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ORIGINAL ARTICLE / ОРИГИНАЛНИ РАД

Anatomical and MRI relations of the cerebral aqueduct to the adjacent parts of the brain and calvaria

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SUMMARY

Introducton/Objective Insufficiency of relevant anatomic data and great neurological and neurosurgical significance were the reasons for this study with scientific and practical implications.

The purpose was to determine, at the transverse in situ section of the head, the position and relations of the sylvian aqueduct of the mesencephalon by measuring its distances from particular brain and calvaria structures. Also, the aim was to determine the same distances according to axial sections by using MRI.

Methods The material consisted of twenty autopsy human heads. The section of the head was made at the level of the tentorial hiatus and the midbrain. After that, we measured the distances between the cerebral aqueduct and a) posterior border of the optic chiasm, b) upper border of the dorsum sellae, c) terminal bifurcation of the basilar artery, d) beginning of the straight sinus, e) internal occipital protuberance, f) tentorial edge (lateral from the aqueduct), and g) internal surface of the calvaria (lateral to the aqueduct). We determined the same distances by the MRI system. The measurements were made in 37 subjects.

Results The numerical data obtained by this study will be of benefit to neurosurgeons in choosing a surgical approach to the contents of the incisural space, and to neurologists for the exact localization of the lesion and interpretation of certain signs and symptoms.

Conclusion The results of a detailed examination of the sylvian aqueduct position and relations have shown that the use of MRI is the morphometric method of choice, because it is more precise for all the parameters monitored than in situ measurements.

Keywords: sylvian aqueduct; measured distances; midbrain section; MRI

INTRODUCTION

The sylvian aqueduct is the central cavity of the midbrain. The cerebral aqueduct was first illustrated by Leonardo da Vinci (1452–1519), who injected the ventricles with a solidifying medium and obtained casts – the first anatomical injection, but it was named after Jacques Dubois (Jacobus Sylvius) (1478–1555), a French anatomist and surgeon from Paris, who is not be confused with Francois de la Boe (1614–1672), known as Sylvius, a professor of medicine in Leyden, known for his descriptions of the brain (sylvian fissure) [1, 2]. According to *Terminologia Anatomica* [3], the aqueduct of the midbrain (aqueductus mesencephali) is also correct, and may be more appropriate recommended term. It lies between the tectum and the tegmentum of the midbrain, connecting the third to the fourth ventricle.

The aqueduct has arcuate shape on the medio-sagittal section of the midbrain [4, 5]. Woollam and Millen [6] have defined its rostral and caudal border. The rostral border is a plane perpendicular to the longitudinal axis of the brainstem, passing through the caudal end of the posterior commissure. The caudal border is a plane, also perpendicular to the longitudinal axis of the brainstem, lying at the level of the lower pole of inferior colliculi of the midbrain. On the frontal section, the aqueduct of Sylvius is of triangular shape, with its apex directed downwards.

The review of comparative anatomy of the mammalian brain shows that the cavity of the midbrain gradually narrows from lower to upper vertebrata; in men, it is reduced to a strip duct, therefore the sylvian aqueduct is the most narrow part of the ventricular system and in many cases the site of the liquor blockade.

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Aqueductal stenosis is most frequently a congenital anomaly occurring as the result of the intrauterine infection or other causes [7]. Progressive stenosis of the sylvian aqueduct initiated during the embryonic period may result from ependymal disruption of the cerebral aqueduct and dysfunction of the subcommissural organ [8]. These childhood forms of stenosis are more dangerous and have been studied more extensively than adult forms, although the latter have not been uncommon [9]. Aqueductal stenosis and the slightest alterations in the position, shape, and size of the aqueduct have serious effects on the function of the midbrain structures, and can lead to different neurologic disturbances (hydrocephalus, spastic paresis, muscular rigidity), and may be accompanied by divergence paralysis [10], hydrocephalus [8, 9], schizophrenia and parkinsonism [11, 12, 13], as well as periaqueductal dysfunction (the sylvian aqueduct syndrome) [14].

