Classification of internal carotid artery injuries during endoscopic endonasal approaches to the skull base

Mohammed Bafaquh1*, Sami Khairy2*, Mahmoud Alyamany1, Abdullah Alobaid1, Gmaan Alzhrani2, Ali Alkhaibary3, Wafa F. Aldhafeeri1, Areej A. Alaman2, Hanan N. Aljohani1, Basim Noor Elahi1, Fatimah A. Alghabban1, Yasser Orz1, Abdulrahman Y. Alturki1

1Department of Adult Neurosurgery, National Neuroscience Institute, King Fahed Medical City, Riyadh, Saudi Arabia, 2Division of Neurosurgery, Department of Surgery, King Abdulaziz Medical City, Ministry of the National Guard - Health Affairs, King Abdullah International Medical Research Center, King Saud bin Abdulaziz University for Health Sciences, Riyadh, Saudi Arabia, 3Department of Neurosciences, Division of Neurosurgery, King Faisal Specialist Hospital and Research Center, Riyadh, Saudi Arabia.

E-mail: *Mohammed Bafaquh - bafaquh@gmail.com; Sami Khairy - drsami2009@hotmail.com; Mahmoud Alyamany - myamany2009@gmail.com; Abdullah Alobaid - abdullah.alobaid@medportal.ca; Gmaan Alzhrani - gmaan1111@gmail.com; Ali Alkhaibary - alkhairabary@hotmail.com; Wafa F. Aldhafeeri - wfa.1995@gmail.com; Areej A. Alaman - areej.alaman@gmail.com; Hanan N. Aljohani - h.n.aljohani@gmail.com; Basim Noor Elahi - basemelahi@gmail.com; Fatimah A. Alghabban - f.a.alghabban@gmail.com; Yasser Orz - yorz@kfmc.med.sa; Abdulrahman Y. Alturki - dr.alturki.neurosurgery@gmail.com

#These authors are equally contributed to this work

ABSTRACT

Background: Internal carotid artery (ICA) injuries are a major complication of endoscopic endonasal approaches (EEAs), which can be difficult to manage. Adding to the management difficulty is the lack of literature describing the surgical anatomical classification of these types of injuries. This article proposing a novel classification of ICA injuries during EEAs.

Methods: The classification of ICA injuries during EEAs was generated from the review of the literature and analysis of the main author observation of ICA injuries in general. All published cases of ICA injuries during EEAs in the literature between January 1990 and January 2020 were carefully reviewed. We reviewed all patients’ demographic features, preoperative diagnoses, modes of injury, cerebral angiography results, surgical and medical management techniques, and reported functional outcomes.

Results: There were 31 papers that reported ICA injuries during EEAs in the past three decades, most studies did not document the type of injury, and few described major laceration type of it. From that review of the literature, we classified ICA injuries into three main categories (Types I-III) and six sub-types. Type I is ICA branch injury, Type II is a penetrating injury to the ICA, and Type III is a laceration of the ICA wall. The functional neurological outcome was found to be worse with Type III and better with Type I.

Conclusion: This is a novel classification system for ICA injuries during EEAs; it defines the patterns of injury. It could potentially lead to advancements in the management of ICA injuries in EEAs and facilitate communication to develop guidelines.

Keywords: Classification, Endonasal, Endoscopic, Internal carotid artery, Injury

INTRODUCTION

Endoscopic endonasal approaches (EEAs) to skull-base lesions have been substantially advanced over the past three decades. [11,24,37] This advancement came from improvements in instruments,
surgical techniques, surgical skills, as well as the use of intraoperative imaging.\cite{27,33,37,40} Such advancements have expanded the use of extended EEA for all ventral skull base lesions from the crista galli to the odontoid process. These approaches are gradually replacing some traditional transcranial approaches as well as microscopic trans-sphenoidal surgery, as they are generally considered safe approaches.\cite{27} The challenge with these approaches is related to the narrow corridors and complex neurovascular anatomy of the surrounding structures where major vessels run within tight boney canals and are crossed by cranial nerves, which makes it very difficult to control or repair if they are injured.\cite{10,13,15,23,24,26}

Internal carotid artery (ICA) injuries are rare but can be catastrophic when they occur during EEAs.\cite{1,4} The reported incidence of ICA injury during EEA to the skull base ranges from 0.2–1.4% compared to 3–8% in standard open skull base approaches.\cite{6,7,11,14,45}

These differences in incidence result from the differences in surgical techniques, complexity of the approach, and size of the tumor.\cite{12} In addition, rates of variation in the course and geometry of the ICA can be as high as 40%, making the risk of potential injury even higher.\cite{24,40}

Unfortunately, the literature lacks a surgical anatomical classification for these injuries, and most publications only reported the mode of injury without detailed anatomical description of the injury.\cite{6,7,11,16,26} Developing a classification based on the pattern of injury and the functional outcome will lead to better advancement in management, as it represents the first step toward creating guidelines for the prevention and perioperative management of these injuries. This study proposes a classification of ICA injuries during EEAs to the ventral skull base.

**MATERIALS AND METHODS**

A literature review of the MEDLINE database using the PubMed search engine was performed. All published cases of ICA injury during EEAs in the literature between January 1990 and January 2020 were thoroughly reviewed. Animal studies, simulation studies, and non-English studies were excluded from the study.

We reviewed all patients’ demographic features, preoperative diagnoses, modes of injury (when available), cerebral angiography results, surgical and medical management strategies, as well as the reported functional outcomes. From the collected data, the authors proposed a new classification system for these injuries. Three main factors were used to defined the three main types, first is the type of vessel injured (parent artery vs. a branch of the ICA); when the injury involves only a branch of the ICA the type of injury was named “branch injury” and it is classified as Type I. The second and third factors (apply to parent vessel injuries) are the cause and degree of the injury (sharp penetrated injury vs. laceration injury); when the injury involves a sharp penetration the type of injury is named “penetration injury” and is classified as Type II and when the injury is a tear in the three layer of the ICA wall it is named “laceration” and is classified as Type III.

