa can potentially damage the ICA.

Finally, the distance of the ICA canal to the nasopharynx and surrounding structures can also contribute to the risk of ICA injury.^{30,31} A study of over 300 magnetic resonance imaging scans

examined the distance of the ICA canal to the nasopharyngeal sub-site, which served as a proxy for “risk” of injury.³² This analysis established a relationship between a shortened ICA-nasopharyngeal distance in patients with ICA aberrancy (tortuous, kinked, or coiled), as well as in patients of older age, female gender, and low body weight index. Reduced intercarotid distances can also increase the risk of ICA injury, especially in patients with midline operative windows around the central skull.^{33,34} Notably, patients with growth-hormone secreting pituitary tumors have been shown to have a reduced intercarotid distance, which should be considered in operative planning.^{34,35}

Patient-specific pathologic factors

Pathologic factors include the nature of the indication for EES. ICA injury is typically reported in studies of oncologic cases; however, events have been reported in other surgeries such as functional endoscopic sinus surgery (FESS).³⁶

If the surgery involves resection of a neoplasm or mass lesion, the size and positioning, including invasion or encasement of the ICA, can substantially influence risk. Notably, anterior cranial fossa lesions carry less risk than lesions of the middle and posterior cranial fossa, where endonasal approaches are extended in the coronal plane and dissection is required in closer proximity to the cavernous, paraclival, and petrous segments of the ICA.³⁷ If the mass lesion displaces the ICA into the surgical corridor, the risk of ICA injury can increase substantially.

Tumor histology and invasiveness can also influence the risk of ICA injury. Chordomas and chondrosarcomas have been shown to increase the risk of ICA rupture due to the displacement of the ICA, destruction of protective periosteum around the cavernous sinus and petrous portion of the ICA, and the need for a more extensive dissection to achieve negative margins.³⁷

Patient history and prior treatment

Previous surgeries and nonsurgical treatment, notably radiotherapy, can impact the risk for ICA injury. These procedures can affect surrounding tissue through scarring, fibrosis, and osteonecrosis of the protective bone, thereby increasing vulnerability to injury.^{19,21,38} Bromocriptine use for pituitary tumors has also been established as a risk factor for ICA injury, possibly due to adhesions and fibrosis.^{19,37}

Provider and hospital factors

There is a well-established inverse relationship between surgeon experience and complications of skull base procedures.³⁹ However, data supporting a relationship between surgeon experience and ICA injury is limited. One study found a slightly higher rate of ICA injury in the first year of experience, while others illustrated an even

distribution of injuries over a surgeon's experience or a higher frequency among experienced surgeons.^{21,37,40}

Preoperative imaging and intraoperative devices may also be related to ICA injury. Notably, cases with inadequate imaging for operative planning could lead to ICA injury through the lack of identification of anatomical landmarks or aberrancies. However, a meta-analysis failed to establish a relationship between utilization of imaging and ICA injury, although these results may be underpowered due to the rarity of ICA injury in general.^{41,42} Calibrated image guidance systems can confirm landmarks and the pathway of the ICA canals, which can improve resection outcomes when vessels may deviate from standard positions. Finally, studies have shown a higher rate of ICA injury when EES involves the use of sharp devices rather than blunt dissection devices,²¹ and the use of larger burrs when drilling may increase the risk of ICA damage.²¹

PREVENTION AND RISK MITIGATION

Protocols to prevent ICA injury have been adopted by many institutions. Such approaches include preoperative and intraoperative strategies to mitigate risk factors as well as increase the likelihood of successful management of ICA injury. Institutions without these measures have been shown to experience a higher incidence of ICA injury than those with such protocols.^{16,21,43}

