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Relationships of the vidian nerve and internal carotid artery: MRI and intraoperative surgical evaluation

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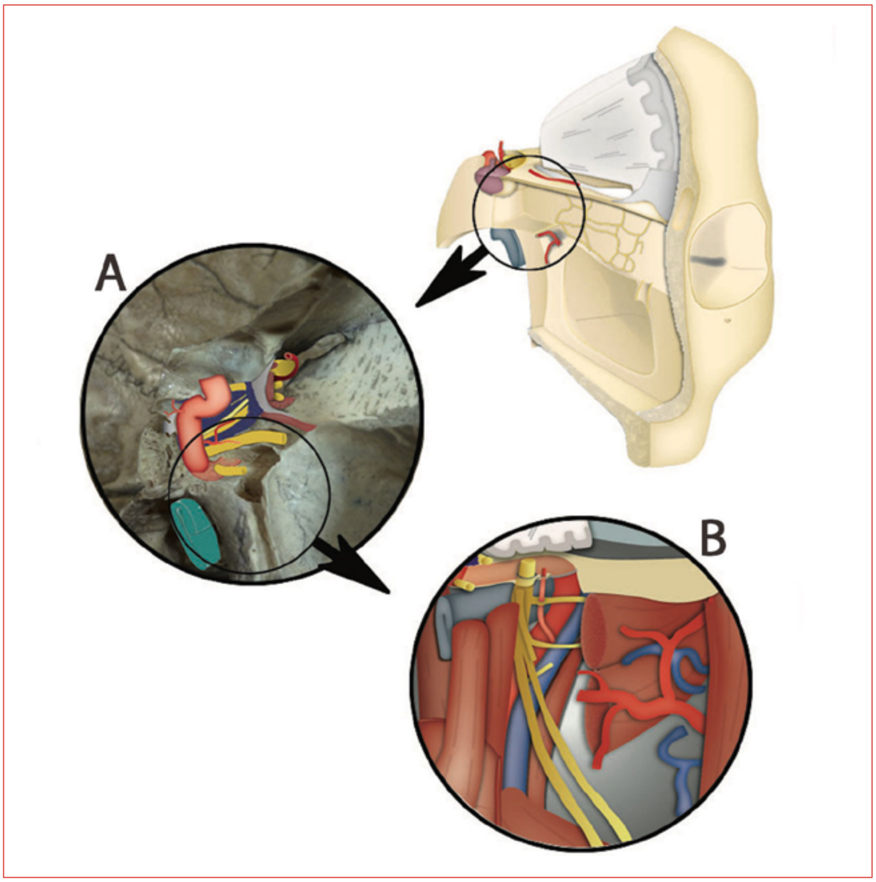

Cover figure. Schematic drawing showing surgical anatomy and steps for an extended exposure of infratemporal fossa, cavernous sinus and petro-clival regions.

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Summary

Objective. Skull base anatomy around the internal carotid artery (ICA) is extremely complex. Among anatomical landmarks studied, the vidian canal has been thoroughly evaluated, unlike the vidian nerve (VN). Our aim is to evaluate the VN-ICA relationships, and understand their role in terms of surgical planning.

Methods. Fifty MRI examinations of 100 healthy petro-spheno-clival regions were reviewed in order to evaluate the relationship between the vidian nerve axis (VNA) and the petrous ICA. Twenty-seven cases of expanded endonasal approaches to petrous apex region were evaluated to check the VN-ICA relationship intraoperatively.

Results. MRI evaluations showed that, in 23% of cases, the VNA was below the edge of the ICA, in 45% it was at the edge of the ICA and in 32% it ended up above the edge of the ICA. Surgically speaking, in 9 of 28 petrous apex approaches, the VN ended above the inferior edge of the petrous carotid.

Conclusions. MRI evaluation adds useful information in planning the surgical approach to petro-spheno-clival regions, even if the identification of VNA, in these cases, may not be radiologically possible. Surgical experience confirms the importance of VN identification in guiding the surgeon in complex cases, and also outline the possible risks of relying only on this landmark.