Further factors were used to divide each type into two subtypes. For the “branch injury” (Type I); the distance of the stump from the ICA is an important factor, thus we divided this type further into branch injury with stump more than 3 mm or <3 mm, this is based on the fact that stumps of <3 mm are difficult to control with bipolar coagulation without further injury to or stenosis of the parent vessel; which is the main author observation. The second type (Type II) is a sharp penetration injury, which is further divided based on number of ICA walls involved; into single wall penetration or two-sided wall penetration “through and through” injury. The third type (Type III) was divided into two subtypes, partial laceration (including branch avulsion) or completes transection of the ICA wall with or without fulguration (burning contusion) of the wall of ICA [Table 1].

**RESULTS**

**The new classification**

ICA injuries during EEAs were classified into three main types and six subtypes [Table 1 and Figures 1-4]. The first type is defined as injury to one of the ICA branches. It can take place during dissection of the petrous or parapharyngeal segments of the ICA, or more distal segments. This type can be further sub-classified based on the distance of the injury to the branch from the parent vessel: branch injury with stump more than 3 mm and branch injury with stump <3 mm [Figure 2]. The second type is the penetration type, where direct sharp penetration of the ICA created by a sharp instrument. This type can be further sub-classified into: injury to the ventral wall of the ICA (one sided), the second subtype is when two walls of the ICA are involved [Figure 3]. The third type is laceration injury, and it can be sub-classified as partial laceration that can be direct tearing.

| Table 1: Internal carotid artery injuries during endoscopic endonasal approaches. |
| --- |
| **Branch injury** | **Type I** | **I-A** | Stump >3 mm |
| | **I-B** | Stump <3 mm |
| **Parent Vessel** | **Type II** | **II-A** | One wall injury |
| **Injury** | **II-B** | Two wall injuries |
| | **Type III** | **III-A** | Partial |
| | | **III-B** | Complete transection or fulguration injury |
Figure 1: Classification of internal carotid artery injury during endoscopic endonasal approaches. Three main types.

Figure 2: Branch injury of the internal carotid artery (Type I). (A) Distal injury located more than 3 mm from the parent vessel. (B) Proximal injury located <3 mm from the parent vessel.

Figure 3: Penetration injuries to the internal carotid artery (ICA). (A) Injury to single wall of the ICA. (B) Two-wall injuries through and through injury puncturing the ICA at two walls (ventral and dorsal), or ventral and side wall.

Figure 4: Laceration injuries of the internal carotid artery (ICA). (A) True laceration typically caused by punch/pituitary instruments or branch avulsion-off the wall of ICA. (B) Complete laceration that includes transection and fulguration (burn/contusion typically caused by aggressive coagulation of the ICA).

The outcome of the injury based on the proposed classification

The review of the literature revealed 31 papers that reported ICA injuries during EEA s to the ventral skull base. A total of 68 patients were reported in the literature with ICA injuries during EEA s. Type III injury was the most commonly reported in 27 patients and was associated with unfavorable outcomes. In the outcome of these injuries, a total of four patients died and five patients were reported to have neurological deficit, three of them were temporary deficits [Table 2], However, many articles reported a good outcome even with severe injuries. In [Table 2] we outlines the indications for EEA s, ICA segment/methods of injury, classifications, angiographic results, and patient outcomes of all reported cases in the literature.
### Table 2: Studies included in the literature review

| Author and year | Study design | No. of cases | Why patient underwent endonasal approach | Extended endonasal Yes or No | ICA segment | Method of injury | Classification of injury 1–3 | Timing of angiography | Angiography results | Type of management | Patient outcome | Comments |
|-----------------|--------------|--------------|------------------------------------------|----------------------------|-------------|-----------------|--------------------------|----------------------|---------------------|-------------------|-----------------|----------|
| Nutai et al., 2019 [31] | Case report | 1 | 1 | Pituitary tumor | No | Cavernous segment | During dura opening | 3 | 3 days post event | Pseudoaneurysm | Pipeline flow diverter stent | At 12 month follow-up asymptomatic |
| Lum et al., 2019 [28] | Case report | 1 | 1 | CSF leak | No | Paraclival segment | Bone removal of an interior wall of sphenoid sinus using Hajek sphenoid punch forceps | 3 | Immediate | Injury to paraclival portion of left ICA with significant flow limitation to the left middle cerebral artery (MCA) | Stenting (thrombosed within 15 min) | Vessel was sacrificed |
| Georgianni et al., 2018 [32] | Case report | 1 | 1 | Pituitary tumor | No | Cavernous portion | High-speed drilling of the bone | NA | Immediate | Extravasation of the contrast agent into the sphenoidal sinus from the anterior genu of intracavernous portion of the right ICA | Pipeline flow diverter stent | Asymptomatic |
| Duek et al., 2017 [33] | Case report | 1 | 1 | Chordoma | Yes | Cavernous segment | Using Kerrison rongeur forceps and a drill | 3 | Not done | Not done | Pipeline flow diverter stent | Asymptomatic |
| Karadag et al., 2017 [34] | Case report | 1 | 1 | Pituitary tumor | No | Cavernous | Not stated | NA | Immediate | Pseudoaneurysm | Flow diverter stent | No deficit |
| Del Carmen et al., 2017 [35] | Case series | 4 | 1 | Pituitary tumor | No | Cavernous | While an ultrasonic aspirator was being used in the right lateral portion | 1 | Immediate | Right ophthalmic artery occlusion | Coiling of the ophthalmic artery | No new deficits |
| Del Carmen et al., 2017 [36] | Case report | 2 | 2 | Tuberculum sellae meningioma | Yes | Cavernous | While drilling the tuberculum sella | 3 | Immediate | Post op | Pseudoaneurysm of right ophthalmic artery | No new deficits |

