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SNI: Neuroendoscopy

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Original Article

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

Mohammed Bafaquh[1#], Sami Khairy[2#], Mahmoud Alyamany[1], Abdullah Alobaid[1], Gmaan Alzhrani[2], Ali Alkhaibary[2], Wafa F. Aldhafeeri[1], Areej A. Alaman[2], Hanan N. Aljohani[3], Basim Noor Elahi[1], Fatimah A. Alghabban[1], Yasser Orz[1], Abdulrahman Y. Alturki[1]

[1]Department of Adult Neurosurgery, National Neuroscience Institute, King Fahed Medical City, Riyadh, Saudi Arabia, [2]Division 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, [3]Department 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 - alkhaibarya@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 contibuted to this work

***Corresponding author:**
Mohammed Bafaquh, National Neuroscience Institute, King Fahad Medical City, Riyadh, Saudi Arabia.

bafaquh@gmail.com

Received : 17 April 2020
Accepted : 20 June 2020
Published : 21 October 2020

DOI
10.25259/SNI_188_2020

Quick Response Code:

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.[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 transsphenoidal surgery, as they are generally considered safe approaches.[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.[10,13,15,23,24,26]

Internal carotid artery (ICA) injuries are rare but can be catastrophic when they occur during EEAs.[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.[6,7,11,12,45]

These differences in incidence result from the differences in surgical techniques, complexity of the approach, and size of the tumor.[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.[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.[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 Injury	Type II	II-A	One wall injury
		II-B	Two wall injuries
	Type III	III-A	Partial
		III-B	Complete transection or fulguration injury

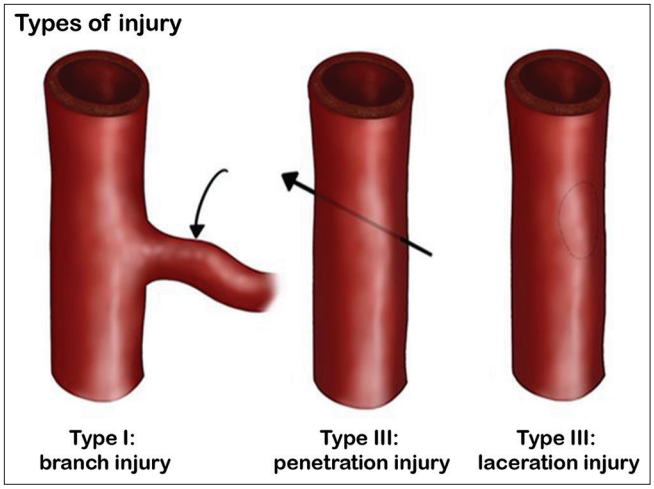

Figure 1: Classification of internal carotid artery injury during endoscopic endonasal approaches. Three main types.

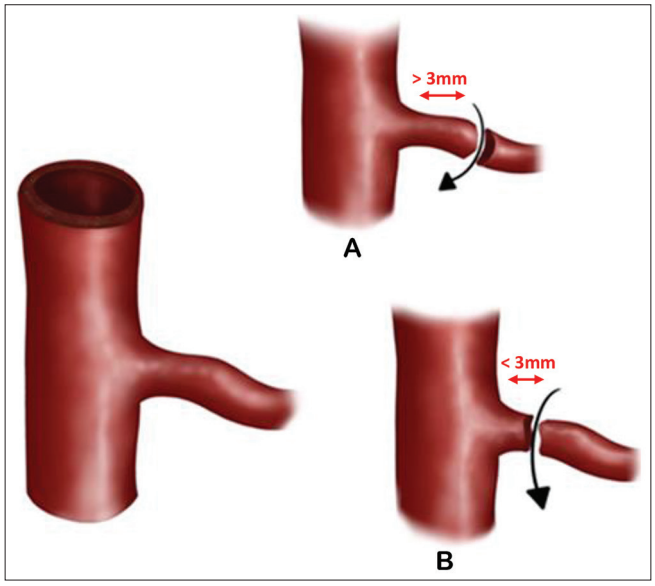

Figure 2: Branch injury of the internal carotid artery (Type I). (A) Distal injury located more than 3 mm from the parent vessel. (B) Proximal injury located <3 mm from the parent vessel.

of the parent artery or branch avulsion, the second subtype is either transection of the ICA, included in this class is burns (fulguration injury) of the ICA, where there is circumferential injury to the artery with critical stenosis. In type III injuries, all walls of the ICA are involved [Figure 4].

