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The abducens nerve: its topography and anatomical variations in intracranial course with clinical commentary

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Background: The sixth cranial nerve (CN VI) — or the abducens nerve — in humans supplies only the lateral rectus muscle. Due to its topographic conditions, including angulations and fixation points along its course from the brainstem to the lateral rectus muscle, the CN VI is vulnerable to injury. Every case of CN VI palsy requires precise diagnostics, which is facilitated by an understanding of the anatomy. The present article's aims include a detailed study of the intracranial course of the CN VI, determination of occurrence of its particular anatomical variations, as well as presentation of some essential anatomical conditions which may conduce to CN VI palsy. Special emphasis was put on the correlation between craniometric measurements and a particular variation of the CN VI, which complements the data that can be found in literature.

Materials and methods: Twenty randomly selected specimens of cadaveric heads fixed in a 10% formalin solution were studied. The study used 40 specimens of the CN VI in order to examine its course variations within the section between the pontomedullary sulcus and the superior orbital fissure.

Results: Detailed analysis of the CN VI topography and anatomy in its intracranial course revealed 3 anatomical variations of the nerve in the studied specimens. Variation I, found in 70% of cases, covers those cases in which the CN VI was found to be a single trunk. Those cases in which there was a branching of the CN VI exclusively inside the cavernous sinus were classified as variation II, occurring in 20% of cases. Cases of duplication of the CN VI were classified as variation III, found in 10% of the specimens. In 75% of cases of CN VI duplication one of the nerve trunks ran upwards from the petrosphenoidal ligament, outside Dorello's canal.

Conclusions: The CN VI throughout its intracranial course usually runs as a single trunk, however, common variations include also branching of the nerve in the cavernous sinus or duplication. Topographic relations of the CN VI with adjacent structures account for the risk of injuries which may be caused to the nerve as a result of a disease or surgical procedures. (Folia Morphol 2015; 74, 2: 236–244)

Key words: abducens nerve palsy, cavernous sinus, duplicated abducens nerve, petrosphenoidal (Gruber's) ligament, petroclival region, posterior clinoid process

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INTRODUCTION

The sixth cranial nerve (CN VI) — or the abducens nerve — in humans supplies only the lateral rectus muscle [40]. One of the earliest documented descriptions of CN VI can be ascribed to Fallopio, who in 1561 referred to this nerve as 'the fourth pair nerves from brain' [41]. In 1664 Willis was the first scholar to use the currently applied number of CN VI (in the Latin original: *Nervorum Par sextum*) [45], but in 1791 Malacarne still referred to it as 'the tenth pair of nerves' (*par decimum*) [41]. The term 'abducens nerve' was used by Heister as early as 1717 [41], however, in the 19th century this term was a synonym applied among many others. Examples of historical names for CN VI include *nervus timidus* (Bidloo, 1685); *nervi motores oculorum externi* or *nervi oculo-musculares externi* (Winslow, 1733); as well as *nervus indignatorius* (Burdach, 1822) [41]. The term 'abducens nerve' in reference to the sixth pair of cranial nerves was also used by the German anatomist Samuel Thomas von Soemmerring (in the Latin original: *par oculos abducens nervorum cerebri*), who provided solid rationale for applying the currently used classification of cranial nerves [9, 41]. Whereas the terms 'cavernous part' (*pars cavernosa*) and 'orbital part' (*pars orbitalis*) in reference to CN VI were used by Arnold in 1834 [41]. Iaconetta et al. [18] proposed an anatomically and surgically oriented classification of CN VI in 2007. In this classification 5 segments of CN VI were distinguished: 3 intracranial (cisternal, gulfar, and cavernous) and 2 orbital segments (fissural and intraconal) [18]. This classification reflects spatial relations between CN VI and other anatomical structures.

Due to topographic conditions, including angulations and fixation points along its course from the brainstem to the lateral rectus muscle, CN VI is vulnerable to injury [3, 18, 33]. There have been 3 changes observed in the CN VI direction, reflecting the angulations of the nerve at the dural entrance porus, the petrous apex, and the lateral wall of the internal carotid artery (ICA) [23, 33]. CN VI palsy can be induced among others by: pontine lesions (for example, infarction or tumours) [3, 40, 46], pathologies in the subarachnoid space (especially leading to CN VI compression against the clivus) [3, 16, 46], arterial compression [13, 38], as well as disease processes within the apex of the petrous temporal bone (for instance, petrous apicitis also known as Gradenigo's syndrome) [3, 20, 26, 46]. CN VI topography within the cavernous sinus (CS), including its anatomical relationship to the ICA, is of particular importance [3, 22, 24, 38]. CN VI may be involved in any disease process within CS (for instance, ICA aneurysm, sinus thrombosis, neoplastic infiltration or inflammation) [38, 46]. CN VI palsy may also be associated with medical procedures, such as skull base surgery and endovascular interventions [15, 18, 22, 24, 48], spinal traction (CN VI is the most commonly injured cranial nerve in halo orthosis placement) [34] or even lumbar puncture [6, 30]. CN VI palsy may also be secondary to systemic diseases (for instance, the nerve can become ischaemic as a result of diabetes or hypertension) [3, 46]. Therefore every case of CN VI palsy requires an exact diagnosis, which is facilitated by an understanding of the anatomy.