**Table Notes:**
- **ICA:** Internal Carotid Artery
- **CSF:** Cerebrospinal fluid
- **MCA:** Middle Cerebral Artery
- **PM:** Pipeline flow diverter stent
- **ANGIO:** Angiography
- **Vessel:** Vessel was sacrificed
- **Mild:** No new deficits
- **Asymptomatic:** Asymptomatic
- **Pseudoaneurysm:** Pseudoaneurysm
- **Coiling:** Coiling of the ophthalmic artery
- **Flow diverter:** Flow diverter stent
- **Stenting:** Stenting
- **Follow-up:** Follow-up
- **Preoperative:** Preoperative
- **Post op:** Postoperative
- **Angiography:** Angiography day 1: small stump in the right ophthalmic artery
- **Follow-up:** Follow-up on day 12 pseudoaneurysm of right ophthalmic artery
- **Immediate:** Immediate

**Study Details:**
- **Nutai et al., 2019**
- **Lum et al., 2019**
- **Georgianni et al., 2018**
- **Duek et al., 2017**
- **Karadag et al., 2017**
- **Del Carmen et al., 2017**

**Comments:**
- **Nutai et al., 2019:** Patient had baseline preoperative weakness of right Hypoglossal nerve
- **Duek et al., 2017:** Patient had stable vision
- **Karadag et al., 2017:** Patient was discharged with a stable preoperative bitemporal hemianopsia.
| Author-year | Study design   | No. of cases | Why patient underwent endonasal approach | ICA segment | Method of injury | Timing of angiography | Angiography results | Type of management | Patient outcome | Comments |
|-------------|---------------|--------------|----------------------------------------|-------------|-----------------|----------------------|----------------------|-------------------|----------------|----------|
| Del Carmen et al., 2017 [8] | Case series   | 3            | Pituitary tumor                        | No          | Comm  | During tumor removal | NA                  | 1: Arterial defect in the anterior communicating artery  
2: Follow-up: no contrast extravasation and normal anterior communicating artery  
3: 10 days postoperative: recurrent pseudoaneurysm with occlusive dissection of right aspect of anterior communicating artery + bilateral spasm of anterior cerebral arteries  
4: 10 days postoperative: pseudoaneurysm and propagation of arterial dissection of right internal carotid artery  
5: Follow-up: persistent occlusion of anterior communicating artery + pseudoaneurysm | Coagulation and muscle graft  
Then clipping  
Surgical + fascia lata  
Asymptomatic at 36 months follow-up |
| Zhang et al., 2016 [48] | Case series   | 2            | Chondrosarcoma                        | Yes         | Cavernous ICA  | During the removal of bone of carotid canal | N/A                  | No pseudoaneurysm after the endovascular treatment | Surgical + fascia lata  
Asymptomatic at 36 months follow-up |
| Cobb et al., 2014 [45] | Technical case report | 1           | Anterior and central skull base osteoblastoma | Yes         | Cavernous ICA  | During tumor resection | N/A                  | N/A | No new deficits  
Staged surgery, injury occurred in the 2nd stage |
| Smith et al., 2015 [46] | Retrospective review | 681         | Cushing's disease (68) and silent corticotroph adenomas (14) | No          | Cavernous | N/A | Immediate | N/A | No neurological deficit. |
| Mathis et al., 2014 [25] | Case report   | 1            | Sinus surgery                         | No          | Right cavernous internal carotid artery | N/A | Immediate | N/A | No neurological deficit. |