The outcome of the injury based on the proposed classification

The review of the literature revealed 31 papers that reported ICA injuries during EEAs to the ventral skull base. A total of 68 patients were reported in the literature with ICA injuries during EEAs. 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 EEAs, ICA segment/methods of injury, classifications, angiographic results, and patient outcomes of all reported cases in the literature.

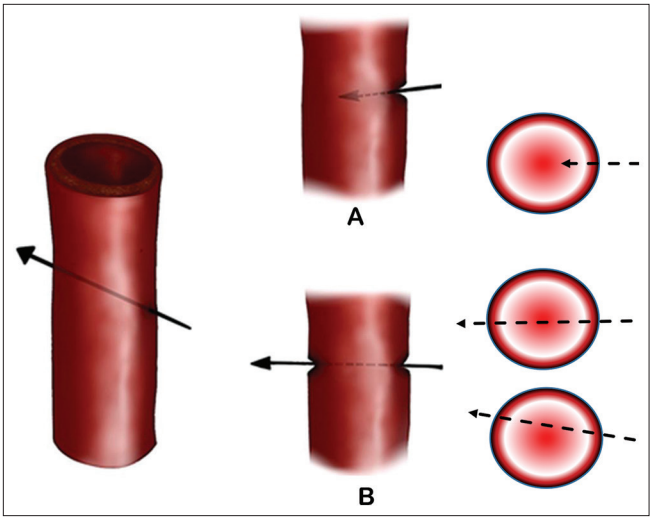

Figure 3: Penetration injuries to the internal carotid artery (ICA). (A) Injury to single wall of the ICA. (B) Two-wall injuries through and through injury puncturing the ICA at two walls (ventral and dorsal), or ventral and side wall.

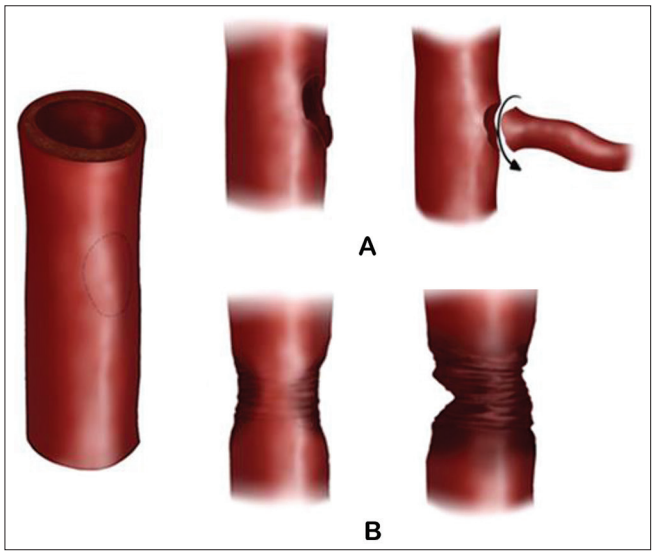

Figure 4: Laceration injuries of the internal carotid artery (ICA). (A) True laceration typically caused by punch/pituitary instruments or branch avulsion-off the wall of- ICA. (B) Complete laceration that includes transection and fulguration (burn/contusion typically caused by aggressive coagulation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

Table 2: Studies included in the literature review.