Horizontal eyeball movements are controlled by 2 extraocular muscles: the lateral rectus and the medial rectus. CN VI palsy results in limited abduction of the affected eye, which leads to the affected eye being pulled medially (medial strabismus) because of unopposed tonus of the medial rectus muscle [38]. Though usually unilateral, CN VI palsy can occur bilaterally. Impaired eye abduction, especially in adults, results in horizontal diplopia [38].

Awareness of the topographic relations between CN VI and adjacent neurovascular structures, as well as the possible variations of the nerve, reduces the risk of complications associated with surgical procedures. The correlation between craniometric measurements and a particular variation of CN VI was particularly underlined this article, complementing the information which can be found in literature.

This work aims at: (1) a thorough study of the intracranial course of CN VI, (2) determination of occurrence of its particular anatomical variations, and (3) presentation of some essential anatomical conditions which may conduce to CN VI palsy.

MATERIALS AND METHODS

A total of 20 randomised cadaveric heads fixed in a 10% formalin solution were used in this study. Forty CN VI were examined along their course from the pontomedullary sulcus to the superior orbital fissure. The Bioethics Commission of the Medical University of Lodz issued a consent for the study (consent no. RNN/518/14/KB).

CN VI distinction according to Iaconetta et al. [18] was adopted, and only intracranial segments of CN VI were studied (cisternal, gulfar, and cavernous). Before opening the skulls, the specimens were examined in order to rule out any possible damages or traces of trauma or neurosurgical procedures, which would exclude the specimen from the study. Upon opening the skull,

Table 1. Frequency of sixth cranial nerve (CN VI) variations occurrence by side and co-occurrence of CN VI variations in pairs

Left side	Right side			
	Variation I	Variation II	Variation III	Total
Variation I	10	2	1	13
Variation II	4	–	1	5
Variation III	1	1	–	2
Total	15	3	2	20

the brain was removed, with special care taken to keep the cranial nerves intact. To that end, access through the posterior cranial fossa was applied, as described by Long et al. [27], consisting in the removal of a wedge-shaped part of the occipital squama. After visualising the posterior cranial fossa, anatomical variations within the cisternal segment of CN VI were evaluated. At this stage the distance between the dural entrance of the right and left CN VI was measured. Distance was also measured on each side from the dural entrance of CN VI to: (1) the trigeminal nerve at the inferior border of the trigeminal porus (trigeminal nerve entrance to Meckel's cave); (2) the internal acoustic opening; and (3) the apex of the posterior clinoid process (PCP) (distinguished as a prominence at the superolateral aspect of the dorsum sellae). The measurements were taken along straight lines, with a Digimatic Calliper (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan). Each measurement was taken twice, accurate within 0.1 mm. The average of both measurements was accepted as the final result. Correlations between the corresponding results on the left and right sides were evaluated. Empirical distribution of the parameters in question was analysed with the Shapiro-Wilk test. Spearman's rank correlation coefficient was applied in this study. Calculations were made with the programme STATISTICA version 10.0 PL.

At the following stage of the dissection, microsurgical instruments were used, under a 2.5 times magnification obtained with a HEINE® HR 2.5 × High Resolution Binocular Loupe (HEINE Optotechnik GmbH & Co. KG, Herrsching, Germany). The dura matter was cautiously detached, visualising the petrosphenoidal ligament (Gruber's ligament) and CN VI course in relation to Dorello's canal. Then the lateral wall of the CS was resected, along with CN VI running within the sinus. The topography of individual parts of the cavernous segment of ICA was described using the nomenclature applied by Bouthillier et al. [5], which reflects the segment's division into: the ascending portion, the posterior genu, the horizontal portion and the ascending genu. Photographs were taken after the dissection.

RESULTS

Anatomical variations of the abducens nerve

The studied material revealed that in the majority of cases (70%) CN VI formed a single trunk throughout its entire course from the brainstem to the superior orbital fissure, whereas in 30% of cases there were deviations from this pattern observed. Taking into account the differences in the topography and anatomy of CN VI, 3 anatomical variations of this nerve were distinguished. Frequency of occurrence of particular CN VI variations, depending on the side and co-occurrence of CN VI in pairs in the studied head specimens, was presented in Table 1.

Those cases, in which CN VI passed as a single trunk throughout its intracranial course, that is, from the brainstem to the superior orbital fissure, were classified as variation I. Twenty-eight CN VI (or 70%) were classified as variation I, while in 10 head specimens this variation was bilateral (Table 1). Such a course of CN VI, as the most common one, was recognised as 'typical'. In all 28 cases, CN VI ran downwards to the petrosphenoidal ligament, that is, within Dorello's canal.

Variation II covers those cases in which CN VI travels through the subarachnoid space and in Dorello's canal as a single trunk (in all cases it ran downwards from the petrosphenoidal ligament), and in CS it branches out at a short length (Fig. 1), the branching usually measuring between 4.5 and 9.5 mm (average: 8.4 mm, SD = 1.8). The branching was located at a point where CN VI adhered to the ascending portion of the cavernous segment of ICA (Fig. 1), whereas in its further course CN VI remerged into a single trunk and ran to the superior orbital fissure. Variation II applied to the cavernous segment of CN VI exclusively. Eight (20%) CN VI were classified as variation II. Variation II in the studied material occurred unilaterally in all cases (Table 1).