1: Glue injection into the arterial wall and suprasellar cistern  
2: Anaglography and stenting  
3: Stenting overlapping the distal aspect of the previously deployed stent  
4: Coiling of the anterior communicating artery  
5: No management stated
| Author-year      | Study design               | No. of cases | Why patient underwent endonasal approach | Extended endonasal Yes or No | ICA segment                      | Method of injury             | Classification of injury 1–3 | Timing of angiography | Angiography results | Type of management | Patient outcome | Comments |
|------------------|---------------------------|--------------|-----------------------------------------|------------------------------|----------------------------------|-----------------------------|------------------------------|------------------------|---------------------|-------------------|-----------------|----------|
| Rangel-Castilla et al., 2014 | Retrospective reviewed   | 235          | - Pituitary adenoma (2) - Rathke cleft cyst (1) - Recurrent skull base chondoma (1) - Cavernous sinus meningioma (1) - Giant Poonmm aneurysm (1) - Cavernous ICA aneurysm (1) - Chronic onf (1)                      | 8                            | Petroous, cavernous, supraclinoid | Direct injury                | 4 cases only | 3                        | Not mentioned for all the cases | Poor collateral follow, large pseudo aneurysm, progressive dissection, subacute stenosis | High flow ICA-middle cerebral artery (MCA) anastomosis with a radial artery graft (RAG) | modified Rankin Scale score 0 or 1 at 19 months follow-up |
| Mortimer et al., 2014 | Case report               | 2            | 1 Nonfunctioning pituitary microadenoma | 1                            | No                                |                           | 2                         | 1 case: Following dural opening (1) | 2 case: During tumor resection (1) | Cavernous | 1 case: Type 2 | 1 case: 3 days post op | 1 case: 4-6 mm pseudo aneurysm | 1 case: Endovascular, coiling | No new deficits at 5 months follow-up |
| Shakir et al., 2014 | Technical note retrospective review | 1            | 1 Left cavernous ICA (Both)               | 1                            | Yes                               |                           | 1                         | 1 case: Type 2 | 1 case: After CTA day 9 | 2 case: N/A | Immediate | Active extravasation from the petrous carotid artery | Endovascular coil embolization device and coils | No deficits |
| Petz et al., 2013 | Case Report               | 1            | Not applicable                           | N.A                          | Anterior segment of the ascending internal carotid artery | Tumematic head injury     | N.A                       | Day 47 after trauma | Cephalo-cavernous fistula (CCF) | Endovascular sacrifice with aneurysm clips | Death after 36 h as result of cardiac ischemia |
| Gardner et al., 2013 | Retrospective assessment between 1998 and 2011 | 7 (0.3%) | Nonfunctional pituitary                   | N.A                          | Parasellar (paraclinoid) | Hemorrhage due to trauma    | 3                         | Immediate post op |                         | Stenosis | Endovascular sacrifice with aneurysm clips | Death after 36 h as result of cardiac ischemia |
| Author year | Study design | No. population | No. of cases | Why patient underwent endonasal approach | Extended endonasal Yes or No | CCA segment | Method of injury | Classification of injury 1–3 | Timing of angiography | Angiography results | Type of management | Patient outcome | Comments |
|-------------|-------------|----------------|--------------|------------------------------------------|-----------------------------|-------------|----------------|-----------------------------|---------------------|---------------------|-----------------|----------------|----------|
| Gardner et al., 2013 | Retrospective review between 1998 and 2011 Case series | 2015 | 1870 | 2 | Medication-resistant prolactinoma Recurrent choroidoma Choledoma Chondrosarcoma | No | Parasympathetic (cavernous) Perforator avulsion during tumor resection Lacrimal | No | 1 – Immediate post op | Pseudoaneurysm | Stenting | No sequelae |
| Golinelli et al., 2012 | Case series | 1870 | 570 | 2 | Medication-resistant prolactinoma Recurrent choroidoma Choledoma Chondrosarcoma | No | Parasympathetic (cavernous) Perforator avulsion during tumor resection Lacrimal | No | 1 – Immediate post op | Pseudoaneurysm | Stenting | No sequelae |
| Trivedato et al., 2011 | Case Report | 1 | 1 | Arachnoid cyst fenestration | Yes | Communicating segment of the right internal carotid | During removal of the arachnoid covering the carotid artery | 3 – After 3 months | A 1.3-mm aneurysm of the communicating segment of the right ICA | Embolization and coiling | Asymptomatic at 2-month follow-up |
| Karaman et al., 2009 | Case Report | 1 | 1 | Chronic sinusitis | No | Left carotid-cavernous fistula | Manipulations during FESS | 3 – 1 month post op | Left carotid-cavernous fistula | Embolization and coiling | Asymptomatic at 2-month follow-up |
| Berker et al., 2012 | Retrospective analysis and review of the literature | 1870 | 570 | 2 | Medication-resistant prolactinoma Recurrent choroidoma Choledoma Chondrosarcoma | No | Parasympathetic (cavernous) Perforator avulsion during tumor resection Lacrimal | No | 1 – Immediate post op | Pseudoaneurysm | Stenting | No sequelae |
| Golinelli et al., 2012 | Case series | 1870 | 570 | 2 | Medication-resistant prolactinoma Recurrent choroidoma Choledoma Chondrosarcoma | No | Parasympathetic (cavernous) Perforator avulsion during tumor resection Lacrimal | No | 1 – Immediate post op | Pseudoaneurysm | Stenting | No sequelae |
| Trivedato et al., 2011 | Case Report | 1 | 1 | Arachnoid cyst fenestration | Yes | Communicating segment of the right internal carotid | During removal of the arachnoid covering the carotid artery | 3 – After 3 months | A 1.3-mm aneurysm of the communicating segment of the right ICA | Embolization and coiling | Asymptomatic at 2-month follow-up |
| Karaman et al., 2009 | Case Report | 1 | 1 | Chronic sinusitis | No | Left carotid-cavernous fistula | Manipulations during FESS | 3 – 1 month post op | Left carotid-cavernous fistula | Embolization and coiling | Asymptomatic at 2-month follow-up |