Key words: endoscopic skull base surgery, petrous internal carotid artery, surgical anatomy, vidian nerve, vidian canal

Introduction

Expanded endonasal approaches (EEA) to the petro-spheno-clival region require careful dissection and maintenance of anatomical orientation in order to avoid damaging critical neurovascular structures. This can be achieved through meticulous understanding of the anatomy and a systematic and reproducible surgical approach. In terms of achieving endoscopic control of the petrous portion of the ICA (pICA) during approaches to the middle third of the clivus and the petrous bone, the available literature suggests that the vidian canal (VC) is a reliable and safe landmark [1,2]. This relationship can be clearly defined on skull base imaging [3,4]. In fact, the bony VC, although radiologically easy to detect, is not the real anatomical structure that surgeons can follow during their practice to identify the ICA. The vidian nerve (VN) is the true intraoperative anatomical landmark. Furthermore, in case of tumour or other bone-remodelling diseases, a variable petrous ICA displacement and an erosion of the posterior vidian region reduces the utility of the VC as a reliable anatomical landmark [5]. This distortion has been well evaluated radiologically in petro-clival chondrosarcoma [6]. Nonetheless, it is commonly accepted in surgical practice that drilling infero-medially to the VC is a safe method to reach the ICA [2]. Our surgical and pre-clinical experience in extended approaches to the petrous apex and nearby areas taught us that this rule, although generally safe, can be dangerous in some patients. Based on these grounds, an MRI based study was planned and conducted on 100 healthy basisphenoid/petrosphenoclival regions with the purpose of establishing the relationship between the VN and the pICA in cases with no distortion by disease and eventually identify patients at "higher" risk. A retrospective evaluation of 27 cases of EEA to petrous apex was conducted to compare radiological results with real-life intraoperative findings.

Materials and methods

Radiological evaluation

We retrospectively evaluated 1.5 T brain MRI examinations including 3D TOF MRA and 3D FSPGR sequences, conducted with the same machinery (Signa HDx GE Healthcare Milwaukee, gradients strength 50 mT/m, maximum slew rate 150 T/m/s). All patients gave informed consent to the diagnostic procedure. All procedures involving human participants were in accordance with the ethical standards of our institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Our standard intracranial 1.5 T 3D TOF MRA protocol was performed before contrast media administration with the following parameters: TR= 23 ms, TE= 2.80 ms, flip angle= 25, matrix (Freq/Phase) 352/256, phase FOV 0.75, slice thickness 1.2 mm, overlap loc 11 mm, locs per slab 36, 4 slabs, receive bandwidth= 31.25 Hz, ASSET with a factor 2, axial plane of acquisition and imaging time of 5.40 min. Our standard intracranial 1.5 T 3D FSPGR protocol was performed after contrast media administration with the following parameters: TR= 7.6 ms, TE= 3.4 ms, flip angle= 12, matrix (Freq/Phase) 256/256, fat saturation, NEX 1, phase FOV 0.90, slice thickness 1.2 mm, locs per slab 128, receive bandwidth= 25 Hz, axial plane of acquisition and imaging time of 4.03 min. Images obtained from 3D TOF MRA and 3D FSPGR acquisition were reciprocally fused using commercially available 3D reformatting software (Voxar 3D; Barco, Edinburgh, Scotland). In all cases the overlap between these two sequences was optimal. By using the overlay function, it was possible to arbitrarily calibrate the degree of superimposition of 3D FSPGR on 3D TOF MRA with a cursor. The intraosseous course of VN was visualised by exploiting images obtained from the maximum overlap of 3D FSPGR upon 3D TOF MRA. We then proceeded by affixing a Cartesian axis running parallel to the intraosseous course of VN (vidian nerve axis, VNA). Successively we removed the superimposition of 3D FSPGR images from 3D TOF MRA images, obtaining VNA visualisation on merely angiographic images, which permitted accurate evaluation of the relationship between the VNA and ICA along the sagittal plane [7]. If the VNA was located above the lower edge of the pICA, it was classified as "red flag" VNA (RF-VNA). If the VNA was located at or below the lower edge of the pICA, it was classified as "green light" VNA (GL-VNA).

Clinical experiences

All cases of EEA to petrous apex and petro-clival region performed from 2018 to 2022 in 2 tertiary-care referral centres in Italy and The Netherlands were carefully evaluated to check the actual role of VN in guiding the surgeon in such complex areas. To do this, surgical videos were accurately reviewed independently by 2 experienced surgeons to identify the VN-ICA relationship in clinical scenarios. In this work, no comparison of intraoperative findings with preoperative imaging was conducted since: 1) it was out of the scope of the study and 2) the identification of the VN in case of expansive/destructive disease is really difficult, if not impossible.