Duplication of CN VI was observed in 4 nerves (10%) and was classified as variation III. This variation occurred unilaterally in the material (Table 1). In these cases, CN VI from its cisternal segment had a form of 2 trunks:

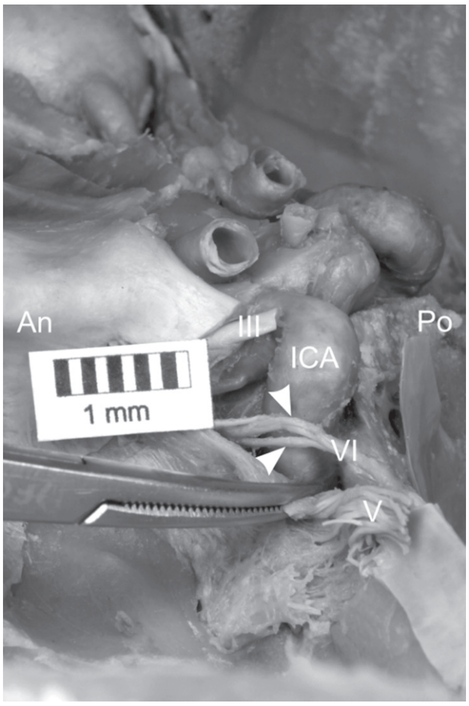

Figure 1. Variation II of the abducens nerve: arrowheads indicate the abducens nerve branching at the point where it adheres to the lateral wall of the ascending portion of the cavernous segment of ICA; III — oculomotor nerve; V — trigeminal nerve; VI — abducens nerve; An — anterior; ICA — internal carotid artery; Po — posterior.

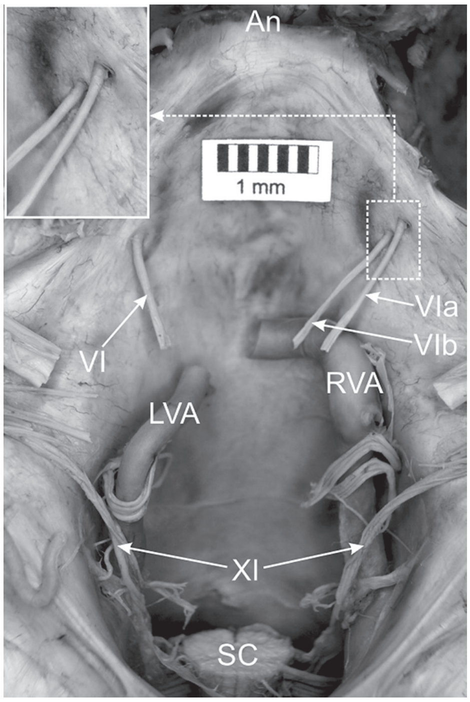

Figure 2. Anatomical variations of the abducens nerve. Magnification shows duplication of the abducens nerve (variation III); VI — single trunk of the abducens nerve; VIa — lateral trunk of the duplicated abducens nerve; VIb — medial trunk of the duplicated abducens nerve; XI — accessory nerve; An — anterior; LVA — left vertebral artery; RVA — right vertebral artery; SC — spinal cord.

lateral and medial (Fig. 2). Both trunks pierced the clival dura mater separately (Fig. 2). In three out of 4 (75%) cases classified as variation III, CN VI emerged from the pontomedullary sulcus as 2 separate trunks. In these cases the cisternal, gulfar, and partially also the cavernous segment of CN VI were duplicated. In the cases at hand, the medial trunk ran downwards, while the lateral trunk ran upwards from the petrosphenoidal ligament, thus the lateral trunk was located outside Dorello's canal (Fig. 3). Both trunks remerged in the CS (Fig. 4). In 1 case CN VI emerged from the pontomedullary sulcus as a single trunk and shortly thereafter it branched out in the subarachnoid space into 2 trunks. In this case both trunks also pierced the clival dura matter separately, but they remerged directly after entering Dorello's canal (downwards from the petrosphenoidal ligament) and then the course of the nerve was typical.

Craniometric measurements

For variations I and II, craniometric measurements of the distance between the dural entrance of CN VI to the selected topographical landmarks are illustrated in Table 2. The measurements are presented together, as in both variations the same reference points for measurement were used (in both variations the clival dura was pierced by a single trunk of CN VI). In variations I and II a significant statistical correlation was observed between the distances on the left and right side from the dural entrance of CN VI to the apex of the PCP ($p < 0.01$). A statistically relevant correlation was also found between the distances on the left and right side between the dural entrance of CN VI and the central part of the internal acoustic opening ($p < 0.01$).

For variation III, craniometric measurements of the distance from the dural entrance of CN VI of both trunks of the duplicated CN VI to the topographical landmarks are illustrated in Table 3.