The midbrain, and the sylvian aqueduct within it, represents the upper part of the brainstem. It lies along the neuraxis passing through the tentorial hiatus, which means that it is both in the supra- and infratentorial space. Therefore, in expansive changes, movements of the brain mass lead to supra- and infratentorial herniation of the midbrain. In these cases, the midbrain is exposed to the pressure from the prolapsed part of the brain and edges of the tentorium, which affects the sylvian aqueduct [15, 16].

Insufficiency of relevant anatomic data and great neurological and neurosurgical significance were the reasons for this study. The aims of our study were to define the position, extent and relationships of the Sylvian aqueduct using transverse sections of the midbrain.

The purpose of this study was to determine, at the transverse in situ section of the head, the position and relations of the sylvian aqueduct of the mesencephalon by measuring its distances from particular brain and calvaria structures. Also, the aim was to determine the same distances by using magnetic resonance imaging (MRI) according to axial sections in FFE-T1 sequence, the slice thickness being 1.5 mm.

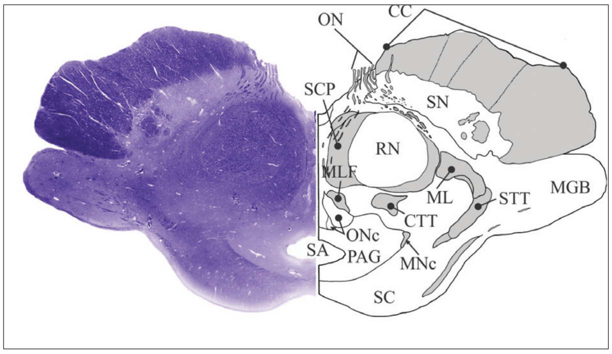

Figure 1. Light microscopy of the transverse section of the midbrain through the superior colliculus (SC), and the red nucleus (RN); SA – Sylvian aqueduct; PAG – periaqueductal grey substance; CC – crus cerebri; SN – substantia nigra; ON – oculomotor nerve; SCP – superior cerebellar peduncle, decussatio; LM – lemniscus medialis; STT – spinothalamic tract; CTT – central tegmental tract; Onc – oculomotor nuclei; MLF – medial longitudinal fasciculus; MNc – mesencephalic nucleus of CN V (cresyl violet and luxol fast blue)

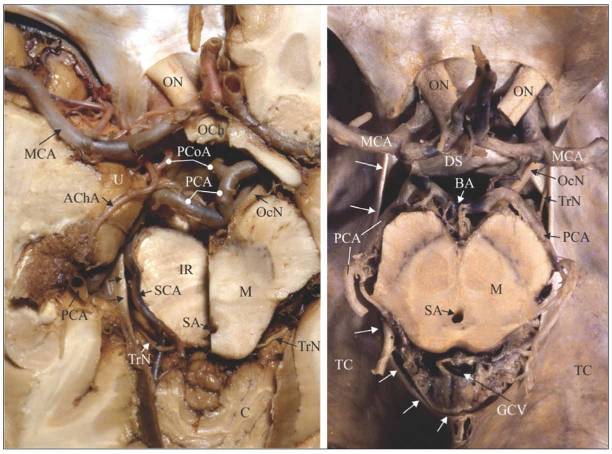

Figure 2. Transverse sections of two heads and midbrains (M) at the level of the tentorial hiatus; SA – sylvian aqueduct; OCh – optic chiasm; ON – optic nerve; IR – isthmus rhombencephali; arrows, tentorial border; TC – tentorium cerebelli; PCA – posterior cerebral artery; PCoA – posterior communicating artery; MCA – middle cerebral artery; AChA – anterior choroidal artery; SCA – superior cerebellar artery; BA – basilar artery; U – uncus; TrN – trochlear nerve; OcN – oculomotor nerve; DS – dorsum sellae; C – cerebellum; GCV – great cerebral vein

METHODS

After a standard preparation procedure for histochemistry, one normal midbrain was embedded in paraffin and sectioned transversely. The slices were stained with cresyl violet and luxol fast blue (Klüver–Barrera method), examined under the light microscope, and photographed using a digital camera (Figure 1). Additionally, we made transverse sections of two formalin injected heads in order to use them for studies of the position, extent, and relationships of the mesencephalon and cerebral aqueduct, as the coronal sections of one formalin injected head (Figures 2 and 3).