**Comments:**
- Immediate post op: Immediate postoperative
- 3 h post-op: 3-hour postoperative
- 2 days post op: 2-day postoperative
- 23 days post op: 23-day postoperative
- 12 days postoperative: 12-day postoperative
- 3 months: 3-month follow-up
- 2 months: 2-month follow-up
- No sequelae: No sequelae
- Delayed death, directly unrelated cause: Delayed death, directly unrelated cause
- No neurological deficits for over 10 years: No neurological deficits for over 10 years
- No visual/ neurological deficits for over 10 years: No visual/ neurological deficits for over 10 years
- No neurological deficit in the follow-up period: No neurological deficit in the follow-up period
- No new deficits: No new deficits
| Author-year | Study design | No. Population | No. of cases | Why patient underwent endonasal approach | Extended endonasal Yes or No | ICA segment | Method of injury | Classification of injury 1–3 | Timing of angiography | Angiography results | Type of management | Patient outcome | Comments |
|-------------|--------------|----------------|--------------|-----------------------------------------|-----------------------------|-------------|----------------|--------------------------|----------------------|------------------|-----------------|-------------|----------|
| Haralampaki et al., 2009 | Case report | 150 | 1 (0.7%) | Endonasal trans-sphenoidal surgery under endoscopic conditions for the treatment of sellar lesions | No | Cavernous | After opening the sella floor | ND | Immediat | N/A | Stenting | No deficits |
| Reich et al., 2009 | Case report | 1 | 1 | Endonasal sinus surgery for polyp excision | No | Cavernous | N/A | 3 | Immediat | Right internal carotid artery pseudoaneurysm | Stenting | No deficits |
| Bious et al., 2004 | Case report | 1 | 1 | Pituitary mass biopsy | No | Cavernous | N/A | 3 | Immediat | Right internal carotid artery pseudoaneurysm | Parent vessel occlusion | No deficits |
| Carholou and al., 2008 | Case report | 1 | 1 | FESS | No | Cavernous | N/A | 3 | Immediat | N/A | Embolization | No deficits |
| Lipper et al., 2007 | Case report | 2 | 2 | 1: Adenoid cystic carcinoma tumor excision involving sphenoid, ethmoid, ant/middle skull base 2: FESS | ? | Cavernous | N/A | 3 | 1: Day 19 post op 2: Immediat | 1: Pseudoaneurysm of the ICA 2: Pseudoaneurysm in the siphon of the right ICA | 1: Intraluminal covered stent 2: Covered stent | No deficits |
| Pepper et al., 2007 | Case report | 2 | 2 | 1: Posterior sphenoid sinus mass biopsy 2: Polypectomy | No | Cavernous | 1: Suctioning of the mass 2: ND | 3 | Immediat | 1: Right ICA bleed near the anterior surface of the vessel at the level of the CS 2: Bleeding from a laceration of the left ICA at the level of the CS | 1: Right ICA occluded with detachable silicone balloons 2: Left ICA occluded with detachable silicone balloons | 1: No deficits 2: Diminished vision in the left eye + mild epistaxis 2 weeks post op small amount of bleeding from branches of the left external carotid was embolized | No deficits |
| Authors-year | Study design | No. | No. of cases | Why patient underwent endonasal approach | Extended endonasal Yes or No | ICA segment | Method of injury | Classification of injury 1–3 | Timing of angiography | Angiography results | Type of management | Patient outcome | Comments |
|--------------|--------------|-----|-------------|------------------------------------------|-----------------------------|-------------|----------------|-------------------------|---------------------|---------------------|-----------------|---------------|----------|
| Koitschev et al., 2006 [23] | Case series | Patients surgically treated for chronic sinusitis and its complications between 1994 and 2004 | 2 | 1: Polyp excision 2: Microscopic sinus procedure in combination with a septoplasty for chronic sinus disease and a septal deviation | No | 1: Infra ophthalmic 2: Infra ophthalmic | 1: Exploration of the sphenoïd sinus 2: Attempt to remove potential polypoid tissue from a posterior ethmoid cell | 3 | Immediate | 1: Laceration of the infra-ophthalmic segment of the right internal carotid artery + direct traumatic carotid-cavernous sinus fistula with venous drainage into the ophthalmic vein and the petrosal sinus 2: Laceration of the ventral wall of the left ICA in the infra-ophthalmic segment with paravasation of blood into the sphenoïd sinus | 1: Balloon-occluded immediately proximal to the fistula + supra-ophthalmic segment of the ICA was occluded with detachable coils 2: PAO with detachable balloon | 1: Unilateral palsy of CN3 & 6 resolved within 6 months 2: No deficits |
| Weidenbecher et al., 2005 [46] | Case series | 4 | 4 | Endoscopic sinus surgery | No | Cavernous | 1: Puncturing the sphenoid sinus with a suction tip 2: While perforating anterior wall of sphenoid 3: While perforating anterior wall of sphenoid 4: ND | N/A | 1: None, patient dead 2: 3 weeks post op 3: 3 weeks post op 4: 5 days | 1: None, patient dead 2: Patent ICA 3: Pseudoaneurysm > clipped 4: Pseudoaneurysm | 1: NA 2: Muscle fascia graft + clipping 3: Muscle fascia graft + clipping 4: Trial of muscle fascia graft, ICA coiling | 1: Dead 2, 3, 4: No deficits |
| Park et al., 1998 [16] | Case report | 1 | 1 | Septoplasty and FESS for | No | Cavernous | During sphenoidotomy | 3 | Immediate | Pseudoaneurysm of the cavernous carotid artery | Right ICA coiling + detachable balloons | No deficits |
| Isenberg and Scott 1994 [11] | Case report | 1 | 1 | Endoscopic sinus surgery and polyp biopsy | No | Cavernous | During polyp biopsy | 3 | After 12 h | Carotid cavernous fistula + pseudoaneurysm | Coiling + detachable balloons | No deficits |
| Hudgins et al., 1992 [10] | Retrospective | 150 | 1 | Endoscopic sinus surgery | No | Cavernous | ND | 3 | Immediate | Small pseudoaneurysm of the left cavernous carotid artery | Permanent balloon occlusion | No deficits |
The “enough distance” of the stump is defined around 3 mm as most bipolar tip is around 2 mm, where the stump can be held by the bipolar tip and coagulated relatively safely, however, when the stump is <3 mm the comfort zone of controlling the bleed using bipolar coagulation is narrowed and might need different technique other than coagulation (e.g., aneurysmal clip) or other management such as endovascular intervention (flow diverters) after temporarily backing.

DISCUSSION

Injury to the ICA during EEAs can occur during any step of the procedure. Multiple modes of injury have been reported in the literature. There are no specific data regarding the most frequent mode of injury. However, many studies have reported unexpected bleeding during removal of bony structures, whether by high-speed drilling, Hajek Sphenoid Punch Forceps, or Kerrison Rongeurs during exposure, with mostly reporting laceration injury, or Type III in our classification.[5,8,16,17,18] In addition, few studies reported small arterial perforators injury during tumor dissection or resection (especially in fibrous tumors), resulting in Type 1 injury.[11] Type II injury was the least reported although one can have a significant unrecognized subarachnoid bleed after packing the injury site in the sphenoid sinus which might give false impression of good control of the hemorrhage, where the bleeding is continued through unrecognized other site of penetration in the dorsum wall of the ICA; Type IIIb.[26]

Although the number of publication on EEAs to the ventral skull-base lesions has increased significantly, ICA injury associated with it is under-reported or not well reported. Five factors can be identified as reasons for not documenting ICA injuries in the literature; first, the ICA injury can happen without been noticed.[2] The second factor is that most of the cases are mild and can be managed during surgery (i.e., branch injury) which was felt not to be worth reporting or publishing by most surgeons, (that is not including attentional controlled scarification of ICA branch as part of the approaches, e.g., pituitary transposition in the upper transclival approaches, where the inferior hypophyseal artery is coagulated and cut). The third reason is that there is no good documentation of an appropriate imaging (digital subtraction angiography [DSA]) post-ICA injury in many cases,[6] the fourth reason is that the focus usually when such injuries happen is toward reporting the management and how the bleeding was controlled rather than the mechanism of injury (including the instrument that was used) and the fifth reason is the lack of a classification system that can direct quick and effective documentation and reporting of such complications.[1,4,26]