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
Nariai *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	Bony removal of anterior 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 sacrifice	At 15 month follow-up asymptomatic	
Giorgianni *et al.*, 2018[13]	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[9]	Case report	1	1	Chordoma	Yes	Cavernous segment	Using Kerrison rongeur forceps and a drill	3	Not done	Not done	Temporalis muscle patch	No deficit from injury	Patient had baseline preoperative weakness of right Hypoglossal nerve
Karadag *et al.*, 2017[21]	Case report	1	1	Pituitary tumor	No	cavernous	Not stated	NA	Immediate Post op	pseudoaneurysm	Flow diverter stent	No deficit	
Del Carmen *et al.*, 2017[8]	Case series	4	1	Pituitary tumor	No		While an ultrasonic aspirator was being used in the right lateral portion	1	Immediate	Right ophthalmic artery occlusion Repeat angiography day 1: small stump in the right ophthalmic artery Follow-up on day 12 pseudoaneurysm of right ophthalmic artery	Coiling of the ophthalmic artery	No new deficits	The patient awoke with stable vision
Del Carmen *et al.*, 2017[8]	Case report	2	2	Tuberculum sellae meningioma	Yes	Cavernous	While drilling the tuberculum sella	3		Active extravasation of contrast at the anterior genu of the cavernous segment of the right ICA	Coiling of right ICA	No new deficits	The patient was discharged with a stable preoperative bitemporal hemianopsia

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
Del Carmen *et al.*, 2017[8]	Case series	3	3	Pituitary tumor	No	Comm	During tumor removal	NA	Different times through post op course	1: Arterial defect in the anterior communicating artery 2: Follow-up: no contrast extravasation and normal anterior communicating artery. + dissection of the right ICA 3: 10 days postoperative: recurrent pseudoaneurysm with saccular outpouching of right aspect of the anterior communicating artery + bilateral spasm of the anterior cerebral arteries + propagation of arterial dissection of the right ICA bulb beyond the distal aspect of the stent 4: postoperative day 15, recurrence of the pseudoaneurysm of the anterior communicating artery, + dissection of left internal carotid 5: follow-up: persistent occlusion of the anterior communicating artery + pseudoaneurysm	1: Glue injection into the arterial wall and suprasellar cistern 2: Angioplasty and stenting 3: Stenting overlapping the distal aspect of the previously deployed stent 4: Coiling of the anterior communicating artery 5: No management stated		
Del Carmen *et al.*, 2017[8]	Case series	4	4	Tuberculum sella meningioma	Yes		While the NICO Myriad was being used to remove fibrous tumor	1		Not stated	Coagulation and muscle graft Then clipping		
Zhang *et al.*, 2016[48]	Case series	2	1	Chondrosarcoma	Labiolingual fold incision then endoscope were used	Carotid canal	During the removal of the bone of carotid canal	3	Not stated	No pseudoaneurysm after the endovascular treatment	Surgical+ fascia lata	Asymptomatic at 36 months follow-up	
Cobb *et al.*, 2014[7]	Technical case report	1	1	Anterior and central skull base osteoblastoma	Yes	Cavernous ICA	During tumor resection	3	Immediate intraoperative angiogram	N/A	-Balloon-assisted EEA primary microsurgical repair of the lacerated ICA	No new deficits	Staged surgery, injury occurred in the 2nd stage
Smith *et al.*, 2015[42]	Retrospective review	681	1	Cushing's disease (68) and silent corticotroph adenomas (14)	No	cavernous	N/A	N\A	Immediate	N/A	PAO	No neurological deficit.	
Mathis *et al.*, 2014[29]	Case report	1	1	Sinus surgery	No	Right cavernous internal carotid artery		3	Not mentioned	Pseudoaneurysm	Embolization and coiling of bilateral sphenopalatine and facial artery - Then complete occluded with balloon-assisted coiling and Onyx	Large nasal septal perforation and nasal crusting. + coil emigration	

