

Contribution of Cerebral CT Angiography in The Study of Anatomical Variations of the Intracranial Internal Carotid Artery: Report of 10 Cases with Literature Review

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Abstract

Case Series

Introduction: The internal carotid artery (ICA), with its complex course and close anatomical relationships, is particularly exposed to the risk of severe intraoperative injury. Thorough knowledge of its variations is essential for surgical safety, especially in endoscopic skull base surgery. The novelty of this work lies in the fact that it represents the first study using CT angiography to characterize anatomical variations of the ICA, which gives this research particular significance. **Objective:** To evaluate the morphological variations of the intracranial ICA using CT angiography and analyze their surgical implications. **Materials and Methods:** This was a prospective descriptive study of 10 patients (20 ICAs) who underwent cerebral CT angiography. The analyzed parameters included diameter, length, curvature angles, distance to the pituitary gland, inter-carotid distance, and the presence of anastomoses or agenesis. **Results:** The mean age was 67.8 years, with 80% male patients. The main indications were stroke and myocardial infarction. Minimal intra-individual variability in ICA diameter was observed. Curvature angles and distances to adjacent structures proved to be key factors in assessing operative risk. **Conclusion:** CT angiography provides substantial value in the anatomical assessment of the ICA, offering precise results to help surgeons avoid iatrogenic injury to this highly exposed vessel, whether approached transcranially or endoscopically. **Keywords:** Internal Carotid Artery (ICA), CT Angiography, Anatomical Variations, Neurosurgery, Intraoperative Injury, Endoscopic Skull Base Surgery.

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INTRODUCTION

The intracranial internal carotid artery (ICA) is a high-risk structure during neurosurgical procedures, particularly in transsphenoidal or endoscopic approaches. Detailed anatomical knowledge of the ICA is crucial to anticipate intraoperative complications.

Iatrogenic injuries of the ICA, although rare (0.4–3.8%) [1], are often severe. Their prevention relies on rigorous identification of individual anatomical variations. In this context, preoperative imaging plays an essential role in evaluation. Among the different available modalities, CT angiography represents an examination of choice due to its wide availability, relatively low cost, rapid acquisition in emergency settings, and its ability to provide high-resolution images with multiplanar reconstructions. It allows for a precise analysis and mapping of ICA anatomical variations in view of optimal surgical management [2].

This study aims to explore the morphological variations of the ICA using CT angiography and to discuss their surgical implications.

MATERIALS AND METHODS

This was a single-center, observational descriptive study including ten patients. Patients were eligible if they underwent cerebral and supra-aortic trunk CT angiography, had no history of hypothalamic–pituitary surgery, and had complete radiological data. Exclusion criteria were contraindications to CT scanning (pregnancy, allergy to iodinated contrast, or advanced renal failure).

Examinations were performed using a Siemens scanner with 1 mm slice acquisitions to optimize spatial resolution. Multiplanar reconstructions (MPR) allowed for a detailed analysis of anatomical parameters.

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The variables studied included: age, sex, indication for CT angiography, diameter and length of the right and left ICA, curvature angles, distance to the pituitary gland, and inter-carotid distance at both cervical and intracranial levels. The presence of carotid-basilar anastomoses or agenesis of the ICA was also investigated.

RESULTS

The mean patient age was 67.8 years, with a predominance of males (80%). Stroke and myocardial infarction were the most common indications for cerebral and supra-aortic trunk CT angiography.

CT image analysis revealed several types of ICA anatomical variations. The results were as follows :

Parameter	Right ICA mean	Left ICA mean	p-value
Cervical diameter (mm)	4.96 ± 0.8	4.77 ± 0.7	0.22
Intracranial diameter (mm)	4.18 ± 0.54	4.06 ± 0.54	0.28
Communicating segment diameter (mm)	3.25 ± 0.44	3.13 ± 0.30	0.22
Cervical length (mm)	83.1 ± 6.5	77.2 ± 7.6	0.02
Intracranial length (mm)	57.4 ± 18.3	64.2 ± 4.6	0.12
Curvature angle C2–C3 (°)	66.4 ± 5.9	73.0 ± 7.52	0.01
Distance to pituitary (mm)	4.96 ± 1.75	5.15 ± 1.53	>0.05
Location	Mean inter-carotid distance (mm)	Standard deviation (±)	
Cervical level	42.6	6.13	
Intracranial level	13.38	2.12	

No fetal anastomoses (trigeminal, hypoglossal, proatlantal) or ICA agenesis were observed.