Measurements were performed on 20 heads of adults, both sexes, aged between 48 and 65 years (12 female, whose average age was 60 years, and eight male of the average age of 58 years), with no pathological findings, during routine autopsies at the Institute of Pathology, School of Medicine, University of Belgrade. We studied the relationships only in fresh cadaver material with short postmortem delays. After the skull had been opened, the dura mater was removed, and frontal lobes of the cerebrum were lifted. This enabled inspection and detection of the optic chiasm and internal carotid arteries. Then we carried out the sectioning of the midbrain in situ at the level of the tentorial notch. The distances were measured using scientific caliper.

The following distances were measured (Figure 4):

a. from the aqueduct to the posterior border of the optic chiasm;
b. from the aqueduct to the upper border of the dorsum sellae;
c. from the aqueduct to the terminal bifurcation of the basilar artery;
d. from the aqueduct to the beginning of the straight sinus;
e. from the aqueduct to the internal occipital protuberance;

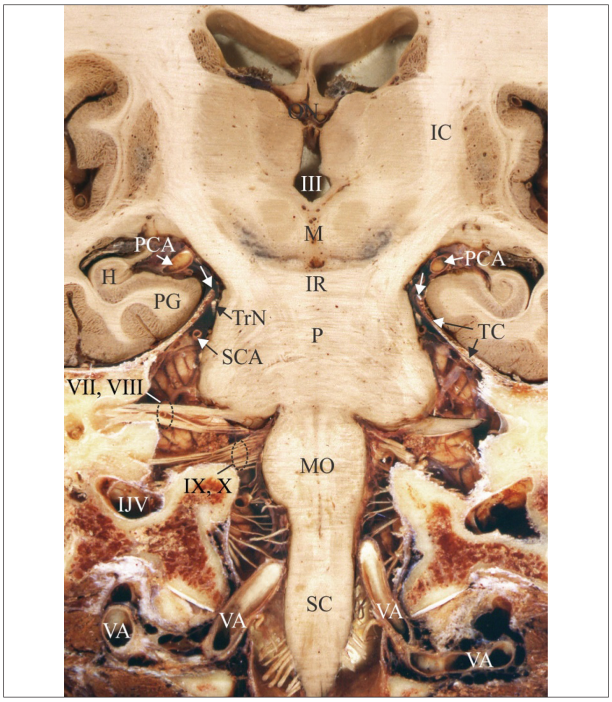

Figure 3. Coronal section of the head through the third ventricle (III); IC – internal capsule; M – midbrain; IR – isthmus rhombencephali; P – pons; MO – medulla oblongata; SC – spinal cord; arrows, tentorial border; TC – tentorium cerebelli; PCA – posterior cerebral artery; H – hippocampus; PG – parahippocampal gyrus; TrN – trochlear nerve; SCA – superior cerebellar artery; VII and VIII – facial and vestibulocochlear nerves; IX and X – glossopharyngeal and vagus nerves; IJV – internal jugular vein; VA – vertebral artery

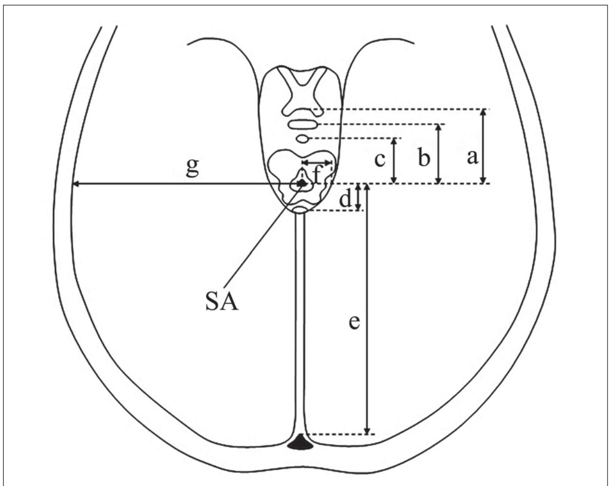

Figure 4. Distances between the sylvian aqueduct (SA) and the: a – posterior border of the optic chiasm; b – upper border of the dorsum sellae; c – basilar artery; d – beginning of the straight sinus; e – internal occipital protuberance; f – tentorial edge; g – internal table of the skull

f. from the aqueduct to the tentorial edge (lateral to the aqueduct), and
g. from the aqueduct to the internal table of the calvaria (lateral to the aqueduct).