Due to the complex anatomy and physiologic considerations of skull base surgery, a multidisciplinary approach should always be utilized during EES to prevent ICA injuries. While certain clinical scenarios, such as large invasive tumors, constitute a higher risk than routine procedures like FESS, all members of the operating team should discuss the surgical plan, and ancillary practitioners should be easily contacted (e.g., vascular surgeon, endovascular neurosurgeon) in the setting of a possible ICA complication. Additionally, if the patient is at a considerable risk of ICA injury based on the risk factors listed above, cases should be discussed with a neurointerventional radiologist, endovascular neurosurgeon, and vascular surgeon. The anesthesia team should also be aware and prepared for these complications, and if at high risk, a neuroanesthesiologist should be involved in the patient's care. The risk of vascular compromise should be communicated with the anesthesiologist, and blood replacement products and vascular access for transfusion should be secured. Literature has established a benefit of having protocols in place for ICA injury, and that otolaryngologists with formal training in vascular emergencies during EES are better equipped to deal with such events.⁴³ Additionally, technical training using animal models can help prepare surgeons to deal with vascular emergencies in the future.⁴⁴

Preoperative work-up should involve comprehensive imaging of the head and neck, as this not only provides diagnostic value but also reveals important considerations for the surgical approach, including detailed anatomy of the ICA, its course, and any aberrations that may increase the risk of ICA injury. Notably, studies have highlighted the occurrence of ICA injuries in the setting of insufficient imaging.^{19,21}

Primary imaging modalities should include computed tomography (CT) and magnetic resonance imaging, with and without contrast. In more complex cases, especially ones involving mass-lesions, CT and magnetic resonance angiograms can be used to visualize the relationship between the vasculature and the intended surgical approach. Surgeons should consider a balloon-occlusion test in high-risk patients to evaluate the adequacy of collateral vasculature and the viability of sacrificing the ICA in the setting of intraoperative injury or other operative needs.^{45,46} However, balloon-occlusion testing has a notable false-negative rate (5%–10%) and comes with the risk of dissection, pseudoaneurysm formation, and thromboembolism.⁴⁷ Therefore, the risks of such a procedure may outweigh potential benefits in low-risk patients. Before operating, standard protocols to reduce bleeding should be implemented, including holding medications that increase the risk of bleeding and communicating the risks and possible complications to the patient and surgical team.

Intraoperative preparation should include image-guided navigation for select endoscopic procedures.⁴⁸ Endoscopy provides a two-dimensional view of a three-dimensional space, which results in some perceptual distortion. Real-time intraoperative image guidance mitigates this issue by providing a three-dimensional map of the relevant anatomy. The effects of intraoperative navigation on clinical outcomes remain unclear, but previous studies have demonstrated that its use reduces the number of complications of EES, particularly major complications.^{41,49} By improving anatomic localization of the ICA and surrounding structures, intraoperative navigation may theoretically reduce the risk of ICA injury. Other preventative intraoperative techniques include acoustic Doppler ultrasound and somatosensory evoked potential monitoring for patients at high-risk of ICA injury.^{50,51} Utility of these devices in the setting of EES can prevent mechanical injury of vascular structures, especially in close proximity to the intracavernous portion of the ICA where visibility and maneuverability are more difficult.⁵² Finally, in the setting of a high-risk patient, prepping and draping the neck is helpful if a possible emergency transcervical access to the common, internal, and external carotid arteries is necessary.⁵³ Prepping the abdomen and thigh for fat and muscle harvesting to repair ICA injury may be considered as well.

MANAGEMENT PRINCIPLES

Intraoperative management of an ICA injury can prove difficult, as access is limited and high-pressure bleeding can severely impair visibility. The first step should be to maintain visualization of the operative field using suction. A two-surgeon team can prove helpful through dynamic handling of the endoscope and suctioning instruments. Two large-bore suction systems, ideally 12 Fr or larger, should be used to clear the field of blood and allow for adequate visualization of the site of injury to properly manage it. Meanwhile, the surgeon handling the endoscope must maintain the surgical view and appropriate orientation. In skull base surgery, the endoscopist may consider entering the contralateral nasal cavity and using the

posterior nasal septal edge as a shield to avoid obscuring the endoscope lens with blood. Integrated endoscope lens cleaning systems can also help maintain visualization of the field. Deliberate hypotension has been previously suggested as a management strategy for patients with carotid artery injury, as this can slow bleeding and help improve visibility.^{19,54,55} However, many surgeons now recommend maintaining normotension through fluid replacement to maintain contralateral cerebral perfusion and prevent ischemic neurologic sequelae.^{36,56}