DISCUSSION

Anatomical variations of CN VI

Classifications of CN VI anatomical variations vary depending on the author, which makes comparison of research results difficult. Nathan et al. [29] in their classification distinguished six types of CN VI. A similar division was used by Özveren et al. [33]. Both authors identified six types of CN VI, covering the following morphology of the nerve: type I — a single trunk of the nerve throughout

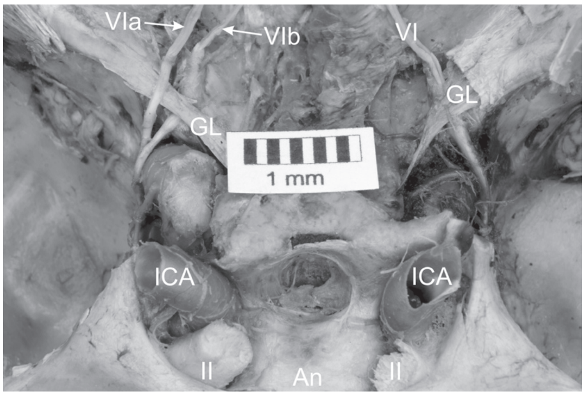

Figure 3. Anatomical variations of the abducens nerve and their relation with the petrosphenoidal ligament. Single trunk of the abducens nerve on the left side of the specimen (variation I). Duplicated abducens nerve (variation III) on the right side of the specimen; II — optic nerve; VI — single trunk of the abducens nerve; VIa — lateral trunk of the duplicated abducens nerve running upwards from the petrosphenoidal ligament; VIb — medial trunk running downwards from the petrosphenoidal ligament; An — anterior; GL — petrosphenoidal ligament (Gruber's ligament); ICA — internal carotid artery.

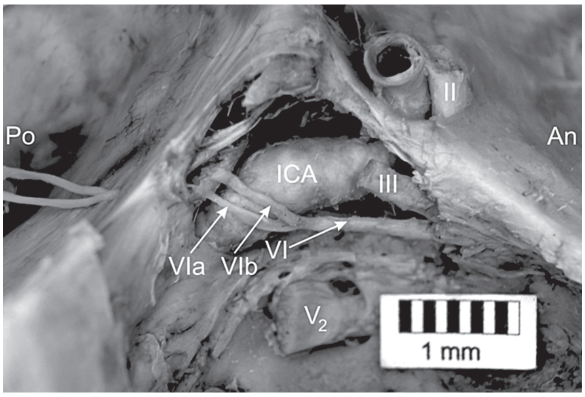

Figure 4. Duplication of the abducens nerve (variation III). The lateral wall of the cavernous sinus has been removed; II — optic nerve; III — oculomotor nerve; V_2 — maxillary nerve; VIa — lateral trunk of the duplicated abducens nerve; VIb — medial trunk of the duplicated abducens nerve; VI — abducens nerve after the lateral and medial trunks remerged within the cavernous sinus; An — anterior; ICA — internal carotid artery; Po — posterior.

Table 2. Summary of sixth cranial nerve (CN VI) craniometric measurement results by point of reference — jointly for variations I and II.

	Measured feature	Minimum value [mm]	Maximum value [mm]	Arithmetic mean [mm]	Median [mm]	Standard deviation [mm]
Right side	DE-PCP	13	23.1	18.8	19.6	2.4
	DE-TG	4.1	8.3	6.2	6.2	1.2
	DE-IAO	15.1	24.4	18.5	18.4	2.5
Left side	DE-PCP	14.3	22	18.6	18.9	2.1
	DE-TG	4.3	7.1	6	6.4	0.9
	DE-IAO	14.4	24.6	18.7	18.5	2.7
RDE-LDE		**17.4**	**24.2**	**21.5**	**21.3**	**1.9**
Total	**DE-PCP**	**13**	**23.1**	**18.7**	**19.5**	**2.3**
	DE-TG	**4.1**	**8.3**	**6.1**	**6.3**	**1.1**
	DE-IAO	**14.4**	**24.6**	**18.6**	**18.5**	**2.6**

DE-PCP — distance between the dural entrance of CN VI and the apex of the posterior clinoid process; DE-TG — distance between the dural entrance of CN VI and the inferior border of the trigeminal porus (trigeminal nerve entrance to Meckel's cave); DE-IAO — distance between the dural entrance of CN VI and the central part of the internal acoustic opening; RDE-LDE — distance between the dural entrance of the left and right CN VI

Table 3. Summary of sixth cranial nerve craniometric measurement results by point of reference for variation III

	Measured feature	Minimum value [mm]	Maximum value [mm]	Arithmetic mean [mm]	Median [mm]	Standard deviation [mm]
Lateral trunk	DE-PCP	15.2	20.8	18.3	18.9	2.3
	DE-TG	3.8	4.3	4	3.9	0.2
	DE-IAO	19	20.7	19.6	19.2	0.2
Medial trunk	DE-PCP	16.4	20.8	18.9	19.6	1.8
	DE-TG	6.2	6.4	6.3	6.3	0.1
	DE-IAO	19.9	20.8	20.3	20.2	0.4

Abbreviations as in Table 2.

its course; type II — a single trunk emerging from the brainstem, splitting in the subarachnoid space into 2 trunks which remerged within CS; type III — 2 trunks separately emerging from the brainstem, reuniting in CS. The following three types covered rare cases: type IV — duplication of the nerve throughout its course from the brainstem to the superior orbital fissure; type V in which CN VI joined the oculomotor nerve within the brainstem and was not visible in its course as a separate structure; and type VI in which the nerve split into 3 branches in the petroclival region [29, 33]. Nathan et al. [29] found only type VI in their research, and they described types IV and V based on literature. CN VI duplication throughout its course (type IV according to Nathan's classification) was reported by Jain [21], while type V was described and discussed in detail by Tillack and Winer [42].