Results

Radiological evaluation

We studied 50 1.5 T brain MRI examinations (14 males, 36 females), and thus the VN-ICA relationship was evaluated in 100 sides. Mean age of the patients was 51.4 years (range 14-85). According to our inclusion criteria, in all cases MRI examination showed no pathologic findings at the level of the basisphenoid/foramen lacerum region on either morphological or angiographic images. Studying the relationship between VN and the ICA along the sagittal plane, we found that on the right side the VNA was below the edge of the pICA in 10 cases and was at its edge in 27 cases, forming 37 cases (74%) of GL-VNA. There were 13 cases (26%) of RF-VNA, where the nerve ended up above the edge of the pICA. On the left side, the VNA was at the edge in 18 cases and inferior to the pICA in 13 cases, forming 31 cases (62%) of GL-VNA. There were 19 cases (38%) of RF-VNA that ended up above the edge of the pICA. Of 100 examined sides, there were 32 cases (32%) of RF-VNA (Tab. I, Fig. 1).

Clinical experiences

Twenty-seven patients were enrolled in this series (10 males and 17 females; mean age of patients was 53 years; range 37-73); 28 petrous apex/petroclival regions were evaluated (in one case both sides were exposed during surgery). This series includes different pathologies, mostly represented by chordomas and chondrosarcomas. Retrospective evaluation of surgical videos showed that in 9 of 28 cases (in one patient both petrous apexes were exposed) the VN ended above the inferior edge of the pICA, in other words on the surface of the vessel. In 7 cases the nerve was not easily identified in close proximity to the vessel (due to the disease itself), while in the other 12 cases the nerve was identified at the level of the fibro-cartilago basalis, where the ICA is "connected" to the fibrous and cartilaginous tissues filling the foramen lacerum area (Fig. 2).

Table I. Anatomo-radiological evaluation: summary of the data.

Level at which VN inserts on pICA	Left side	Right side	Both sides
Below inferior edge of pICA	10 (20%)	13 (26%)	**23%**
Inferior edge of pICA	27 (54%)	18 (36%)	**45%**
Above inferior edge of pICA	13 (26%)	19 (38%)	**32%**
Total	**50**	**50**	**100%**

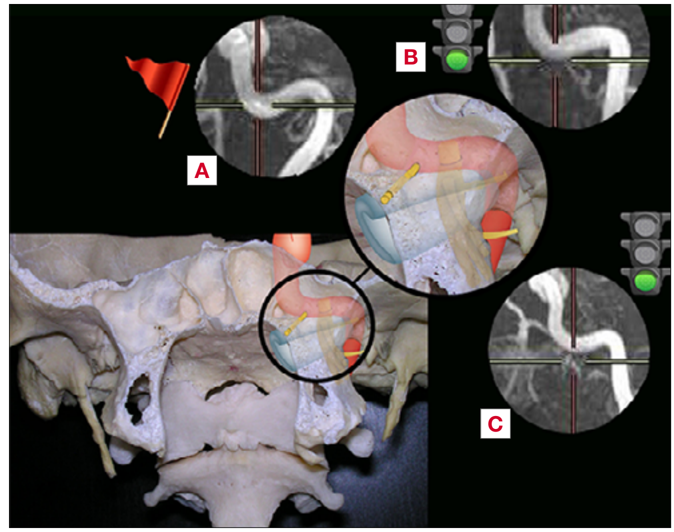

Figure 1. Schematic representation of the possible relationships between vidian nerve (VN) and internal carotid artery (ICA). **A)** Red flag condition: VN ends up above the inferior edge of the ICA; **B)** Green light condition: VN ends up at the level of the inferior edge of the ICA; **C)** Green light condition: VN ends up below the level of the inferior edge of the ICA.

Discussion

EEA are nowadays the workhorse in the treatment of several ventral and paramedian skull base pathologies and, in this context, the identification of the petrous and paraclival portions of the ICA is of paramount importance. The bony VC has been proposed as an anatomical landmark to gain safe access to the pICA since it has been reported that it usually terminates inferiorly to the petrous ICA [1,8,9]. From an anatomical viewpoint, the VC is a bony tunnel that runs from the pterygo-palatine fossa to the foramen lacerum and contains the vidian nerve (VN) and, in some cases, the vidian artery and vein. Anatomically speaking, the VC has a strong