We measured the same distances using the Philips Intera 3+ (Koninklijke Philips N.V., Amsterdam, Netherlands) MRI system, using axial sections in the FFE-T1 weighted sequence, TE 15, TR 450, FOV 192 × 240, slice thickness 1.5 mm. The measurements were performed at the Health Centre for Railway Workers, Belgrade, on 37 subjects (20 men of the average age of 44 years, and 17 women of the average age of 41 years), with no pathological findings, after the approval obtained from each person and the institutional ethics committee.

Data obtained by two different methods were compared. Specific matching was performed, and in statistical analysis of data, we used the descriptive statistics (mean value, standard deviation and standard error) implementing the SPSS Statistics for Windows, Version 17.0 (SPSS Inc., Chicago, IL, USA) software. Statistical significance of the differences among the mean values was tested by Student's t-test.

RESULTS

The cerebral aqueduct, surrounded by the periaqueductal grey substance (PAG), separates the tectum from the tegmentum. PAG contains important structures, such as dorsal raphe nucleus, dorsal tegmental nucleus, dorsal longitudinal fasciculus, and some monoaminergic bundles. The midbrain tegmentum, ventral to the cerebral aqueduct, and dorsal to the substantia nigra, contains the trochlear and oculomotor nuclei, the trigeminal mesencephalic nucleus, the red nuclei, and many smaller cell groups, as well as a curved band of somatic sensory fibers. The massive crura cerebri contain descending corticofugal fibers (Figure 1).

In the tentorial hiatus area, there are also other structures: rhombencephalic isthmus, rostral portion of the cerebellum, uncus, and the parahippocampal gyrus, and a large number of cerebral vessels and cranial nerves (Figures 2 and 3). Major arteries in this area include the anterior choroidal artery, posterior cerebral artery, and superior cerebellar artery. The lateral posterior choroidal arteries and thalamogeniculate arteries, side branches of the posterior cerebral artery, course just medial to the free edge of the tentorium. In this region, the internal cerebral veins and the basal vein of Rosenthal unite to form the great cerebral vein of Galen, which joins the inferior sagittal sinus to form the straight sinus. The trochlear nerve passes through this region and is closely related to the tentorial free edge.

We compared anatomical and radiological distances (diameters) to define the exact position of the Sylvian aqueduct. In order to accomplish this we measured distances between the cerebral aqueduct and particular structures: a) posterior border of the optic chiasm, b) upper border of the dorsum sellae, c) terminal bifurcation of the basilar artery, d) beginning of the straight sinus, e) internal occipital protuberance, f) tentorial edge (lateral to the aqueduct), and g) internal table of the calvaria (lateral to the aqueduct) (Figure 4).

a) The average distance between the aqueduct and the posterior border of the optic chiasm was 43.2 mm, SD 3.76, SE 0.84. The minimal value was 40 mm and maximum 48 mm (Table 1A). The average value of the same distance obtained by MRI was 44.6 mm,

Table 1. Statistics of all measured distances in situ and on MRI

Distance from the cerebral aqueduct to:	a. Chiasma opticum	b. Dorsum sellae	c. Basilar artery	d. Straight sinus	e. Internal occipital protuberance	f. Tentotial edge			g. Internal table of calvaria		
						Left	Right	Mean	Left	Right	Mean
A. Measured on sections											
Mean	43.2	36.8	26.2	22.1	63.2	10.8	11.2	11	65.9	66.1	66
SD	3.76	2.40	2.69	3.10	3.22	0.89	0.91	0.89	3.49	3.67	3.49
SE	0.84	0.54	0.6	0.69	0.72	0.2	0.17	0.2	0.78	0.82	0.78
Min.	40	31	23	17	56	9	10	9	57	57	57
Max.	48	41	32	28	71	12	12	12	71	72	72
B. Measured on MRI											
Mean	44.6	36.3	26.3	22.9	61.9	10.5	10.8	10.6	64.1	64.3	64.2
SD	2.33	2.83	2.26	3.71	3.7	0.94	0.96	0.94	4.81	4.78	4.8
SE	0.38	0.47	0.37	0.61	0.61	0.15	0.16	0.16	0.79	0.79	0.79
Min.	40.5	31.5	22.2	17.2	57.2	9.2	9	9.2	57.2	57.8	57.5
Max.	48.1	40.7	31.8	28.9	70.9	12	12.1	12	72.2	72	72.1
DF = 72											
t	1.925	0.820	0.173	1.007	1.612	1.410	1.839	1.880	1.842	1.817	1.845
p	0.058	0.415	0.863	0.318	0.111	0.163	0.070	0.064	0.070	0.073	0.069