A question arises about the clinical relevance of anatomical variations. For instance, the abducens nucleus and nerve are found to be absent or hypoplastic in patients suffering from Duane's syndrome (congenital strabismus associated with inability to abduct the affected eye) [1]. Hotchkiss et al. [17], during a dissection of a patient with Duane's syndrome, noted that the lateral rectus muscle on both sides was supplied by a branch of the oculomotor nerve, while the abducens nuclei and nerves were absent. Congenital abnormalities of cranial nerve development, along with their molecular mechanisms, are described in detail by Traboulsi [43]. On the other hand, reports can be found in literature of correct abduction of the eye in patients with CN VI duplication observed with magnetic resonance imaging (MRI) [25]. Therefore the question about the borderline between an anatomical variation within 'a norm' in a broad sense and an 'anomaly' leading to clinical symptoms remains relevant.

As there are many possible variations of CN VI, it seems clinically relevant to classify them by topographical location. Thus, this study proposes a simplified classification, adopting the 'branching and its segment' rule suggested by Ozer et al. [31]. It should be noted that the term 'CN VI duplication' was reserved in this study for those cases in which two separate trunks were found in the cisternal and gulfar segments of CN VI, as it is clinically relevant, particularly due to many surgical procedures performed in the petroclival region.

A classical anatomical description applies to the cases in which CN VI runs as a single trunk [40, 46]. This type was found by Nathan et al. [29] in 86.5% of cases in 62 cadavers (114 specimens), while Ozer et al. [31] reported this variation's occurrence in only 45% of cases. In the present study this type of CN VI (classified as variation I) was observed in 28 out of 40 nerves (70%).

Another variation (variation II) encompasses the cases in which CN VI split into branches at a short length in CS. This variation was described by Harris and Rhoton [15], Ozer et al. [31], as well as Zhang et al. [48]. Harris and Rhoton [15] stated that CN VI in CS may occasionally split into as many as 5 rootlets. In the research by Ozer et al. [31], the frequency of branching in the cavernous segment of CN VI at a limited length was estimated at 37.5% (double branching accounting for 20%, triple branching accounting for 17.5%). Joo et al. [23] reported CN VI branching within CS in 35% of cases, including double and triple branching. In the present study this type of CN VI was found in 8 (20%) cases, while the average length of the branching nerve was 8.4 mm. Distinguishing this version as a separate variation is clinically motivated, as CN VI branching directly by the ascending portion of the cavernous segment of ICA may be relevant during endovascular procedures or interventions within CS.

CN VI duplication frequency reported in different studies ranges from 5% to 28.6% [2, 18, 19, 26, 29, 32]. There are also case reports on CN VI duplication in literature [7]. Nathan et al. [29] found such a duplication in 9 out of 62 specimens (14.5%). Iaconetta et al. [19] reported its occurrence in 8% of cases. According to Özveren et al. [32, 33], the frequency of duplication is 15% (in 100 specimens), with types II and III by Nathan et al.'s [29] classification put together. In Özveren et al.'s research [32], there were 4 cases of bilateral duplication and 7 cases of unilateral duplication in 50 dissected heads. Based on a collective analysis of data found in literature, Kshettry et al. [26] estimated CN VI duplication frequency at 7.6% (35 out of a total of 462 specimens described in literature). In the present study, CN VI duplication was observed in 4 out of 40 (10%) cases, and occurred only unilaterally in the research material. CN VI duplication may be significant for surgical access to the petroclival region, as an unexpected second branch of CN VI can be injured [19, 31]. CN VI variations, including duplication, can be assessed with preoperative MRI [2, 19]. Based on MRI, Alkan et al. [2] estimated the frequency of occurrence of double rootlets in the cisternal segment of the CN VI at 25.2% of the examined population, and in 4.5% of the study group such a duplication was bilateral.

Relation with the course of the petrosphenoidal ligament

Typically, in the majority of cases, CN VI runs downwards from the petrosphenoidal ligament, within