After bleeding of the ICA is identified and properly visualized, hemostatic control should be achieved as quickly as possible. One strategy is to pack the surrounding area to tamponade the vascular injury. Various materials have been used for this purpose, including gauze, cotton pledgets, fibrin glue, gel foam, cellulose packing, and Teflon and methyl methacrylate. The choice of material ultimately depends on surgeon preference and the size of the vascular injury. However, excessive packing can prevent the surgeon from relocating the source of bleeding and may result in occlusion and stenosis of the ICA or compression of the basilar artery.^{19,57} Certain topical agents, such as Floseal (Baxter International Inc.), a thrombin-gelatin matrix, can aid in hemostatic control without requiring tamponade, although high-pressure arterial bleeding is unlikely to resolve from such matrices alone. Another option is the crushed muscle patch, which may be harvested from the sternocleidomastoid muscle, crushed with a mallet, and placed over the injury without direct tamponade.^{58,59} Additionally, direct closure may be achieved using Debakey-style clamps and sutures, such as the U-clip anastomotic device, which employs a self-closing wire that obviates the need for endoscopic knot tying.⁵⁹ In a study comparing the efficacy of five hemostatic agents (Floleal, Chitosan gel, oxidized regenerated cellulose, muscle patch, or U-Clip sutures) in sheep models, the muscle patch and U-clip were the most effective at achieving rapid hemostasis and minimizing blood loss.⁵⁸

One management technique that has fallen out of favor is surgical ligation of the ICA. While this was historically the technique of choice, studies have illustrated a higher incidence of stroke and death using this strategy, especially in the setting of patients with insufficient or unknown collateral circulation.⁶⁰ Even in those with adequate collaterals, the bleeding is still likely to be rapid and disorienting. Ligation also limits the extent of further management by the interventional radiologist.

After temporary hemostatic control is achieved, the patient should be immediately transferred to the angiography suite. Even for patients with successful hemostasis, angiography should be conducted promptly to effectively characterize the extent of the carotid injury. Current endovascular techniques, including balloon and coil embolization as well as stent-graft placement to a lesser degree, may prove useful in achieving hemostasis.⁶¹ The presence of collateral cerebral flow should also be assessed using MR angiography or other imaging modalities. If there is inadequate collateral flow, endovascular or surgical bypass is the necessary next step.

Lastly, postoperative management and monitoring are important to be kept in mind, as ICA complications may occur after a seemingly

uneventful surgery. For example, delayed formation and rupture of pseudoaneurysm in the ICA, occurring days to years after the original procedure, has been described in multiple case reports.^{16,19} Thus, all patients with ICA injury should undergo active follow-up with regular angiographic screening.

SUMMARY

ICA injury is a potentially catastrophic complication of EES. Fundamentally, the focus should be placed on prevention, as this is the best way to optimize patient outcomes. Identifying patients with notable risk factors and obtaining the appropriate preoperative imaging for surgical planning are key prevention efforts. Of the risk factors mentioned in this review, the most pertinent are anatomic aberrations that distort the normal characteristics of the ICA by displacement, encasement, or invasion. Finally, if faced with an ICA injury, having the appropriate equipment, team members, and preparation can help reduce morbidity and mortality from such a catastrophic event.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest.

ETHICS STATEMENT

This study is based on published data and not individual patients and is therefore exempt from IRB approval.

AUTHOR CONTRIBUTIONS

Rahul K. Sharma: idea generation, study design, data collection, analysis, manuscript drafting, manuscript approval **Alexandria L. Irace:** idea generation, study design, data collection, analysis, manuscript drafting, manuscript approval **Jonathan B. Overvest:** idea generation, study design, data collection, analysis, manuscript drafting, manuscript approval. **David A. Gudis:** idea generation, study design, data collection, analysis, manuscript drafting, manuscript approval.

DATA AVAILABILITY STATEMENT

All data for this manuscript is in the published studies referenced.

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