Chin et al. systematically reviewed ICA injuries during EEA. A total of 38 patients reported no neurological deficits on follow-up. Five patients reported neurological deficits; however, only one patient was found to have persistent neurological deficits on follow-up for the ICA injury. Four patients were pronounced dead intraoperatively due to cardiovascular collapse, and one patient passed away 3 days after the injury.[6]

Cobb et al. presented a technical case report on ICA injury during an EEA. The patient was diagnosed with skull base osteoblastoma. During the surgery, the cavernous segment of the ICA was injured. Postoperatively, the patient’s neurological status remained unchanged.[7]

Mortimer et al. reported two cases of ICA injury. The first patient remained well 5 years after the surgery, the second patient reported good recovery and remained well 6 months after the operation.[10]

Gardner et al., in case series, reported the incidence and outcome of ICA injury during EEA. They encountered seven patients with ICA injury, with an incidence of 0.3%. One patient experienced excessive bleeding intraoperatively from the injured ICA during pituitary surgery. The patient died 36 h postoperatively due to cardiac ischemia.[12]

Golinelli et al. reported two cases of pseudoaneurysm after ICA laceration during endonasal surgery. The first patient had uneventful outcome postoperatively, and the 10-year follow-up revealed no visual or neurological deficits. The second patient developed postoperative right hemispheric stroke, resulting from a thrombus occluding the ICA.[14]

After maintaining hemostasis, DSA must be performed immediately to evaluate the nature of the injury.[1,2,11,47,49] If DSA is negative, the packing can be loosened in the angiogram suite to exclude any injury that is concealed by the packing. If DSA, however, shows sign of active extravasation, pseudoaneurysm, or CCF, the proper endovascular management can be immediately implemented.[8,9,20,21,43] When it is available, intraoperative DSA can help understand the type and pattern of injury and a management plan can be devised. The previous belief that ICA occlusion and sacrifice represent the most reliable treatment for ICA injuries should be revised with the current expansion of reconstructive endovascular options. Even with a negative balloon test occlusion (BTO) preoperatively, the risk of ischemic complications remains relatively high.[10,38] Linskey et al. reported that abrupt ICA occlusion with a negative BTO was associated with a stroke rate of up to 26% and a mortality rate of 12%.[25]

Gardner et al. described their institutional algorithm for iatrogenic ICA injury in EES, which was practical and helpful at that time.[11] Nonetheless, the advancements in endovascular interventions have expanded management options and mandated an update of the management protocols.

Zhang et al. proposed a modified endovascular treatment protocol that demonstrated that covered stent as the ideal
management for ICA injuries. Covered stents have the ability to close the injury site while maintaining the patency of the parent vessel. Moreover, with the introduction of the Wilis stent, which has unique enhanced flexibility,[43,48] ICA preservation rate increased to 83.3% compared to 20% using the older versions of stents.[41] Nonetheless, covered stents require anticoagulant and antiplatelet treatment, which increase the risk of rebleeding mandating clinical judgment on the use of stents.

Many authors have suggested that stent placement should be attempted in all patients before considering ICA sacrifice. Parent artery occlusion is considered if sufficient collateral arterial supply from the contralateral ICA is confirmed by BTO; however, there is still a 5–10% risk of delayed stroke after BTO, and 4.7% of patients develop a permanent deficit.[25] The treating physician also has to contemplate the alteration in hemodynamic stress on the cerebral vasculature, which can subsequently increase the risk of de novo aneurysms formation (which occurs in up to 20% of patients after carotid sacrifice).[41] If BTO is not tolerated, bypass surgery is described as the standing option, however, due to the high complication rate of this procedure, it has been abandoned, and it was not described in the recent literature.

The above review of the literature clearly justifies the need for a classification of the ICA injuries with the objectives of better communication, prevention, management, and advancement of the practice and research in this very important complication of the EEAs.

We faced multiple difficulties in creating this classification, including the underreporting of ICA injuries during EEAs in the literature as well as the limitation of mechanism description, the type of injury and the instrument causing the injury. We believe that this classification system will improve communication in clinical practice and scientific publications and provide a better understanding of the prognosis of these injuries; furthermore, this system should help with the progression from a subjective opinion of surgeons to objective and measurable data that can be documented easily and followed effectively. Despite these limitations, we emphasize the importance of and the need for further anatomical and clinical studies to validate the classification system and modify it accordingly.

CONCLUSION

This is a novel classification system for ICA injuries during extended endonasal endoscopic approaches. This classification system defines the patterns of injuries and the relationship between the injury and the complication’s mortality and functional neurological outcome. Although it is still need to be validated, we strongly believe. It will lead to better recognition of the ICA injuries during EEAs, which will be the first step toward creating protocols for perioperative management of these injuries.