Dorello's canal. Such a course was observed in the present study in all cases (100%) classified as variations I and II. However, CN VI occasionally takes an unusual course upwards from this ligament. Ozer et al. [31] reported such a course in 5% of cases. CN VI duplication cases in which there are two separate trunks of the nerve in the petroclival region may be accompanied by an unusual course of one of the trunks, upwards from the petrosphenoidal ligament [7, 19, 26, 32], and thus outside Dorello's canal. In the research by Nathan et al. [29], mentioned above, in all of the 9 reported cases of CN VI duplication one trunk ran above and one below Gruber's ligament. In Özveren et al.'s research [32], out of 15 cases of CN VI duplication there were only 2 cases of a trunk running outside Dorello's canal (in 1 case upwards from the petrosphenoidal ligament and in the other within the 'bony canal formed by the petrous apex and the superolateral border of the clivus'). In this study, there were 3 cases of one of the trunks of a duplicated CN VI running outside Dorello's canal out of 4 cases of CN VI duplication (75% of CN VI duplication). Dorello's canal was defined in line with the classical description: as an area located below the petrosphenoidal ligament [26]. Destrieux et al. [10] introduced a term broader than Dorello's canal: petroclival venous confluence (PVC). PVC is a venous space whose location was described as follows: 'The posterior petroclinoid fold and the axial plane below the dural foramen of the abducent nerve (sixth cranial nerve) limited the PVC at the top and bottom, respectively'. PVC is divided by the petrosphenoidal ligament into the superior and inferior compartment [10, 26]. Hence, CN VI always runs within PVC. The petrosphenoidal ligament protects CN VI running below, which is extremely important in practice, for instance, when drilling the petrous bone [23, 33]. Additionally, Tubbs et al. [44] suggested in their work that ossification of the petrosphenoidal ligament might account for unexplained cases of CN VI palsy.

Craniometric measurements

CN VI is a part of the middle neurovascular complex, which encompasses structures related to the anterior inferior cerebellar artery, including the middle cerebellar peduncle, pons, facial, and vestibulocochlear nerves [28, 36]. CN VI is adjacent to these structures. The topographic relations account for the risk of nerve injury as a result of disease processes, such as cerebellopontine angle tumours or neurovascular compressions [13, 16, 28, 36]. In the craniometric measurements taken for the purpose of this study, the shortest distance observed between CN VI and the central part of the internal acoustic opening (including the facial and vestibulocochlear nerves) amounted to 14.4 mm (18.6 mm on average for variations I and II). For variation III with a duplicated CN VI, the mean distance was slightly longer, averaging 19.6 mm for the lateral trunk and 20.3 mm for the medial trunk. Taking into account that there are various surgical procedures performed in the petrous apex, as well as in the inner auditory canal (for instance, resection of the apex of the pyramid and unroofing of the inner auditory canal), CN VI's close vicinity to the inner auditory canal and the apex of the temporal bone pyramid is topographically relevant [11, 14, 18, 23]. Another example of clinical relevance of the spatial relations in the area of the apex of the temporal bone pyramid can be Gradenigo's syndrome, consisting in the co-occurrence of sixth nerve palsy, ipsilateral decreased hearing (VIII nerve involvement), ipsilateral facial pain in the distribution of cranial nerve V and ipsilateral facial paralysis (VII nerve involvement) [3]. Such presenting features are caused by inflammation of the petrous apex — a complication of the otitis media [3].

Trigeminal neuralgia may be secondary to intracranial tumours or aneurysms which require a neurosurgical intervention [12, 23]. Joo et al. [23] estimated the average distance between the trigeminal nerve entrance to Meckel's cave (trigeminal porus) and the dural entrance of CN VI at 9.4 mm (ranging from 6.4 to 12.5 mm). In this study, the average distance from the inferior border of the trigeminal porus to the dural entrance of CN VI, measured for the variations with a single trunk, amounted to 6.1 mm, ranging from 4.1 to 8.3 mm. However, if CN VI is duplicated, the distance may be even shorter — in this study, the shortest distance from the lateral trunk of a duplicated CN VI (running always slightly upwards from the medial trunk) to the trigeminal porus was 3.8 mm. Hence, at the posterior cranial fossa CN VI is located only a few millimetres from the trunk of the trigeminal nerve. Such relations can be regarded as immediate vicinity, which may be clinically important. For instance, there have been reported cases of CN VI neuropraxia after procedures of microvascular decompression for trigeminal neuralgia [8].

Removal of the PCP during surgical procedures has been described in literature [14, 37, 39, 47]. Salma et al. [37] claim that the PCP has a 'unique location in the centre of skull base, which makes it a useful cornerstone for building an anatomical map of the skull base'. Removal of the PCP and a part of the dorsum sellae was described, among others, as a possible surgical access to low-lying distal basilar artery aneurysms [14, 47]. Such a low location of those aneurysms, as well as variations of this vessel have been described in literature [4, 35]. A possible complication of removal of the PCP is CN VI palsy in Dorello's canal [47]. This relationship (of considerable clinical importance) was reflected in this study, which provides a measurement of the distance between the PCP apex and the dural entrance of CN VI — for the variations with a single trunk of CN VI in the petroclival region averaging 18.7 mm, with the shortest distance measuring 13 mm. For a duplicated CN VI the shortest distance between PCP and the lateral trunk (running slightly upwards from the medial trunk) recorded in this study was 15.2 mm. Ozer et al.'s [31] research provided even lower values for the distance between CN VI and the PCP measured at the level of the petrosphenoidal ligament, ranging from 3.6 to 15.1 mm [O1]. Such close vicinity of the PCP should be taken into account when planning surgical procedures, for example, posterior clinoidectomy.

In summary, this study provides clinically useful information on the course and location of CN VI.