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
Rangel-Castilla *et al.*, 2014[38]	Retrospective reviewed	235	8	-Pituitary adenoma (2) -Rathke cleft cyst (1) -Recurrent skull base chordoma (1) -Cavernous sinus meningioma (1) -Giant Pcomm aneurysm, (1) - Cavernous ICA aneurysm (1) , - Chronic otitis (1)	4 cases only underwent endoscopic trans-sphenoidal, 2 was extended.	Petrous, cavernous, supraclinoid	Direct injury	3	Not mentioned for all the cases For some are immediate	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 of 0 or 1 at 19 months follow-up	
Mortimer *et al.*, 2013[30]	Case report	2	2	1 Nonfunctioning pituitary macroadenoma 1 pituitary macroadenoma.	Endoscopic trans-sphenoidal resection (1)	Cavernous	1st case: Following dural opening (1) 2nd case: During tumor resection (1)	1st case: Type 3 2nd case: Type 2	1st case: 3 days post op 2nd case 2nd post op	1st case: 4×3 mm aneurysm 2nd case: Mild narrowing of the cavernous ICA + pseudo aneurysm	1st case: Endovascular, coiling 2nd case: endovascularly (not specified)	No new deficits at 5 months follow-up	
Shakir *et al.*, 2014[41]	Technical note	1	1	Clival Tumor	Yes	Petrous	During tumor resection	2	Immediate	Active extravasation from the petrous carotid artery	Stenting with stent graft and two flow diverter stents	No deficits	
Nerva *et al.*, 2014[32]	retrospective review	4	2	1st case: Sellar lesion 2nd case: Not mentioned	No	Left cavernous ICA (Both)	1st case during tumor resection 2nd case: Not mentioned	1st case: Type 2 2nd case: N/A	1st case: After CTA day 9 2nd case: Not mentioned	1st case: 1.5×2 mm pseudoaneurysm of the left cavernous ICA 2nd case: pseudoaneurysm (20×3×3)	1st case: PED (pipeline Embolization device) 2nd case: PED (pipeline embolization device) and coils	1st case: No deficits 2nd case: Dying of unrelated causes (sepsis)	
Paiva *et al.*, 2013[34]	Case Report	1	1	Not applicable	N/A	Anterior segment of the ascending internal carotid artery	Traumatic head injury	N/A	Day 47 after trauma	Carotid-cavernous fistula (CCF)	Endovascular coil embolization	At 15 days follow-up, no improvement of the right eye vision with no headache	
Gardner *et al.*, 2013[12]	Retrospective review between 1998 and 2011	2015	7 (0.3%)	Nonfunctional pituitary		Parasellar (paraclinoida)	Kerrison rongeur during exposure	3	Immediate post op	Stenosis	Endovascular sacrifice with aneurysm clips	Death after 36 h resulting from cardiac ischemia	