SD 2.33, SE 0.38, the lowest value 40.5 mm, and the highest 48.1 mm (Table 1B).

b) The mean value of the distance between the aqueduct and the upper border of the dorsum sellae was 36.8 mm, SD 2.4, SE 0.54, the minimal value was 31 mm, and the maximal 41 mm (Table 1A). The average value of that distance on MRI was 36.3 mm, SD 2.83, SE 0.47, the lowest value 31.5 mm, and the highest 40.7 mm (Table 1B).

c) The mean value of the distance between the aqueduct and the terminal bifurcation of the basilar artery was 26.2 mm, SD 2.69, SE 0.6, the minimal value was 23 mm, and the maximal 32 mm (Table 1A). The average value of the same MRI distance was 26.3 mm, SD 2.26, SE 0.37, the lowest value 22.2 mm and the highest 31.8 mm (Table 1B).

d) The mean value of the distance between the aqueduct and the beginning of the straight sinus was 22.1 mm, SD 3.1, SE 0.69, the minimal value was 17 mm, and the maximal 28 mm (Table 1A). The average value of the same distance obtained by MRI was 22.9 mm, SD 3.71, SE 0.61, the lowest value 17.2 mm and the highest 28.9 mm (Table 1B).

e) The mean value of the distance between the aqueduct (section at the level of hiatus tentorii) and the most prominent point of the internal occipital protuberance was 63.2 mm, SD 3.22, SE 0.72, the minimal value was 56 mm, and the maximal 71 mm (Table 1A). The average value of that distance on MRI was 61.9 mm, SD 3.7 mm, SE 0.61, the lowest value 57.2 mm and the highest 70.9 mm (Table 1B).

f) The mean value of the distance between the aqueduct (section at the level of hiatus tentorii) and the tentorial edge was, on both sides, 11 mm, SD 0.89, SE 0.2, with the minimal value of 9 mm, and the maximal 12 mm (Table 1A). The average value of the same distances obtained by MRI for the left and the right side on average was 10.6 mm, SD 0.94, SE 0.16, the lowest value 9.2 mm, and the highest 12 mm (Table 1B).

g) The mean value of the distance between the aqueduct and the internal table of the calvaria was, on both sides, 66 mm, SD 3.49, SE 0.78, with the minimal value of 57 mm, and the maximal 72 mm (Table 1A). The average value of these distances on MRI for the left and right side was 64.2 mm, SD 4.8, SE 0.79, the lowest value 57.5 mm and the highest 72.1 mm (Table 1B).

Additionally, we compared the accuracy of measurements made using MRI axial sections (Figure 5) with anatomical measurements obtained by using a sliding caliper. There were no statistically significant differences between the MRI and the anatomical measurements (Student's t-test; $p > 0.05$) (Table 1). Our results demonstrated that MRI sections can provide accurate and relevant measurements which are in good correlation with performed anatomical measurements.

The results of a detailed examination of the sylvian aqueduct position and relations have shown that use of MRI is morphometric method of choice, because it is more precise for all the parameters monitored than in situ measurements. The bony tissue is not prone to postmortal alterations, and it has been well known that connective membranes are more resistant, but with increasing post mortem delay softening of nervous tissue occurs. This may result in deformation and significant changes of the brain stem position in the supratentorial and infratentorial compartments.

