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ORIGINAL ARTICLE

Individual variability and marginal types of the human vertebral artery (V3) subject to the skull shape

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Summary

Variability of the third segment (V3) of vertebral artery (VA) in correlation with individual shape of skull was studied by analyses of 32 MRI and angiograms of 64 arteries. According to value of cranial index, the group under research was divided into three subgroups: dolichocephalic (15.6%), mesocephalic (43.8%), and brachycephalic (40.6%). The V3 was studied according to its conventional division into three sections: vertical (vV3), horizontal (hV3), and oblique (oV3), with proximal and distal loop formations along its length.

The mean diameter and length of vV3 and hV3 had minimal value in the patients with brachycephalic shape of skull. The angle between bends of proximal loop of V3 progressively increased from 67.5 ± 0.75 degree in the dolichocephalic group to 77.1±0.44 degree in the brachycephalic group, while the angle between bends of distal loop was decreasing from the dolichocephalic group (79.6 ± 4.7 degree) to the mesocephalic group (74.85±2.4), reaching the minimal value in the brachycephalic group (79.6 ± 4.7 degree). In the dolichocephalic group downward deviation of hV3 was more in evidence than in all the rest groups, with inclination to minimal or zero-deviation in brachycephalic group.

The results have showed that the anatomical variability of V3 significant correlates with the shape of skull. The findings open up possibilities for primary diagnosis and prognosis of acute and chronic disorders in posterior circulation enabling to choose the individual surgical approach to the craniocervical junction and base of skull.

Key words: Vertebral artery – V3 segment – Variability – Cranial index – Shape of skull

Introduction

The problem of cerebral circulation is a topical problem of modern medicine due to significant share in the structure of morbidity and mortality of population (Ingall, 2004).

The posterior circulation of the brain is of particular interest because of complex course and relations of the vertebral artery (VA) and frequent issues of the chronic and acute disorders therein (Inamasu and Guiot, 2005; Sanelli et al., 2002; William et al., 2012). The VA is a branch of subclavian artery that ascends toward the transverse foramens of C6 vertebrae (V1), then it passes upward through

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the transverse foramina of C6 to C2 (V2); afterwards, it runs over the axis and atlas (V3) to enter the cranial cavity (V4); eventually, VA joins the similar vessel of the opposite side, forming the basilar artery (Turliuk et al., 2009). The course of VA changes three times over its third segment: from vertical (vV3) to horizontal (hV3), and then to oblique (oV3). Certain anatomical variations of the V3 can serve as prerequisites for development of stenosis, obstructions, as well as VA dissections that must be taking into account by specialists (Ravensbergen et al., 1998). Study of variability of the cerebral vessels is of great practical importance, since it allows us to predict the course of pathological processes and to avoid serious iatrogenic injury during diagnostic and therapeutic procedures (Inamasu et al., 2005).

The objective of this study is to determine and characterize the range of anatomical variability of the V3 of VA in connection with the individual shape of the skull.

Materials and methods

A total of 32 patients (64 sides) without known vascular pathology in the vertebrobasilar system were included to our study (15 men and 17 women; age range 35-79 years; mean age 58 years). The patients underwent routine MRA examination of the head and neck during the period from 1.10.2011 to 30.04.2012 under the direct supervision of one of the authors and in accordance with the ethical standards.

Magnetic resonance images of head were obtained with a 3-tesla magnetom Verio (Siemens, Erlangen, Germany). Twenty consecutive sagittal T1-weighted Gradinat echo images of the head were taken under the time of repetition (TR) 280 milliseconds and the echo time (TE) of 2.6 milliseconds for each patient. Images were obtained using a 5-mm slice thickness and a 23-cm field of view with a 0.10 distant factor (DF). The axial slices of the head were scanned parallel to the axis of the lateral ventricle. The longitudinal (LD) and transverse (TD) diameters of the skull were measured on sagittal and transverse MR images of the head to determine their individual constitution; the dimensions were equal to the distances from the glabella to the opisthocranium (G-OP) and from the euryon to euryon (EU-EU), respectively (Fig.1). The cranial index (CI) was computed based on standard anatomical descriptions as the ratio of TD to LD percentagewise (Bannister, 1995; Kolar and Salter, 1997). According to value of CI, the research group was divided into three subgroups: 1) dolichocephalic -

