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ANATOMIC BASES OF MEDICAL, RADIOLOGICAL AND SURGICAL TECHNIQUES

Anatomical location of the abducens nerves (VI) in the ventral approach of clival tumors

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Abstract
The aim of this work was to determine reliable anatomical landmarks for locating and preserving the abducens nerves (6th cranial nerves) during trans-facial or trans-nasal endoscopic approaches of skull base tumors involving the clivus and the petrous apex. In order to describe this specific anatomy, we carefully dissected 10 cadaveric heads under optic magnification. Several measurements were taken between the two petro-sphénoidal foramina, from the bottom of the sella and the dorsum sellae. The close relationship between the nerves and the internal carotid artery were taken into account. We defined a trapezoid area that allowed drilling the clivus safely, preserving the 6th cranial nerve while being attentive to the internal carotid artery. The caudal part of this trapezium is, on average, 20 mm long at mi-distance between the two petro-sphenoidal foramina. The cranial part is at the sella level, a line between both paraclival internal carotid arteries. Oblique lateral edges between the cranial and caudal parts completed the trapezium.

Keywords Abducens nerve · Petrous apex · Petro-sphenoidal foramen · Anterior clival surgical approach

Introduction

Optimal tumor resection is an essential goal of skull base tumor surgery. In transfacial or transnasal endoscopic approaches, preservation of the vessels and nerves may be challenging. Anatomical knowledge of landmarks and careful assessment of preoperative planning are essential, although local anatomy may be modified by the tumors.

Unilateral or bilateral abducens nerve (6th nerve) palsy is a frequent presentation of skull base tumors involving the clivus and the petrous apex. Postoperative functional nerve recovery is often good because the palsy is often due to mass effect. However, intraoperative 6th nerve injury is frequent in extended lateral approaches especially in the middle third of the clivus.

The main objective of this study was to determine reliable landmarks for locating and preserving the 6th cranial nerves in the ventral surgical approach of the skull base tumors mainly those with lateral extension, because the nerve position does not vary in the petro-sphenoidal foramen (Dorello).

Materials and methods

Heads from 10 human cadavers have been dissected. Two of them have been injected with colored neoprene latex.

After neck section, colored neoprene latex was injected, red for carotid and vertebral arteries and blue for the jugular veins. Then, all the specimens colored or not, were fixed with a 10% formalin solution for at least 4 weeks.

After midfacial deglowing, large bilateral maxillectomy, complete ethmoidectomy and hard palate removal were performed, providing a large exposure of the clival region. Clivus, sella turcica and ethmoid were first drilled away to expose dura mater, then petrous bone on both sides. This provided a large exposure of the clival, sellar and cavernous dura mater. Carotid arteries were exposed in their intrapetrous and cavernous portions (Fig. 1).

The retroclival dura mater was then carefully divided from the midline towards lateral in order to locate the

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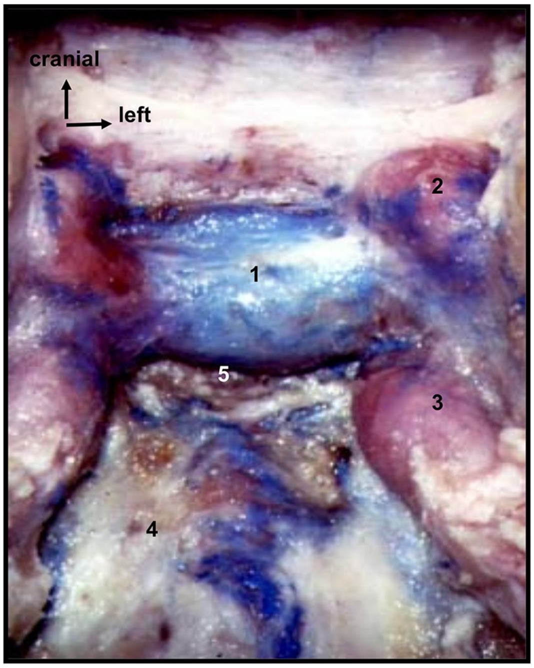