CONCLUSIONS

This study revealed that CN VI through its entire intracranial course typically formed a single trunk, however, CN VI branching within CS (20%), as well as CN VI duplication (10%) were relatively frequent variations. In a duplicated CN VI, one of the trunks sometimes ran outside Dorello's canal, upwards from the petrosphenoidal ligament, which may be clinically relevant for surgical procedures.

CN VI proved to be closely related to the middle neurovascular complex. The nerve was also found to lie immediately by the trigeminal porus and the PCP. These topographic relations account for the risk of nerve injury as a result of disease processes and surgical procedures in the petroclival region.

REFERENCES

1. Alexandrakis G, Saunders RA (2001). Duane retraction syndrome. Ophthalmol Clin North Am, 14: 407–417.
2. Alkan A, Sıgırcı A, Özveren MF, Kutlu R, Altınok T, Onal Ç, Sarac K (2004) The cisternal segment of the abducens nerve in man: three dimensional MR imaging. Eur J Radiol, 51: 218–222.
3. Azarmina M, Azarmina H (2013) The six syndromes of the sixth cranial nerve. J Ophthalmic Vis Res, 8: 160–171.
4. Battal B, Akgun V, Sari S (2014) Variations of the vertebrobasilar circulation and its impact on the clinical and radiologic evaluation. Surg Radiol Anat, 36: 203–204.
5. Bouthillier A, van Loveren HR, Keller JT (1996) Segments of the internal carotid artery: a new classification. Neurosurgery, 38: 425–433.
6. Cain RB, Patel NP, Hoxworth JM, Lal D (2013) Abducens palsy after lumbar drain placement: a rare complication in endoscopic skull base surgery. Laryngoscope, 123: 2633–2638.
7. Choi CY, Han SR, Yee GT, Lee CH. (2010) A case of aberrant abducens nerve in a cadaver and review of its clinical significance. J Korean Neurosurg Soc, 47: 377–380.
8. Choudhari KA (2005) Isolated abducent nerve palsy after microvascular decompression for trigeminal neuralgiia: case report. Neurosurgery, 57: E1317.
9. Davis MC, Griessenauer CJ, Bosmia AN, Tubbs RS, Shoja MM (2014) The naming of the cranial nerves: a historical review. Clin Anat, 27: 14–19.
10. Destrieux C, Velut S, Kakou MK, Lefrancq T, Arbeille B, Santini JJ (1997) A new concept in Dorello's canal microanatomy: the petroclival venous confluence. J Neurosurg, 87: 67–72.
11. Dolenc VV, Rogers L (2010) Cavernous sinus: developments and future perspectives. Springer, Wien, New York, pp. 70–74.
12. Dzierżanowski J, Słoniewski P (2014) Trigeminal neuralgia caused by aneurysm of the posterior cerebral artery: a case description and the analysis of anatomical variety of vascular complex in the rood entry zone of trigeminal nerve. Folia Morphol, 73: 224–228.
13. Esmer AF, Sen T, Bilecenoglu B, Tuccar E, Uz A, Karahan ST (2010) Neurovascular relationship between abducens nerve and anterior inferior cerebellar artery. Folia Morphol, 69: 201–203.
14. Figueiredo EG, Zabramski JM, Deshmukh P, Crawford NR, Preul MC, Spetzler RF (2006) Anatomical and quantitative description of the transcavernous approach to interpeduncular and prepontine cisterns. Technical note. J Neurosurg, 104: 957–964.
15. Harris FS, Rhoton AL. (1976) Anatomy of the cavernous sinus. A microsurgical study. J Neurosurg, 45: 169–180.
16. Hashimoto M, Ohtsuka K (1998) Compressive lesions of the abducens nerve in the subarachnoid space disclosed by thin-slice magnetic resonance imaging. Ophthalmologica, 212: 188–189.
17. Hotchkiss MG, Miller NR, Clark AW, Green WR (1980) Bilateral Duane's retraction syndrome. A clinical-pathologic case report. Arch Ophthalmol, 98: 870–487.
18. Iaconetta G, Fusco M, Cavallo LM, Cappabianca P, Samii M, Tschabitscher M. (2007) The abducens nerve: microanatomic and endoscopic study. Neurosurgery, 61: 7–14.
19. Iaconetta G, Tessitore E, Samii M. (2001) Duplicated abducent nerve and its course : microanatomical study and surgery-related considerations. J Neurosurg, 95: 853 –858.
20. Jacobsen CL, Bruhn MA, Yavarian Y, Gaihede ML (2011) Mastoiditis and Gradenigo's Syndrome with anaerobic bacteria. BMC Ear Nose Throat Disord, 12: 10, doi: 10.1186/1472-6815-12-10.
21. Jain KK (1964) Aberrant roots of the abducens nerve. J Neurosurg, 21: 349–351.
22. Jittapiromsak P, Sabuncuoglu H, Deshmukh P, McDougall CG, Spetzler RF, Preul MC (2010) Anatomical relationships of intracavernous internal carotid artery to intracavernous neural structures. Skull Base, 20: 327–336.
23. Joo W, Yoshioka F, Funaki T, Rhoton AL Jr. (2012) Microsurgical anatomy of the abducens nerve. Clin Anat, 25: 1030–1042.
24. Kashiwazaki D, Kuwayama N, Akioka N, Kuroda S (2014) Delayed abducens nerve palsy after transvenous coil em-