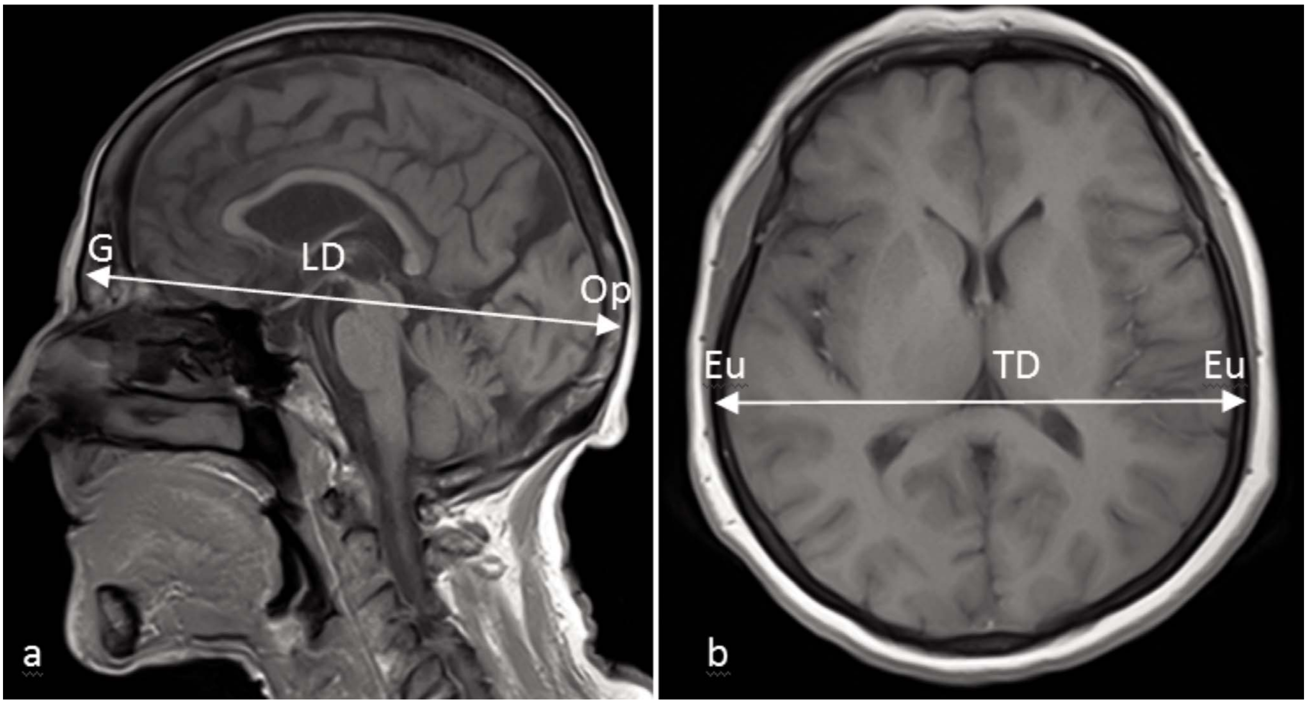

Fig. 1. MRI of a head: **a)** Sagittal head and neck: LD - the distance from the glabella (G) to the opisthocranium (OP); **b)** Axial head: TD - the distance from euryon to euryon (EU-EU).

with a narrow skull (CI < 74.9%), 2) mesocephalic - with a proportional skull (CI in the range 75%-79.9%), and 3) and brachycephalic - with a wide skull (CI > 80%). The anatomical variability of V3 was examined according to the cranial type with detection of the marginal forms for each concerned dimension.

MR angiography was performed with the patients' heads in the neutral position. After injection of a low-osmolarity iodinated contrast material through a peripheral vein, the Flash 3D sequence scanning from the head to the aortic arch was triggered automatically 3 s later. The parameters for CT angiographic acquisition were a 1.4-mm slice thickness, TR - 3.2 ms, TE - 1.2 ms and 34 cm FOV. On obtained MRA images, the course and tortuosity of the third segment of the VA (64 arteries) were studied and analyzed according to its conventional division into three sections: vV3, hV3, and oV3 (Fig. 2). On the antero-posterior view angiograms, the following quantitative anatomical measurements were made: length and outer diameter of each segment of V3, the angles *a1* and *a2* between the bends of the proximal and distal loops (PL and DL, respectively), the angle *a3* between the hV3 and oV3 segments of VA, and the distance between the upper edge of hV3 and imaginary transverse line drawn through its origin and ending (Fig. 2, a-b). On the lateral view angiograms, the distance between the apices of the proximal and distal loops (PL-DL) was measured (Fig. 2c).