DISCUSSION

The region of the tentorial notch can be classified as the: anterior, middle (paired), and posterior incisural space. The posterior incisural space is also known as the pineal region. It lies in front of the cerebellum, posterior to the

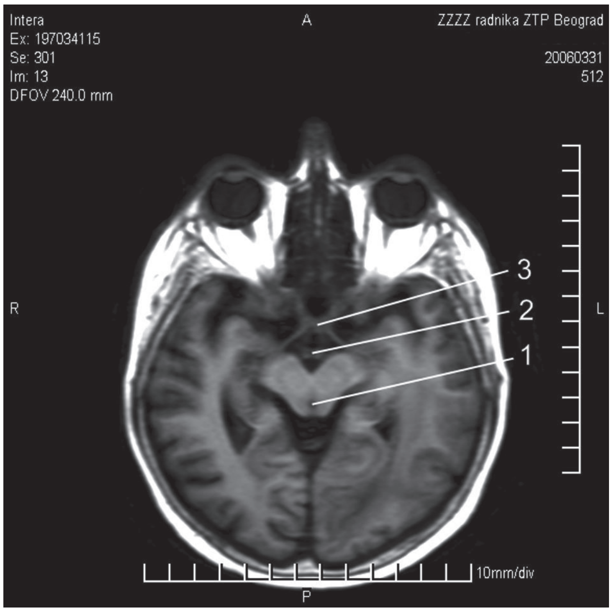

Figure 5. Section of mesencephalon at the level of hiatus tentorii obtained by MRI; 1 – sylvian aqueduct; 2 – basilar artery; 3 – optic chiasm

midbrain, partly situated in the cerebello-mesencephalic fissure. It corresponds to a quadrigeminal cistern, extending superiorly to the lower surface of the splenium, and posteriorly to the level of the tentorial apex. Its lateral borders are the pulvinares of thalami and the posterior part of parahippocampal gyrus, laterally extending to the middle incisural space. The middle incisural space is a narrow space between the upper part of the brainstem medially (at the level of pontomesencephalic juncture) and the medial side of the temporal lobe, more precisely, the parahippocampal gyrus. Superiorly, this space is bounded by the posterior part of the optic tract and the lower surface of the thalamus, and it continues inferiorly into the cerebello-mesencephalic fissure. The middle incisural space corresponds to the ambiens and crural cisterns [15, 16].

Lang and Buhler [17] and Lang [18] presented data on the dimensions of certain midbrain structures: crus cerebri, lamina tecti, tegmentum, superior colliculi, inferior colliculi, interpeduncular fossa, but none of the distances from the aqueduct to surrounding structures. Our measurements, which have not been performed before, are collected and compared with those made by using MRI, and showed, in general, position and relations of the sylvian aqueduct with possible clinical implications.

A specific challenge for a neurosurgeon is the approach to the contents of the incisural space, particularly the lesions along the posterolateral midbrain. In these cases, the adequate surgical approach is supracerebellar and infratentorial [19]. This approach has three variants: middle, paramedian (lateral), and extremely lateral. Therefore, it is important to evaluate the relations of the aqueduct to the tentorial notch, elements of the incisural space, as well as other parts of the brain and calvaria. Neurosurgical significance of the mesencephalic aqueduct and PAG is manifested in appropriate neurosurgical interventions at the mesencephalic level. The most frequent surgeries are in the vicinity of the midbrain, both dorsally (in the pineal body area), and ventrally (in patients with craniopharyngioma). Surgical procedures at the level of the mesencephalon have been rare. Therefore, the knowledge of aqueductal topography is of importance in both fields – neurology and neurosurgery.

Even though neurosurgeons consider the aqueduct an untouchable cerebrospinal fluid channel, with increasing popularity of neuroendoscopy and stereotactic neurosurgery, structures in its vicinity could be managed endoscopically or stereotactically. Longatti et al. [2] described the findings of endoscopic aqueductal exploration. But, the anatomy of the periaqueductal region is extremely complex, and the idea that the aditus can be forced and the aqueduct itself mechanically enlarged with a larger endoscope is certainly hard to accept [20].