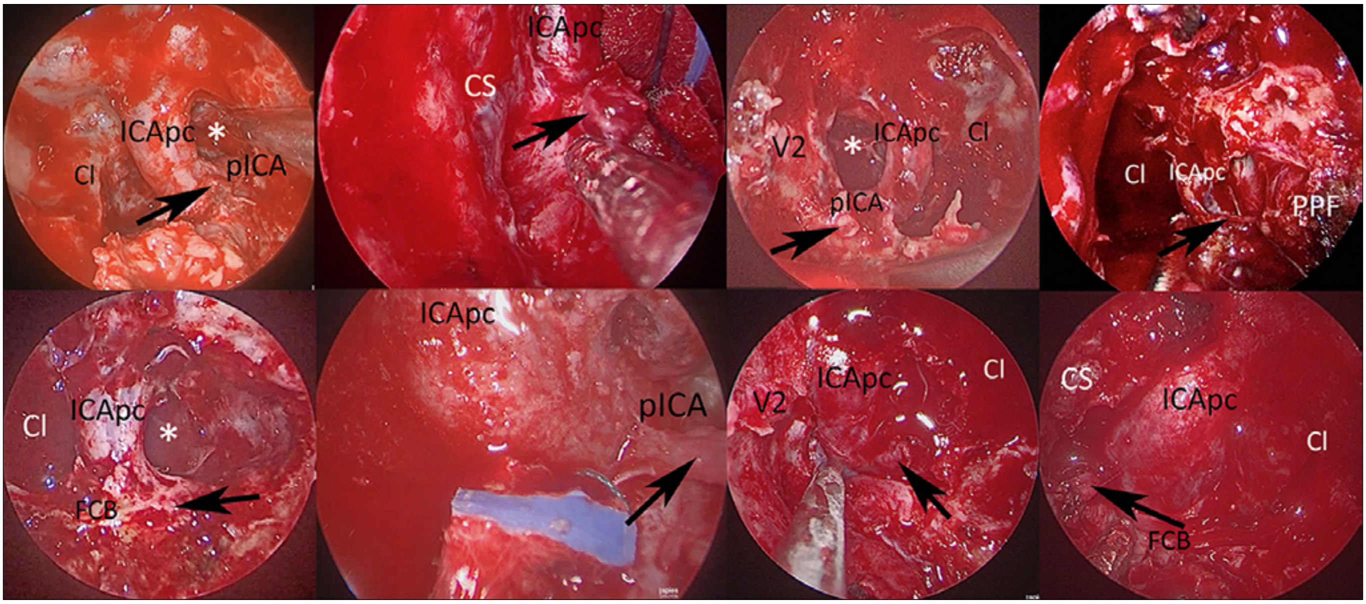

Figure 2. **Intraoperative views of some cases of extended petrous apex approaches, showing different VN-ICA relationships.**
Cl: clivus; CS: cavernous sinus; FCB: fibrocartilago-basalis; ICApc: paraclival portion of the internal carotid artery; pICA: petrous portion of the internal carotid artery; PPF: pterygo-palatine fossa; V2: second branch of the trigeminal nerve, white asterisk-petrous apex, black arrow-vidian nerve.

relationship with the carotid bony canal, while the VN has a clear relationship with the vessel itself. This bias could hamper some of the considerations based on radiological studies limited to the bony evaluation. As stated, although prominent data from the literature appear to support that the VC is always located inferiorly to the petrous ICA, anecdotally there is a discrepancy in this condition [2,3,8]. Thus, this questions the absolute safety of using only this landmark as a guide to find the pICA. According to Mason et al., the VC terminated directly at the level of petrous ICA in 33% of cases [3]. Other authors present different results [10,11].

These differences are not of minor importance, given the potential catastrophic consequence of improper orientation. Therefore, if in a variable, not completely established proportion of cases, the VC terminates directly at the level of the pICA, drilling inferiorly to the VC close to the vessel may not be safe and could result in accidental injury to the artery. Based on these considerations, we planned an MRI evaluation of the relationship between the VN and pICA in cases with no pathologies at the level of foramen lacerum region (to evaluate the position of the nerve in "anatomical" situations) and reviewed the surgical videos of our experience in extended endonasal petrous apex and petro-clival approaches (to check the VN-ICA relationship in normal and pathological scenarios). We decided not to radiologically study the position of the VN in pathological condition because it adds nothing to the main target of our study and the surgical identification of the VN in case of destructive disease is very difficult if not impossible. We chose the VN because it is a virtually constant structure and has a clear relationship with the vessel, while the VC has a strong relationship with the carotid bony canal but not with the artery itself. Furthermore, in case of bone-remodelling disease (mostly tumours, such as chondrosarcomas and chordomas), the VC is not rarely destroyed and the vessel itself even displaced[5]. In fact, the VN, and not the VC, is the real landmark commonly followed during EEA. Furthermore, practically speaking, the VN is often sacrificed, especially during major procedures or in relation to the biological behaviour of the pathology being treated. That said, our radiological and clinical data support our preliminary anatomical feelings [12,13], showing that in almost 30% of the cases the VN reaches the petrous ICA within its anterior surface, and not in its inferior aspect or below. These preliminary data seem to cast doubt on the complete safety of drilling inferiorly to the VN in close proximity to the vessel. Moreover, these results are partially in contrast with previous and recent published data and these discrepancies could be related to the plane of observation [10,11,14]. We do feel that, at the level of vessel wall, and not on the plane of bony carotid canal (there is a small but significant distance), the nerve could be a little more cranial than previously thought.