The statistical analysis was performed using descriptive statistics i.e. mean (m) and standard deviation (SD). The investigation of VA variance in THE different craniometric groups was analyzed with Student's paired t-test and ANOVA tests. A p-value ≤ 0.05 was considered to be statistically significant. In addition, the linear regression and correlation analyses were performed to investigate the correlation of each parameter with CI.

Fig. 2. MR angiography of head and neck: anteroposterior view. vV3 - vertical segment of the vertebral artery; hV3 - horizontal segment of vertebral artery; oV3 - oblique segment of the vertebral artery; PL - proximal loop of V3; DL - distal loop of V3; a1 - angle between bends of the proximal loop; a2 - angle between bends of the distal loop; a3 - angle between the hV3 and oV3.

Results

The *vertical segment of VA (vV3)* had mean diameter of 3.9 ± 1.08 mm and a length of 23.22 ± 2.7 mm. Subject to CI, the diameter of vV3 varied from 3.74 ± 0.37 mm in the brachycephalic group to 4.18±0.65 mm in the mesocephalic group (Tab. 1). The mean diameter of vV3 corresponded to the dolichocephalic group and was equal to 3.81 ± 0.96 mm. The maximum length of vV3 was found in the dolichocephalic group, while the minimum length corresponded to the brachycephalic shape of the skull.

The *proximal loop of V3 (PL)* is the first lateral extension of V3 in the coronal plane. It is formed by the length of the vertical section of VA along the C1 - C2 interval, which turns giving ascending bend, and then deviates medially under an acute angle, providing the descending bend of the loop (Fig. 2). The value of the angle (*a1*) was in direct correlation with CI. It increased progressively from 67.5 ± 0.75 degrees in the dolichocephalic group to 77.1±0.44 degrees in the brachycephalic group (Tab. 2). The mean value of *a1* corresponded to the individuals with the mesocephalic shape of the skull.

The *horizontal part of the VA (hVA)* starts just after leaving the transverse foramen of the atlas, after which the vessel loops backward and downwards and runs medially in a transverse direction. The maximum value of the outer diameter of the hVA was observed in the mesocephalic group (4.1 ± 0.35 mm), while the minimal width was found in the brachycephalic one (3.57 ± 0.61 mm). A similar trend was observed in the length measuring (Table 1).

The projection of hVA over posterior arch of the atlas is labeled as *a distal loop (DL)*. It is the largest extension of V3 that goes at first backward in the sagittal plane, and then turns medially, often deflecting down or straight in the transverse plane (Fig. 3). The angle between ascending and descending bends of DL (*a2*) varied in wide range: from 54 to 110 degree. Statistical distribution of *a2* according to CI deserves our attention: its maximum value belonged to the dolichocephalic group, then it decreases in the mesocephalic group, reaching the minimal value in the brachycephalic one (Table 2). The greater value of the distance from the imaginary horizontal