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
Gardner *et al.*, 2013	Retrospective review between 1998 and 2011 Case series	2015 1870	7 (0.3%) 2	Medication- resistant prolactinoma	No	Parasellar (cavernous)	Perforator avulsion during tumor resection	1	Immediate post op	Pseudoaneurysm	Stenting	No sequelae	
Golinelli *et al.*, 2012[14]				Recurrent chordoma		Paraclival	Injury during exposure	3	3 h post op	Stenosis	Coiling	No sequelae	
				Chordoma		Lacerum	Thrucut rageur during tumor exposure	3		Middle cerebral artery thromboembolus	Proximal coiling	No sequelae	
				Chondrosarcoma		Paraclival	Blunt dissection during tumor resection (micotear)	1		ICA intact	Bipolar coagulation	Delayed death, directly unrelated cause	
				Nasopharyngeal carcinoma		Lacerum	Tumor resection	3		Stenosis	Clip sacrifice	No sequelae	
				Planum meningioma		Paraclival – parasellar transition	Drill injury during exposure	N\A		Middle cerebral artery thromboembolus	Focal packing with half-inch cottonoid	No sequelae	
				1st case: Sudden recurrent mucocele with headache and diplopia that was managed 3 years back with left endoscopic sphenoidectomy		Cavernous segment (ICA siphon)	suctioning	3		Normal ICA	A balloon occlusion of the ICA	No visual/ neurological deficits for over 10 years	
Golinelli *et al.*, 2012[14]	Case series	1870	2	1st case: Sudden	No	Cavernous	Suctioning	3	2 days post op	Normal ICA	A balloon occlusion of the	No visual/	
Berker *et al.*, 2012[2]	Retrospective analysis and review of the literature	570	1 (0.16%)	recurrent mucocele with headache and diplopia that was managed 3 years back with left endoscopic sphenoidectomy 2nd case: Symptomatic left sphenoidal "fungus ball"	No	segment (ICA siphon) Distal cavernous segment of the left ICA	Not stated	3	23 days post op 12 days postoperative	A pseudoaneurysm in the siphon of the ICA and sufficient collateral circulation from the contralateral ICA and the vertebral artery system A pseudoaneurysm of the distal cavernous segment of the left ICA; no adequate cross circulation	ICA Stenting	neurological deficits for over 10 years Right hemispherical stroke developed due to thrombosis of the ICA few h postprocedure	
				Recurrence of ACTH- secreting macroadenoma	No	Cavernous ICA	During the bony removal of the sellar floor	3	Immediate	Cavernous ICA aneurysm	Endovascular stent-graft placement	No neurological deficit in the follow-up period	F/u period not specified
Trivelato *et al.*, 2011[44]	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 13-mm aneurysm of the communicating segment of the right ICA	Embolization and coiling	No new deficits	
Karaman *et al.*, 2009[22]	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	

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[15]	retrospective	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	Immediate	N\A	Stenting	No deficits	
Reich *et al.*, 2009[39]	Case report	1	1	endonasal sinus surgery for polyp excision	No	Cavernous	N\A	3	Immediate	Right internal carotid artery pseudoaneurysm	Stenting	No deficits	
Biswas *et al.*, 2008[3]	Case report	1	1	Pituitary mass biopsy	No	Cavernous	N\A	3	Immediate	Right internal carotid artery pseudoaneurysm	Parent vessel occlusion	Transient right hemiparesis	
Cathelinaud *et al.*, 2008[5]	Case report	1	1	FESS	No	Cavernous	N\A	N\A	Immediate	N\A	Embolization	No deficits	
Lippert *et al.*, 2007[26]	Case series	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: Immedite	1: Pseudoaneurysm of the ICA 2: Pseudoaneurysm in the siphon of the right ICA	1: Intraluminal covered stent 2: Covered stent	1: No deficits 2: Stent migration and residual aneurysm > treated with 2 bare stents and fascia graft endonasal > complete recovery	
Pepper *et al.*, 2007[36]	Case series	2	2	1: Posterior sphenoid sinus mass biopsy 2: Polypectomy	No	Cavernous	1: Suctioning of the mass 2: ND	3	Immediate	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 > embolized	

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
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 sphenoid 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 sphenoid 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 died 2: 3 week post op 3: 3 weeks post op 4: 5 days	1: NA 2: Patent ICA 3: Pseudoaneurysm > clipped 4: Pseudoaneurysm	1: NA 2: Muscle fascia graft 3: Muscle fascia graft + clipping 4: 2 Trial of muscle fascia graft, ICA coiling	1: Died 2,3,4: No deficits	
Park *et al.*, 1998[35]	Case report	1	1	Septoplasty and FESS for	No	Cavernous	During sphenoidotomy	3	Immediate	Pseudoaneurysm of the cavernous carotid artery	Right ICA coiling	No deficits	
Isenberg and Scott 1994[19]	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	Transient CN6 paresis	
Hudgins *et al.*, 1992[16]	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 IIb.[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.[30]

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.[4,9,20,21,43] 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,[43,49] 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).[4] 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.

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