Fig. 1 Ventral view of the middle and posterior skull base. The clivus, sella turcica, ethmoid and petrous bone have been drilled. Bottom of the sella (1), cavernous portion of the internal carotid (2), intrapetrous portion of the internal carotid (3), dura mater of the clivus with intradural veins or sinus (4) and the location of the dorsum sellae (5)

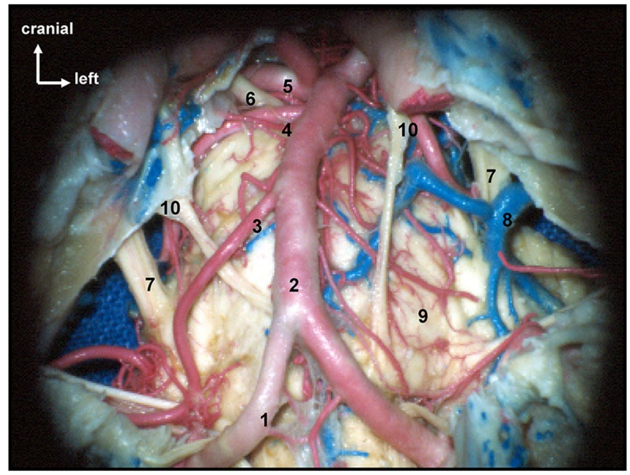

Fig. 2 Ventral view of the cerebral trunk. The clival dura mater and the posterior cerebral fossa arachnoid have been opened. Right vertebral artery (1), basilar artery (2), antero-inferior cerebellar artery (3), superior cerebellar artery (4), posterior cerebral artery (5), ocular motor nerve or 3th cranial nerve (6), trigeminal nerve or 5th cranial nerve (7), superior petrous vein (8), ventral part of the pons (9) abducens nerve with its course in the petro-sphenoidal foramen on the right, with the venous confluence and the dura mater sheath (10)

abducens nerve pathway through the petro-sphenoidal foramen in which the nerve is surrounded by meningeal layers (Fig. 2).

Microdissections were performed under optic magnification (Zeiss OPMI Pentero 900; 250 and 300 mm focal distances). Location and direction of the 6th nerves were observed in their cisternal portion, then in their petro-sphenoidal foramen.

Several measurements were taken:

- Distance between the midline and the petro-sphenoidal foramen.
- Distance between the right and left petro-sphenoidal foramina.
- The height between the sella turcica (inferior line of the dorsum sellae) and the line joining both petro-sphenoidal foramina (Figs. 3, 4).

The sphenoid rostrum is considered in the literature as a reliable landmark of the midline [26]. However our reference for the midline was the most inferior point of the dorsum sellae for repeatable length measurement.

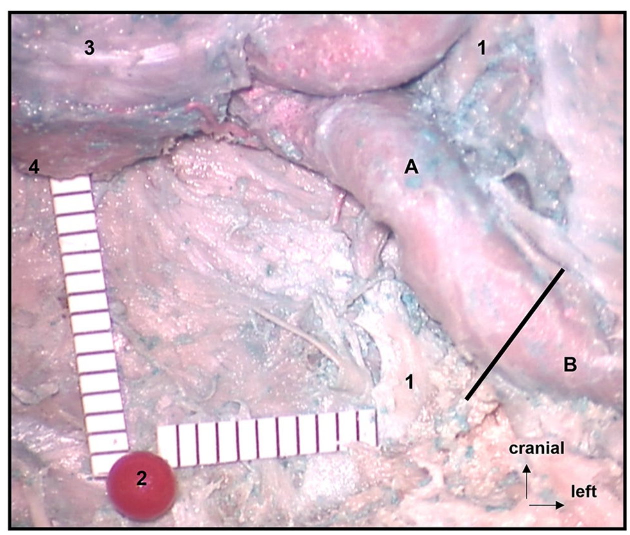

Fig. 3 The height between the sella turcica (dorsum sellae) and the middle of a line joining both petro-sphenoidal foramina and the distance between the midline and the petro-sphenoidal foramen. The paraclival internal carotid artery (**a**) and the intrapetrous carotid artery (**b**). The abducens nerve initially in the dural sheath of the petro-sphenoidal foramen, then in the cavernous sinus at the dorsal and lateral aspect of the carotid artery (1). The midline (2). Bottom of the sella (3). Location of the dorsum sellae (4)