Declaration of patient consent
Institutional Review Board permission obtained for the study.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

REFERENCES

1. AlQahtani AA, Castelnuovo P, Nicolai P, Prevedello DM, Locatelli D, Carrau RL. Injury of the internal carotid artery during endoscopic skull base surgery: Prevention and management protocol. Otolaryngol Clin North Am 2016;49:237-52.
2. Berker M, Hazer DB, Yü cel T, Gürlek A, Cila A, Aldur M, et al. Complications of endoscopic surgery of the pituitary adenomas: Analysis of 570 patients and review of the literature. Pituitary 2012; 15:288—300.
3. Biswas D, Daudia A, Jones NS, McConachie NS. Profuse epistaxis following sphenoid surgery: A ruptured carotid artery pseudoaneurysm and its management. J Laryngol Otol 2009; 123:692--4.
4. Briganti F, Cirillo S, Caranci F, Esposito F, Maiuri F. Development of de novo aneurysms following endovascular procedures. Neuroradiology 2002;44:604-9.
5. Cathelinaud O, Bizeau A, Rimbot A, Arteaga C, Verdule P. Endoscopic endonasal surgery complication: New methods of intracavernous internal carotid artery injury treatment. Rev Laryngol Otol Rhinol (Bord) 20092008; 129:305--8.
6. Chin OY, Ghosh R, Fang CH, Baredes S, Liu JK, Eloy JA. Internal carotid artery injury in endoscopic endonasal surgery: A systematic review. Laryngoscope 2016;126:582-90.
7. Cobb MP, Nimjee S, Gonzalez LF, Jang DW, Zomorodi A. Direct repair of iatrogenic internal carotid artery injury during endoscopic endonasal approach surgery with temporary endovascular balloon-assisted occlusion: Technical case report. Neurosurgery 2015;11:E483-6.
8. Del Carmen A, Romero B, Gangadharan JL, Bander ED, Gobin YP, Anand VK, et al. Managing arterial injury in endoscopic skull base surgery: Case series and review of the literature. Oper Neurosurg (Hagerstown) 2017; 13:138—49.
9. Dusek I, Svirí G, Amit M, Gil Z. Endoscopic endonasal repair of internal carotid artery injury during endoscopic endonasal surgery. J Neurol Surg Reports 2017; 78:e125—8.
10. Fukushima T, Maroon JC. Repair of carotid artery perforations during transphenoidal surgery. Surg Neurol 1998;50:174-7.
11. Gardner PA, Tormenti MJ, Pant H, Fernandez-Miranda JC, Snyderman CH, Horowitz MB. Carotid Artery injury during
endoscopic endonasal skull base surgery. Oper Neurosurg 2013;73:261-70.
12. Gardner PA, Tormenti MJ, Pant H, Fernandez-Miranda JC, Snyderman CH, Horowitz MB. Carotid artery injury during endoscopic endonasal skull base surgery: Incidence and outcomes. Neurosurgery 2013; 73:261-9.
13. Giorgianni A, Pozzi F, Pellegrino C, Padovan S, Karlikiotis A, Castelnuovo P, et al. Emergency placement of a flow diverter for an iatrogenic internal carotid artery injury during endoscopic pituitary surgery. World Neurosurg 2019;122:376-9.
14. Golinelli G, Toso A, Taranto F, Aluffi P, Pia F. Delayed carotid pseudoaneurysm: A life-threatening complication after endoscopic sinus surgery. J Craniofac Surg 2012;23:1822-4.
15. Haralampaki P, Ayyad A, Kockro RA, Perneckzy A. Surgical complications after endoscopic transphenoidal pituitary surgery. J Clin Neurosci 2009; 16:786—9.
16. Hudgins PA, Browning DG, Gallups J, Gussack GS, Peterman SB, Davis PC, et al. Endoscopic cranial base surgery: Radiographic evaluation of severe complications. In: AJNR American Journal of Neuroradiology. 1999; Vol.13, pp.:1161—7.
17. Inamasu J, Guiot BH. Iatrogenic carotid artery injury in neurosurgery. Neurosur Rev 2005;28:239-47.
18. In-Ping Huang Cobb M, Nimjee S, Gonzalez LF, Jang DW, Zomorodi A. Direct repair of iatrogenic internal carotid artery injury during endoscopic endonasal approach surgery with temporary endovascular balloon-assisted occlusion: Technical case report. Clin Neurosurg 2015; 11:E483—6.
19. Isenberg SF, Scott JA. Management of massive hemorrhage during endoscopic sinus surgery. Otolaryng Head Neck Surg 1994; 111:134—6.
20. Karadag A, Kinali B, Ugor O, Oran I, Middlebrooks EH, Senoglu M. A case of pseudoaneurysm of the internal carotid artery following endoscopic endonasal pituitary surgery: Endovascular treatment with flow-diverting stent implantation. Acta Medica (Ihradec Královo) 2017;60:89-92.
21. Karadag A, Kinali B, Ugor O, Oran I, Middlebrooks EH, Senoglu M. A case of pseudoaneurysm of the internal carotid artery following endoscopic pituitary surgery: Endovascular treatment with flow-diverting stent implantation. Acta Medica (Ihradec Královo) 2017; 60:89—92.
22. Karaman E, Isildak H, Haciyev Y, Kaytaz A, Enver O. Carotid-cavernous fistula after functional endoscopic sinus surgery. J Craniofac Surg 2009; 20:556—8.
23. Koitschev A, Simon C, Löwenheim H, Naegle T, Ernemann U. Management and outcome after internal carotid artery laceration during surgery of the paranasal sinuses. Acta Otolaryngol 2006; 126:730—8.
24. Labib MA, Prevedello DM, Carrau R, Kerr EE, Naudy C, Abou Al-Shaar H, et al. A road map to the internal carotid artery in expanded endoscopic endonasal approaches to the ventral cranial base. Neurosurgery 2014;10:448-71.
25. Linskey ME, Jungreis CA, Yonas H, Hirsch WL, Sekhar LN, Horton JA, et al. Stroke risk after abrupt internal carotid artery sacrifice: Accuracy of preoperative assessment with balloon test occlusion and stable xenon-enhanced CT. AJNR Am J Neuroradiol 1994;15:829-43.
26. Lippert BM, Ringel K, Stoeter P, Hey O, Mann WJ. Stentgraft-implantation for treatment of internal carotid artery injury during endonasal sinus surgery. Am J Rhinol 2007; 21:520—4.
27. Little AS, Kelly DF, White WL, Gardner PA, Fernandez-Miranda JC, Chicoine MR, et al. Results of a prospective multicenter controlled study comparing surgical outcomes of microscopic versus fully endoscopic transsphenoidal surgery for nonfunctioning pituitary adenomas: The transsphenoidal extent of resection (TRANSSPHER) study. J Neurosurg 2019;132:1-11.
28. Lum SG, Gendeh BS, Husain S, Gendeh HS, Ismail MR, Toh CJ, et al. Internal carotid artery injury during endonasal sinus surgery: Our experience and review of the literature. Acta Otorhinolaryngol Ital 2019;39:130-6.
29. Mathis JM, Barr JD, Jungreis CA, Yonas H, Sekhar LN, Vincent D, et al. Temporary balloon test occlusion of the internal carotid artery: Experience in 500 cases. AJNR Am J Neuroradiol 1995;16:749-54.
30. Mortimer AM, Klimczak K, Nelson RJ, Renowden SA. Endovascular management of cavernous internal carotid artery pseudoaneurysms following transsphenoidal surgery: A report of two cases and review of the literature. Clin Neuroradiol 2015;25:295-300.
31. Nariai Y, Kawamura Y, Takigawa T, Hyodo A, Suzuki K. Pipeline embolization for an iatrogenic intracranial internal carotid artery pseudoaneurysm after transsphenoidal pituitary tumor surgery: Case report and review of the literature. Interv Neuroradiol 2020;26:74-822019.
32. Nerva JD, Morton RP, Levitt MR, Osbun JW, Ferreira MJ, Ghodke B V, et al. Pipeline embolization device as primary treatment for blister aneurysms and iatrogenic pseudoaneurysms of the internal carotid artery. J Neurointerv Surg 2015; 7:210-6.
33. Ozgur Z, Celik S, Govsa F, Aktug H, Ozgur T. A study of the course of the internal carotid artery in the parahyoid space and its clinical importance. Eur Arch Otorhinolaryngol 2007;264:1483-9.
34. Paiva WS, De Andrade AF, Beer-Furlan A, Neville IS, Noleto GS, Bernardino LS, et al. Traumatic carotid-cavernous fistula at the anterior ascending segment of the internal carotid artery in a pediatric patient. Child’s Nerv Syst 2013; 29:2287-90.
35. Park AH, Stankiewicz JA, Chow J, Azar-Kia B. A protocol for management of a catastrophic complication of functional endoscopic sinus surgery: Internal carotid artery injury. Am J Rhinol 1998; 12:153—8.
36. Pepper JP, Wadhwa AK, Tsai F, Shibuya T, Wong BJF. Cavernous carotid injury during functional endoscopic sinus surgery: Case presentations and guidelines for optimal management. Am J Rhinol 2007; 21:105-9.
37. Prevedello DM, Doglietto F, Jane JA, Jaganathan J, Han J, Laws ER. History of endoscopic skull base surgery: Its evolution and current reality. J Neurosurg 2007;107:206-13.
38. Rangel-Castilla L, McDougall CG, Spetzler RF, Nakaji P. Urgent cerebral revascularization bypass surgery for iatrogenic skull base internal carotid artery injury. Neurosurgery 2014;10:640-7.
39. Reich O, Ringel K, Stoeter P, Maurer J. Verletzung der ACI bei nasennebenhöhlenoperation und management durch endovaskuläre stentapplikation. Laryngorhinootologie 2009; 88:322-6.
40. Renn WH, Rhoton AL. Microsurgical anatomy of the sellar region. J Neurosurg 2009;43:288-98.
41. Shakir HJ, Garson AD, Sorkin GC, Mokin M, Eller JL, Dumont TM, et al. Combined use of covered stent and flow diversion to seal iatrogenic carotid injury with vessel preservation during transsphenoidal endoscopic resection of clival tumor. Surg Neurol Int 2014;5:81.