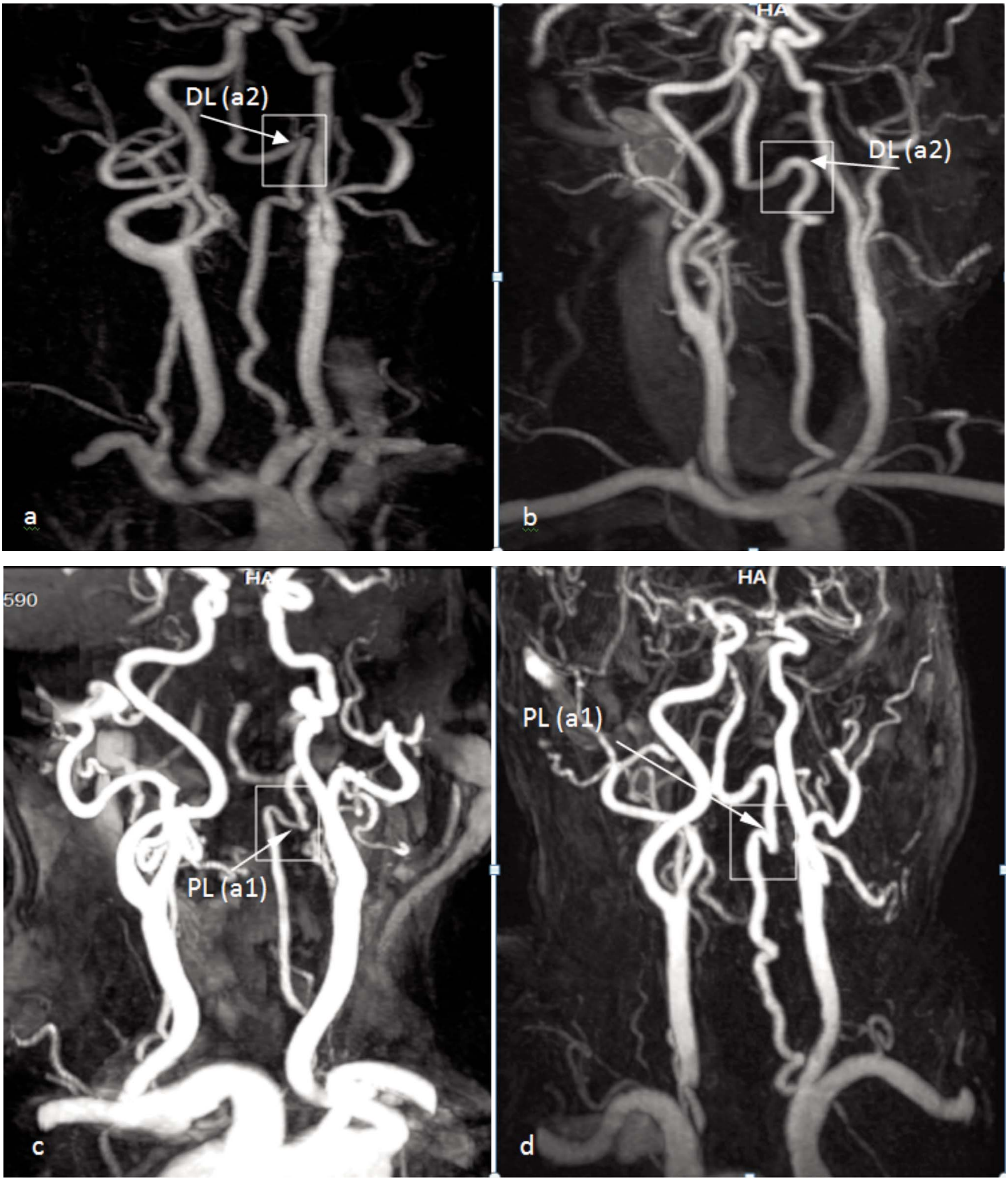

Fig. 3. MR angiography of head and neck.The V3 of the left VA is marked. The marginal forms of the proximal and distal loops of V3 are visible on the angiograms. The angle 2 (a2) between the bends of the distal loop (DL) of V3 has extremely acute degree in the persons with brachycephalic shape of skull. **(a)** *Sheet 4. Male, 62 years old, CI=88.2%,* while bumpless bending of DL is characteristic for the dolichocephalic group; **(b)** *Sheet 11. Female, 48 years old, CI=74.5%).* On the contrary, the angle 1 (a1) between the bends of the proximal loop (PL) of V3 has the minimal value in the individuals with dolichocephalic shape of skull; **(c)** *Sheet 32, male, 52 years old, CI=73.8%*, and the maximal value of degree **(d)** in the brachycephalic patients *(Sheet 20. Male, 67 years old, CI=82.7%).*