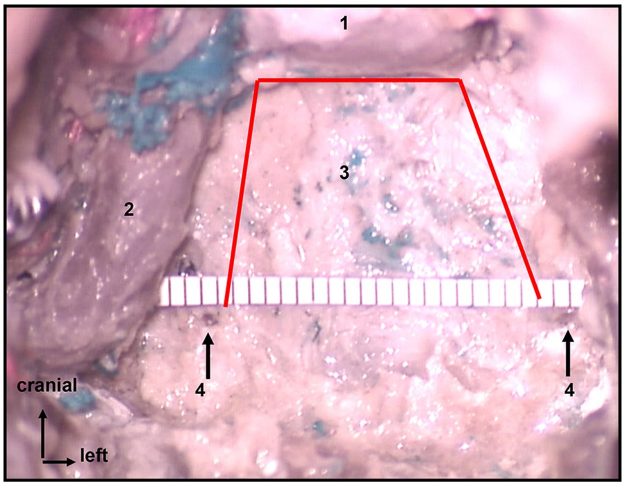

Fig. 4 "The drilling area" delimited for ventral approach of the clivus. Bottom of the sella (1), internal carotid artery (2), clival dura mater (3) and the location of the penetration of the abducens nerve in the petro-sphénoidal foramen (4)

Results

Among the 20 abducens nerves dissected in 10 specimens, all but one originated from a unique trunk of the brain stem. One nerve on the right side, originated as two separate branches until it penetrated the dura mater and entered in the petro-sphenoidal foramen.

In the cisternal portion, directions of the 6th nerves were cranial, ventral then lateral. This latter direction became more pronounced just before their penetration in the petro-sphenoidal foramen.

The distance between the petro-sphenoïdal foramen and the midline was 10.5 mm ± 1 mm and the distance between the left and right petro-sphenoidal foramen was 21 mm ± 1.5 mm.

In all the specimens, the 6th nerves emerged ventrally at the medial part of the carotid artery genu, immediately after the foramen lacerum.

The distance separating the sella turcica (dorsum sellae) and a line between both 6th nerves on the ventral part of the clivus, just before the petro-sphenoidal foramen, was 16.5 mm ± 1.5 mm.

At the exit of the petro-sphenoidal foramen, the 6th nerves run into a dural sleeve to the cavernous sinus where they cross the intracavernous carotid artery at its dorsal part.

Discussion

In the middle of the twentieth century, transsphenoidal approach was described as the preferred route to reach the sella, especially for pituitary adenoma. This transsphenoidal approach has evolved over the last decades with the development of the endoscopy which offers a wider view and which allows an improved handling of instruments, enabling much more invasive surgery close to the cavernous sinus [6, 19]. Other surgical approaches like trans-clival and trans-pterygoid, used for tumor extending laterally to the paraclival carotid artery, are associated with a higher incidence of carotid injury [2, 7, 11].

In the literature, only a few reports have analysed the landmarks of the 6th cranial nerves to guide a transsphenoidal approach [3, 28]. Nevertheless, we believe that having this point in mind would help achieve a gross total resection of a midline tumor in order to preserve the 6th cranial nerve's function. Magnetic resonance imaging (MRI) poses some challenges in identifying the 6th cranial nerve not only in the cavernous sinus but also when it penetrates the dura mater at the ventral part of the clivus [10, 18, 21]. The tumor mass effect makes MRI identification of the 6th cranial nerve much more difficult. Therefore, we proposed this anatomical study in order to define morphological parameters which would help locate the abducens nerve when it comes out of the clival intradural space towards the foramen petro-sphenoidal.

The abducens nerve is tightly fixed to the skull base at the level of the petrous apex [8, 24]. This nerve is like a rope stretched between two fixed points, its apparent origin on the brain stem at the level of the bulbo-pontic sulcus and its arrival in the petro-sphenoidal foramen. This situation probably explains the paralysis of the 6th nerve after a head injury or a subarachnoid haemorrhage depending on the partitioning of the basal cisterns. Generally, the nerve itself is not directly damaged leading to "the famous paralysis without localizing value". Like previous authors, we observed variabilities in the intracisternal course of the 6th nerve and its relationship with the antero-inferior cerebellar artery. The nerve is sometimes partially or completely split [17, 20].