42. Smith TR, Hulou MM, Huang KT, Nery B, de Moura SM, Cote DJ, et al. Complications after transsphenoidal surgery for patients with Cushing’s disease and silent corticotroph adenomas. Neurosurg Focus 2015;38:E12.

43. Tan HQ, Li MH, Li YD, Fang C, Wang JB, Wang W, et al. Endovascular reconstruction with the willis covered stent for the treatment of large or giant intracranial aneurysms. Cerebrovasc Dis 2011;31:154-62.

44. Trivelato FP, Rezende MTS, Ulhôa AC, Giannetti AV. Endovascular treatment of a traumatic carotid artery aneurysm after endoscopic arachnoid cyst fenestration. Child’s Nerv Syst 2011;27:1329-32.

45. Valentine R, Wormald PJ. Carotid artery injury after endonasal surgery. Otolaryngol Clin North Am 2011;44:1059-79.

46. Weidenbecher M, Huk WJ, Iro H. Internal carotid artery injury during functional endoscopic sinus surgery and its management. Eur Arch Oto-rhino-laryngology 2005;262:640-5.

47. Willinsky RA, Taylor SM, TerBrugge K, Farb RI, Tomlinson G, Montanera W. Neurologic complications of cerebral angiography: Prospective analysis of 2,899 procedures and review of the literature. Radiology 2003;227:522-8.

48. Zhang HK, Ma N, Sun XC, Wang DH. Endoscopic repair of the injured internal carotid artery utilizing oxidized regenerated cellulose and a free fascia lata graft. J Craniofac Surg 2016;27:1021-4.

49. Zhang Y, Tian Z, Li C, Liu J, Zhang Y, Yang X, et al. A modified endovascular treatment protocol for iatrogenic internal carotid artery injuries following endoscopic endonasal surgery. J Neurosurg 2019;132:343-50.

How to cite this article: Bafaquh M, Khairy S, Alyamany M, Alobaid A, Alzhari G, Alkhairi A, et al. Classification of internal carotid artery injuries during endoscopic endonasal approaches to the skull base. Surg Neurol Int 2020;11:357.