Radiologically speaking, CT is efficient in providing accurate volumetric visualisation of the bony VC and its relationship with carotid bony canal, but not of the soft tissue within such canals. Furthermore, as said, it should be also well outlined that expansive diseases can create anatomical distortions and that, not rarely, bony structures can be destroyed or severely altered. Thus, in these situations, especially when dealing with large tumours associated with severe bone erosion and distortion, it is very difficult to recognise anatomical landmarks in pre-operative imaging using CT- and/or MR-based scans. Not surprisingly, some authors have very recently pointed out the need for additional landmarks in orientating the surgeon in such complex areas, especially when the disease creates anatomical alterations. In this context, the so called "triangulation technique" has been proposed as a safer combination of different landmarks to identify the lacerum foramen below the ICA [10,15]. We completely agree with these and other authors in pointing out the extreme usefulness of the Eustachian tube (ET) as a landmark [11]. We do strongly advise to combine, when dealing with foramen lacerum area, information from the VN, the ET and also the pharyngo-basilar fascia (PBF). It must be underlined that, although anatomical knowledge is essential, this kind of disease should be treated only by very experienced teams, in a fully-equipped and well-organised structure, where all the required technological facilities are easily available.

The preliminary results emerging from the present radiological and surgical study confirm the importance of the VN as a critical landmark to be identified in petro-spheno-clival region, and, at the same time, stresses the concept that in more or less one of three patients following "blindly" the VN can be absolutely risky given the trajectory of the nerve directed straight to the vessel. This is by far more important in real scenarios where anatomical distortions can increase the risk of disorientation. Our data point out the necessity of personalised evaluation of the anatomical scenario in any given patient using dedicated MRI and CT evaluation and possibly CT angiography. Moreover, the intraoperative use of a magnetic navigation system with CT-MRI fusion images can be useful, even if it will never replace anatomical knowledge and surgical experience.

Clearly, it must be stressed once again that the VN and VC can be very difficult to identify in the presence of extended and highly destructive lesions (like we manage in most cases). Therefore, multiple anatomical landmarks, in addition to VN and VC, such as PBF, ET, pterygo-clival ligament and the spheno-occipital synchondrosis can provide insights for intraoperative anatomical orientation in complex cases [16]. Finally, multidisciplinary collaboration among the different physicians involved in these difficult cases is crucial to safely manage this region, with particular regard to the absolute importance of a dedicated neuroradiologist who should be specifically trained as much as surgeons.

Conclusions

Dedicated MRI evaluation of the relationship between the VN and petrous portion of ICA adds useful information in planning the surgical approach to petrous apex, Meckel's cave and upper parapharyngeal infrapetrous regions. Based on our preliminary findings, about one of three patients may present a "red flag" condition, at high risk of ICA injury if the surgeons only rely on the position of the vidian nerve. The importance of complete 3D understanding of this complex anatomy should be pointed out, as well as the preclinical training and the use of adequate technology, but probably surgical experience and flexibility of the operating team are the most critical factors.

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Conflict of interest statement

The authors declare no conflict of interest.

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Author contributions

ID: conceptualisation, data curation, writing original draft; MV: investigation, data curation; SC: conceptualisation, data curation; GF: writing-review & editing; MTZ: writing-review & editing, validation; CG: writing-review & editing; CC: data curation, formal analysis; DP: supervision, methodology; WvF: supervision, validation.

Ethical consideration

This study was performed in compliance with the Helsinki Declaration and approved by the Institutional Ethics Committee of Azienda Ospedaliero-Universitaria Pisana (Ethical committee protocol number 20147).

Written informed consent was obtained from all patients prior to any diagnostic or therapeutic procedure. Written informed consent was obtained from each participant/patient for study participation and data publication.

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