For these reasons, we focused on the emergence of the 6th nerve at the petro-sphenoidal foramen which is made of a bony part and the petro-sphenoidal ligament [25]. Using the paraclival carotid as the only landmark to pinpoint the 6th cranial nerve is not reliable because of anatomical variations of the internal carotid artery in this segment [4, 9].

Furthermore, the 6th cranial nerve has the most medial entry point of all the nerves passing through the cavernous sinus [12]. Additionally location of the 6th nerve makes it easier to avoid the other nerves, that is the ocular motor nerve (III), the trochlear nerve (IV) and the ophthalmic branch of the trigeminal nerve (V).

The distance between the two 6th nerve penetration points in the dura mater, from their cisternal space, was 21 mm ± 1.5 mm, and was consistent with the findings of Lang et al. and Zhang et al. [14, 27].

On the ventral aspect of the clivus, the mean distance between, the dural penetration point of the 6th nerve and the midline was 10.5 mm ± 1 mm. This value is consistent with the distance between both 6th nerves on the dorsal part of the clivus. Al-Mefty et al. [1] found a distance separating both petrous apexes of 21.5 mm (19–25) to plan ventral approaches of the clivus. Campero et al. [5] showed that the 6th nerve, protected in this segment by a sleeve of dura mater, crosses the internal carotid artery in it dorsal part.

On a ventral view of the skull base, the line from the lower part of the sella, i.e. the dorsum sellae, to that between the two 6th nerve dural penetration points is 16.5 mm ± 1.5 mm long.

Based on this data, we have defined a trapezoid area that allows drilling the clivus safely preserving the 6th cranial nerves. The caudal part of this trapezium is 20 mm long centered on the midline, separating the genu from each of the internal carotid artery. The cranial part of the trapezium is at the sella level, a line between both paraclival internal carotid arteries. This is the most variable landmark because of the anatomical variations of the internal carotid arteries in this portion. The same precautions should be taken, as in pituitary surgery, not to exceed the lateral limits of the bottom of the sella. The lateral ends of the cranial and caudal parts of the trapezium join and form the right and left lateral edges of this trapezium. The lateral edges follow the medial part of each of the internal carotid arteries in their paraclival segment.

The 6th cranial nerves are always more lateral compared to the medial aspect of the internal carotid artery at the level of the foramen lacerum. Also it is important on the one hand to keep a safe distance from the dural penetration point of the nerve and on the other hand to locate the internal carotid artery to avoid its injury. Internal carotid artery injury remains a rare but a serious complication that has become more frequent proportional to the endoscopic procedures used to widely expose the clival area [2, 7]. Computer assisted surgery may be helpful, especially in endoscopic surgery, because of the loss of three-dimensional vision [16]. Intraoperative doppler ultrasonography is useful to locate the internal carotid artery during bone drilling. The latter is routinely used in our clinical practice because of its ease of use and its cost effectiveness.

Pre-operative imaging (MRI or Computed Tomography scanners) is not accurate enough to locate the 6th cranial nerves, especially in case of tumor mass effect. Per-operative imaging will probably be efficient in the next few years, the main limitation being its accessibility.

To date, 6th cranial nerve monitoring is mainly effective for mapping the location of the nerves in skull base surgery, especially used for tumors located in the cavernous sinus [13, 15, 22]. However, the predictive value of the post-operative nerve's function is poor and required improvement in technicity and interpretation [23].

Conclusions

Based on these anatomical data, we have defined a trapezoid area that allows drilling the clivus safely.

In this study, we found an average distance of 16 mm from the lower part of the sella to the line between the two dural penetration points of the 6th nerves.

The average distance between the petro-sphenoïdal foramen and the midline was 10.5 mm and the average distance between the left and right petro-sphenoidal foramen was 21 mm. In the future, technical advances (ultrasonography and neuromonitoring) will allow us to optimize the identification of the vascular and nervous structures of this region, during trans-facial and transnasal endoscopic approaches, in surgery of skull base tumors.

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Author contributions VJ: project development, data collection, data analysis, manuscript writing and editing. MS: manuscript review of English spellings and grammatical errors. DL: protocol project development, data analysis.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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