Neurological significance of PAG is reflected in appearance of various signs and symptoms in patients with dorsal tegmental lesion (the aqueduct and PAG lesion). Lesions can be of vascular, neoplastic and demyelinating in their natures. Vascular lesions most frequently occur after occlusion of paramedian perforating branches of posterior cerebrale and/or terminal part of the basilar artery [21]. Tumors appear either out of the mesencephalon, for example in the region of the pineal body with compression on the dorsal tegmentum, or in the PAG proper [22, 23, 24]. Finally, demyelinating diseases may affect certain parts of PAG and surrounding formations. For interpretation of mental correlates accompanying structural lesions in the mesencephalic region, it is important to properly interpret alterations and form of mesencephalic aqueduct, its distance from the left and right substantia nigra and dorsal tegmentum, as well as asymmetry of the above elements on MRI scans. The fact is that, namely, substantia nigra, nucleus raphe dorsalis and PAG are responsible for affective functions and emotions, as well as that there coexist different neurotransmitters and neuropeptides with a particular role in modulating mental functions. There are 40% of all GABA cerebral axonal terminals in substantia nigra, representing the most potent inhibitory neurotransmitter in the mammalian central nervous system.

The tentorial hiatus is a frequent site of herniation in cases of intracranial hypertension. The supratentorial expansive processes lead to descending herniation and infratentorial processes to ascending herniation. In both cases there is compression, dislocation, elongation and, eventually, laceration of the cerebral tissue, nerves, arteries, veins, and liquor space. As a result, edema, infarction, hemorrhage, and hydrocephalus develop [15]. Considering the fact that the aqueduct is a very narrow channel, it can easily be narrowed by expansive and other processes, either in or adjacent to the aqueduct, and produce stenosis and hydrocephalus [7, 9, 25]. The aqueduct can be expanded in patients with generalized cerebral atrophy, as well is in head injuries followed by the loss of periaqueductal neuronal and axonal substance. A tumor can develop inside the aqueduct, connected to the intraventricular tumors of the third and fourth ventricle. The tumors of the posterior cranial fossa can displace the aqueduct posteriorly, anteriorly, laterally, or can lead to posterolateral shifting [26].

This study has a both neurosurgical and neurological significance. The data obtained will be of benefit to neurosurgeons in choosing a surgical approach to the contents of the tentorial notch, and to neurologists and neuroradiologists for the exact localization of the lesion and further interpretation of certain signs and symptoms.

CONCLUSIONS

The data obtained during this study may facilitate establishing diagnosis of pathological processes in the central part of the cerebral base, since they contribute to the exact location of pathological processes. They may also assist in interpreting the occurrence of accompanying neurologic and psychiatric patient signs and symptoms.

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Односи Силвијевог канала са околним деловима мозга и лобање мерени анатомски и магнетном резонанцом

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САЖЕТАК

Увод/Циљ Недостатак одговарајућих анатомских података и велики неуролошки и неурохируршки значај су били разлози за покретање ове студије са научним и практичним значајем.

Циљ рада је био да се, на попречном пресеку главе, одреде положај и односи Силвијевог канала средњег мозга мерењем раздаљина до одређених структура мозга и лобање. Такође, циљ је и да се одреде исте раздаљине коришћењем попречних пресека магнетне резонанце (МР) главе.

Методе рада Материјал су чинили пресеци 20 глава добијени током рутинске обдукције. Пресеци главе и мозга су прављени у нивоу зјапа шатора малог мозга и средњег мозга. Мерили смо растојања између Силвијевог канала и а) задње ивице оптичке раскрснице, б) горње ивице леђног дела хипофизне јаме, в) завршне рачве базиларне артерије, г) почетка правог синуса, д) унутрашње потиљачне кврге, ђ) ивице тенторијума (упоље од канала средњег мозга) и е) унутрашње површине крова лобање (упоље од канала средњег мозга). Мерили смо исте раздаљине коришћењем МР. Мерење је обављено на 37 особа.

Резултати Нумерички подаци добијени овом студијом биће од користи неурохирурзима у проналажењу хируршког приступа садржају простора између слободних ивица тенторијума, као и неуролозима за прецизну локализацију лезија и интерпретацију неких знакова и симптома.

Закључак Резултати детаљног проучавања положаја и односа Силвијевог канала показали су да је коришћење МР морфометријска метода избора јер је много прецизније за све посматране параметре од мерења током обдукције.

Кључне речи: Силвијев канал; мерене раздаљине; пресек средњег мозга; МР