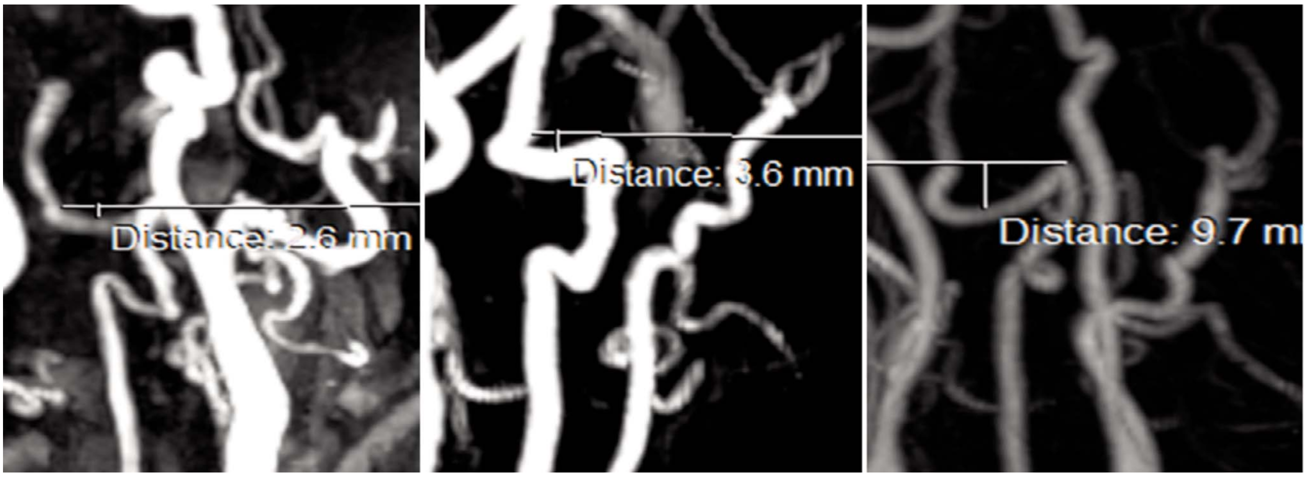

Fig. 4. MR angiography of head and neck. The hV3 of the left VA is marked. Marginal types of variability of hV3 are presented on the angiograms. The horizontal part of V3 deviates downward (DD) in the largest measure in the persons with dolichocephalic shape of skull. **(c)** *Sheet 21. Male, 60 years old, CI=74.6%,* but it has the minimal value in the individuals with brachycephalic shape of skull **(a)** *Sheet 20. Male, 67 years old, CI=82.7%*. The DD interval had mean value in the mesocephalic group of patients **(b)** *Sheet 28, female, 52 years old, CI=78.9%.*

line, drawing through origin and ending of hVA to the most superior edge of the DL, marked as DD, was revealed in the dolichocephalic group (6.28 ± 0.35 mm), and the least value belonged to the brachycephalic group (5.03 ± 1.26 mm). The group with mesocephalic shape of skull had intermediate value of DD (Fig. 4).

The termination of the V3 segment is the *oblique part (oV3),* which follows an oblique direction, running up and medially to enter the foramen magnum and to pierce the dura mater. The segment corresponds to the vessel's extension over the interval between the vertebral groove of the posterior arch of the atlas and the inner edge of the foramen magnum. The length of oV3 was maximal in the group with the dolichocephalic shape of the skull (12.9 ± 3.55 mm), and it was minimal in the brachycephalic group (11.83 ± 1.16 mm). The diameter of oV3 was longer in the mesocephalic group (3.65 ± 0.86 mm) and nearly equal in the two other groups.

The transition from hV3 to oV3 was evaluated as a blunt angle between them *(a3).* The value of the angle varies inversely with the CI (Table 2). The value of *a3* was maximal in the dolichocephalic group (116.4 ± 6.38 degree), and it was minimal in the brachycephalic group (98.35 ± 14.8 degree).

Discussion

At present, the scope of craniology in medicine is significantly expanded. In pediatrics, the normal range of variability of the skull subject to CI was examined by Salvador et al. (2006) for the purpose of predicting and quantifying head- and skull-shape deformity in children. Clinical observations of Albajalan et al. (2011) revealed relation of the obstructive sleep apnoea in adults with the shape of skull-base and individual features of the airways. Knowledge of the main types of variability of the vascular system of head and neck in relation with the shape of skull is a fundamental principle of primary diagnostics and cure planning. It allows fitting an individual approach and method of surgical intervention on neck and head in certain clinical situation. The CI usability makes this method of variance estimation as a universal tool in the surgical practice that is available in any circumstances and for various strata of society.

According to our findings, the mesocephalic shape of the skull predominates among the adult Asian population (43.8%); the brachycephalic type was found in 40.6%, and the dolichocephalic shape of the skull corresponded to a small group of patients (15.6%).

Characteristics of V3 in the brachycephalic group

In the literature, we did not find any collations of V3 variability with the shapes of skull. According to the present results, the minimal outer diameter and length of all the segments of V3 are statistically valid for individuals with a brachycephalic type of skull. The analysis of V3 width showed that the posterior cerebral circulation is at risk of insuffi-

Table 1. Distribution of V3 parameters according to shape of skull; mean (μ) ± SD (σn-1), mm.

	vV3		hV3		oV3	
	diameter	length	diameter	length	diameter	length
Dolichocephalic CI[1]<74.9%	3.81 ± 0.96*	23.57 ± 0.56**	3.92 ± 0.35**	17.03 ± 0.96*	3.41 ± 1.37*	12.9 ± 3.55 NS
Mesocephalic CI[1] (75%-79.9%)	4.18 ± 0.65**	23.09 ± 0.44NS	4.1 ± 0.37*	18.15 ± 1.26*	3.65 ± 0.86**	11.59 ± 1.26*
Brachycephalic CI[1]>80%	3.74 ± 0.37**	22.85 ± 0.31*	3.57 ± 0.61**	11.83 ± 1.16**	3.22 ± 0.64***	11.83 ± 1.16*

[1] Confidence interval for CI (0.9140, 0.9464) at $p \leq 0.05$ significance level.