Figures



Figure 1: CT angiography image showing the course of the ICA (Radiology Department, Avicenne Military Hospital)



Figure 2: (Left) CT reconstruction of ICA course. (Right) 3D CT reconstruction of ICA



Figure 3: CT reconstruction showing the ICA course

DISCUSSION

Iatrogenic ICA injuries during open or endoscopic skull base surgery represent a serious complication and may cause intraoperative death. In addition to accidental ICA rupture, complications include postoperative pseudoaneurysm or mycotic

aneurysm, vasospasm, vascular occlusion, or carotid-cavernous fistula [3].

Factors suggested to increase the likelihood of ICA injury include right-handed surgical dominance, vascular involvement by disease, type of instrumentation, revision surgery, and vascular

malformations. The cavernous segment of the ICA has been most frequently injured in an American study of 50 intraoperative cases, likely due to its close relationship with sphenoidal sinus anatomy [3].

Our findings confirm that anatomical variations of the ICA are frequent and must be carefully assessed prior to any surgical intervention. CT angiography allows for detailed and accurate evaluation of numerous parameters related not only to the ICA itself but also to its relationship with surrounding anatomical structures [4].

The low intra-individual variability of ICA diameter suggests that the contralateral diameter could be used as a reference for estimating stenosis when ipsilateral measurement is difficult. Many studies report ICA diameters with varying results, due to different exploration methods and measurement sites. Most agree that ICA caliber decreases from its origin to its distal part. In our series, a more significant reduction in diameter was noted after the emergence of the ophthalmic artery [5].

Endoscopic transnasal dissections on 20 cadaveric heads in a study by H. Cebula *et al.* adapted the classification of intracranial ICA segments (C1–C7) proposed by Bouthillier *et al.* and later modified by De Powell *et al.* They analyzed anatomical variations in curvature angles and ICA course from the lacerum segment (C3) to the clinoid segment (C5), as observed in endoscopic endonasal views. They also identified inter-carotid distance and the ICA–pituitary distance [6].

This endoscopic classification described four morphological types at C3–C5 based on the angle between the ascending posterior portion and the horizontal portion of C4 [7]:

- **Type I:** Sharp C4 curvature ($<80^\circ$), highly tortuous, often in direct contact with the pituitary, sometimes hidden behind it.
- **Type II:** Moderate angle ($80\text{--}100^\circ$), more vertical ascending portion, with frequent pituitary contact, especially at the horizontal C4 segment.
- **Type III:** Wide angle ($>100^\circ$), mild curvature, less tortuous, with pituitary contact in two-thirds of cases.
- **Type IV:** Asymmetrical, characterized by a difference in angle between right and left sides.

Recent studies reported bilateral ICA symmetry. However, in our series, ICAs were not always mirror images, showing slight variability in length and curvature angles, consistent with De Powell's Type IV asymmetry. Another key parameter is the ICA–pituitary distance, which varies with the anatomy of both structures. This is particularly relevant in sellar region tumors, where invasion of adjacent structures poses a risk of vascular injury during surgery [8].

The most common persistent fetal carotid–vertebrobasilar anastomosis is the persistent trigeminal artery (PTA), representing 80% of such cases, with a prevalence of about 0.2% in the general population. Patients with these vascular anomalies are prone to aneurysm formation due to altered hemodynamic flow. The rarity of this variation explains its absence in our series [9].

Congenital ICA agenesis is a rare anatomical variation, with an incidence of about 0.01% [10]. It represents complete interruption of ICA development with absence of the ipsilateral carotid canal. Agenesis implies the presence of alternative collateral pathways to maintain cerebral perfusion, explaining why many patients remain asymptomatic [11].

Because many lesions of the anterior and middle skull base distort ICA anatomy, sometimes encasing or narrowing it, anatomical knowledge becomes an essential tool to optimize surgical resection and safety. Careful preoperative imaging, including CT angiography with fine slices through the skull base, is imperative in the evaluation of any skull base lesion.

LIMITATIONS

This study has several limitations. From a technical perspective, CT angiography has inherent constraints. External delineation of the artery may be challenging, especially in thin patients, due to close contact between the arterial wall and surrounding tissues. Short acquisition time can also reduce opacification of adventitial vasa vasorum, while dental metallic artifacts may hinder evaluation of the subpetrous ICA segment. Methodologically, our sample was small and heterogeneous, limiting the assessment of demographic influences on anatomical variations. A larger cohort would be required for more robust conclusions.

Finally, in Morocco, the absence of a legal framework for cadaveric dissection restricts anatomical teaching and research, and the scarcity of related literature limits comparison with other studies.

CONCLUSION

Cerebral CT angiography provides significant value in evaluating anatomical variations of the ICA. It allows anticipation of surgical complications and adaptation of operative approaches based on individual anatomical features. This study, the first to use this imaging modality to characterize ICA anatomical variations, highlights the necessity of including CT angiography in preoperative assessments of neck and skull base surgery, in order to prevent iatrogenic injury to this highly exposed vessel, whether approached transcranially or endoscopically.

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