bolization for cavernous sinus dural arteriovenous fistulae. Acta Neurochir, 156: 97–101.
25. Kim JH, Hwang JM (2005) Normal abduction in a patient with duplicated abducens nerve. Korean J Ophthalmol, 19: 305–306.
26. Kshettry VR, Lee JH, Ammirati M (2013) The Dorello canal: historical development, controversies in microsurgical anatomy, and clinical implications. Neurosurg Focus, 34: E4, doi: 10.3171/2012.11.FOCUS12344.
27. Long J, Roberts DJ, Pickering JD (2014) Preservation of cranial nerves during removal of the brain for an enhanced student experience in neuroanatomy classes. Clin Anat, 27: 20–24.
28. Martin RG, Grant JL, Peace DA, Theiss C, Rhoton AL Jr. Microsurgical relationship of the anterior inferior cerebellar artery and the facial vestibular nerve complex. Neurosurgery, 23: 58–80.
29. Nathan H, Ouaknine G, Kosary IŻ (1974) The abducens nerve. Anatomical variations in its course. J Neurosurg, 41: 561–566.
30. Niedermüller U, Trinka E, Bauer G (2002) Abducens palsy after lumbar puncture. Clin Neurol Neurosurg, 104: 61–63.
31. Ozer E, Icke C, Arda N (2010) Microanatomical study of the intracranial abducens nerve: clinical interest and surgical perspective. Turk Neurosurg, 20: 449–456.
32. Özveren MF, Sam B, Akdemir I, Alkan A, Tekdemir I, Deda H (2003) Duplication of the abducens nerve at the petroclival region: an anatomic study. Neurosurgery, 52: 645–652.
33. Özveren MF, Uchida K, Aiso S, Kawase T (2002) Meningovenous structures of the petroclival region: clinical importance for surgery and intravascular surgery. Neurosurgery, 50: 829–836.
34. Pinches E, Thompson D, Noordeen H, Liasis A, Nischal KK (2004) Fourth and sixth cranial nerve injury after halo traction in children: a report of two cases. JAAPOS, 8: 580–585.
35. Polguj M, Majos M, Topol M, Majos A (2014) An asymmetrical fenestration of the basilar artery coexisting with two aneurysms in a patient with subarachnoid haemorrhage: case report and review of the literature. Folia Morphol, 73: 229–233.
36. Romero FR, Ramos JG, Chaddad-Neto F, Bethencourt JM, de Oliveira E (2009) Microsurgical anatomy and injuries of the abducens nerve. Arq Neuropsiquiatr, 67: 96–101.
37. Salma A, Baidya NB, Wendt B, Aguila F, Sammet S, Ammirati M (2011) Qualitative and quantitative radio-anatomical variation of the posterior clinoid process. Skull Base, 21: 373–378.
38. Sargent JC (2005) Nuclear and infranuclear ocular motility disorders. In: Walsh and Hoyt's Clinical Neuro-Ophthalmology. Vol. 1. 6th Ed. Lipincott Williams & Wilkins, Philadelphia, pp. 969–1040.
39. Seoane E, Tedeschi H, de Oliveira E, Wen HT, Rhoton AL Jr. (2000) The pretemporal transcavernous approach to the interpeduncular and prepontine cisterns: Microsurgical anatomy and technique application. Neurosurgery, 46: 891–899.
40. Standring S ed. (2008) Gray's anatomy: the anatomical basis of clinical practice. 40th Ed. Churchill Livingstone, London, pp. 295, 466–467.
41. Swanson L (2014) Neuroanatomical Terminology. A Lexicon of Classical Origins and Historical Foundations. Oxford University Press, Oxford, New York, pp. 24–27.
42. Tillack TW, Winer JA (1962) Anomaly of the abducens nerve. Yale J Biol Med, 34: 620–624.
43. Traboulsi EI (2004) Congenital abnormalities of cranial nerve development: overview, molecular mechanisms, and further evidence of heterogeneity and complexity of syndromes with congenital limitation of eye movements. Trans Am Ophthalmol Soc, 102: 373–389.
44. Tubbs RS, Sharma A, Loukas M, Cohen-Gadol AA (2014) Ossification of the petrosphenoidal ligament: unusual variation with the potential for abducens nerve entrapment in Dorello's canal at the skull base. Surg Radiol Anat, 36: 303–305.
45. Willis T (1664) Cerebri anatome: cui accessit nervorum descriptio et usus. Typis Ja. Flesher, Impensis Jo. Martyn & Ja. Allestry, Londini, pp. 24–25, 63–64.
46. Wilson-Pauwels L, Stewart PA, Akesson EJ, Spacey SD (2010) Cranial nerves: function and dysfunction. 3rd Ed. People's Medical Publishing House-USA, Shelton, Connecticut, pp. 112–118.
47. Youssef AS, van Loveren HR (2009) Posterior clinoidectomy: dural tailoring technique and clinical application. Skull Base, 19: 183–91.
48. Zhang Y, Yu H, Shen BY, Zhong CJ, Liu EZ, Lin YZ, Jing GH (2012) Microsurgical anatomy of the abducens nerve. Surg Radiol Anat, 34: 3–14.