Significance levels: ***p < 0.001; ** p<0.01; * p<0.5; NS – no statistical significance.

Table 2. Evaluation of V3 tortuosity according to shape of skull; mean (μ) ± SD (σn-1), mm.

	a1[1], D	**a2[2], D**	**a3[3],**	**D DD, mm**
Dolichocephalic CI<74.9%	67.5 ± 0.75**	79.6 ± 4.73*	116.4 ± 6.38**	6.28 ± 0.35*
Mesocephalic CI (75%-79.9%)	72.5 ± 0.82***	74.85 ± 2.4**	102.5 ± 8.48**	5.89 ± 2.12
NS **Brachycephalic CI>80%**	77.1 ± 0.44*	68.8 ± 1.3*	98.35 ± 14.8**	5.03 ± 1.26

NS Significance levels: ** p<0.01; * p<0.5; NS - no statistical significance

[1] - angle between bends of the proximal loop of V3; [2] - angle between bends of the distal loop of V3; [3] - angle between the hV3 and oV3.

ciency in the patients with a brachycephalic skull shape.

The horizontal segment of V3 follows a more diametrical course in comparison with the mesocephalic and dolichocephalic groups, as shown by the smallest DD distance in describable group (Fig. 4). In addition, the zero-DD of hV3 mainly corresponded to the patients with a brachycephalic skull. This means that the distance between the lower surface of the occipital bone and the upper edge of the horizontal segment of V3 is the shortest up to the complete absence, posing a threat of iatrogenic injury.

It was observed that the angle between the bends of the distal loop of V3 (a2) was minimal in the brachycephalic group (Fig. 3), creating the initial conditions for the development of chronic pathology in this area.

Characteristics of V3 in the mesocephalic group

The patients with mesocephalic shape of skull have most favorable anatomical conditions for adequate vertebrobasilar blood circulation. The outer diameters of the vV3, hV3, and oV3 were the widest in comparison with other studied groups. The hV3 deviates downward at the middle distance, hereby allowing exposure of the craniovertebral junction by posterolateral access without threatening of V3 injury (Fig. 4). In terms of the angle estimation, the course of V3 in the mesocephalic group is less bumpy in comparison with the other groups. Absence of sharp bends along the hV3 reduces the risk of chronic diseases such as arteriosclerosis, thrombosis, and wall calcification.

Characteristics of V3 in the dolichocephalic group

The length of all segments of V3 is dominant in the dolichocephalic group of patients. The diameter of V3 has intermediate value in comparison with mesocephalic and brachycephalic groups. The distance between lower surface of occipital bone and upper edge of hV3 is maximal (Fig. 4), so V3 is subject to injury by posterior surgical approach the least in this group. But, excessive sagging of hV3 can lead to inflection of the distal loop during excessive head rotation and severs as important prerequisite for the Bow Hunter's syndrome, also known as rotational occlusion of the vertebral artery (William et al., 2012). The proximal loop of V3 has acute angle between its ascending and descending bends with minimal value in individuals with the dolichocephalic shape of skull (Fig. 3). This anatomical feature indicates the potential area of increasing resistance of blood flow that leads to the chronic damages of intimae with following occlusion.

Thereby, valuable information about the individual variability of the vertebral artery was hidden behind the banal shape of skull. The study showed that certain anatomical signs of the vertebral artery have close correlation with the variability of skull. The persons with the brachycephalic skull shape are at risk of the vertebrobasilar insufficiency with following ischemic stroke due to small width of the arteries and presence of the anatomic prerequisites for obstruction of the distal loop of VA. From a surgical point of view, the greatest attention should be also given to the patients of the brachycephalic group, because they have the horizontal part of the VA in close proximity to the base of the skull. As far as possible, when the kind of approach to the foramen magnum or craniovertebral junction is in choice, preference should be given to the anterolateral or the lateral approaches in this category of patients. The individuals with dolichocephalic skull shape have anatomical prerequisites that contribute to the development of the Bow Hunter's syndrome.

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