EXTREME TYPES OF VARIABILITY OF THE VERTEBRAL ARTERY (V3) SUBJECT TO SHAPE OF SKULL

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ABSTRACT

The problem of cerebral circulation is one of the topical problems of modern medicine, because cerebral blood supply disturbance occupies a leading place in the structure of morbidity and mortality of population (Ingall, 2004).

Under normal conditions, cerebral blood flow is independent from systemic blood pressure in a wide range. The adequacy of cerebral blood circulation is maintained due to special arrangement of vascular system of the brain that is an anatomical foundation of its self-regulation (Musienko, 2001). In the cranial cavity, the internal carotid artery by means of the anterior and middle cerebral arteries, and the vertebral artery through the posterior cerebral arteries are merged by connecting arteries into a vascular circle (Circle of Willis) that actively participates in restoring of cerebral blood flow in case of any violation (Hillen et al., 1991). Plasticity of the arterial bed of brain is a unique compensatory ability of human’s circulatory system; however, capacity of this complex depends to a large extent on anatomical variability of its constituents (Bekov et al., 2003). 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). At present, there are a lot of studies describing of shapes, sizes, abnormal origins of the main resources of brain’s blood supply (Gluncic et al., 1999; Hong et al., 2008; Shoja et al., 2006; Bruneau, 2006). However, most authors report the individual cases or analyze the variations of the vessels without taking into account the main parameter of human variability – individual type of constitution. We correlate our findings with structural features of the body to collate wide range of individual anatomical variability and make these data practically useful.

The posterior circulation of brain is of particular interest due to complex course and relations of the vertebral artery and frequent development of the chronic and acute disorders in it. Especial accumulation of bends, loops and angles is typical for the third segment (V3) of VA that runs over atypical C1-C2 vertebrae. Certain anatomical variations of the V3 can serve as prerequisites for development of stenosis, obstructions, as well as VA dissections and must be taking into account by specialists.
The objective of this study is to determine and characterize the range of anatomical variability of the V3 of vertebral artery and identify the correlation with individual shape of skull, by analysis of MRI and MRA. The anatomical grounds predisposed to development of V3 pathology are planned to be figured out.

**KEY WORDS**: Vertebral artery - V3 segment – Variability - Cranial index - Shape of skull

**EXTREME TYPES OF VARIABILITY OF THE VERTEBRAL ARTERY (V3) SUBJECT TO SHAPE OF SKULL**

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 research group 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 head. 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 (74.8±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.

Thereby, the anatomical variability of V3 has evident correlation with the shape of skull revealing wide facilities for primary diagnostic and prognosis of acute and chronic disorders of posterior circulation, as well as for choice of the right surgical approach to the craniocervical junction and base of skull.

**METHODS**

In total 32 patients (64 sides) without vascular pathology in the vertebrobasilar system were included in our study (15 men and 17 women; age range 35–79 years; mean age 58 years). The patients were subjected to routine MRA examination of head and neck under the direct leadership of staff of radiological department of the Hospital of University of Jordan during period from 1.10.2011 to 30.01.2012.

Magnetic resonance imaging of head was performed on a 3 Tesla magnetom-Verio (Siemens, Erlangen, Germany). Sagittal T1-weighted Gradient echo images with a repetition time (TR) of 280 milliseconds and echo time (TE) of 2.6 milliseconds with 1 acquisition and 1 saturation of the head showing the sagittal slices, comprising 20 consecutive images for each patient. Images were taken using 5 mm slice thickness and 23 cm field of view with a 0.10 distant factor. The axial slices of the head were
scanned parallel to the axis of lateral ventricle. To determine the individual constitution of head, the longitudinal (LD) and transverse (TD) diameters of skull were measured on the sagittal and transverse MR-images of a head as 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 on the ground of the standard anatomical descriptions (Banister M, 1995). According to value of CI, the research group was divided into three subgroups: 1) dolichocephalic - with narrow skull (CI < 74.9%), 2) mesocephalic - with proportional skull (CI in the range 75%-79.9%), and 3) and brachycephalic - with wide skull (CI > 80%). The anatomical variability of V3 examined according to the cranial type with detection of the extreme forms for each concerned dimension.

The MR angiography was performed with the patients’ heads in neutral position. After the contrast medium was injected into the forearm vein, the Flash 3D sequence scan from head to aortic arch were carried on automatically with slice thickness 1.4 mm and TR 3.2 ms, TE 1.2 ms and Fov 34 cm. On the obtained MRA images, course and tortuosity of the third segment of VA were considered with representatives of the radiological department. The third segment of VA was studied according to its conventional division into three sections: vV3, hV3, and oV3 (Fig. 2).

On the anteroposterior view angiograms, following quantitative anatomical measurements were made: the length and outer diameter of each segment of V3, the angles between bends of the proximal and distal loops (PL and DL, respectively), the angle between the hV3 and oV3 segments of VA, and the distance between the upper edge of the hV3 and imaginary transverse line, drawing through its origin and ending (Figure 2, a-b). On the lateral view angiograms, the distance between apices of the proximal and distal loops (PL-DL) was measured (Figure 2, c).

The statistical analysis was performed by analysis of variance. The means and standard deviations of resultant data were calculated for each studied group individually. Student paired t-tests and ANOVA tests were used to detect significant differences (P=<0.05) in concerned signs of V3 between the studied groups. Correlation tests between the CI and dimension of V3 were also performed and correlation coefficient (r) was calculated. All resultant data was analyzed by using an IBM compatible personal computer.

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RESULTS

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

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

<table>
<thead>
<tr>
<th></th>
<th>vV3</th>
<th>hV3</th>
<th>oV3</th>
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<tbody>
<tr>
<td></td>
<td>diameter</td>
<td>length</td>
<td>diameter</td>
</tr>
<tr>
<td>Dolichocephalic</td>
<td>3.81 ± 0.96</td>
<td>23.57 ± 0.56</td>
<td>3.92 ± 0.35</td>
</tr>
<tr>
<td>CI&lt;74.9%</td>
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<tr>
<td>Mesocephalic</td>
<td>4.18 ± 0.65</td>
<td>23.09 ± 0.44</td>
<td>4.1 ± 0.37</td>
</tr>
<tr>
<td>CI (75%-79.9%)</td>
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<tr>
<td>Brachycephalic</td>
<td>3.74 ± 0.37</td>
<td>22.85 ± 0.31</td>
<td>3.57 ± 0.61</td>
</tr>
<tr>
<td>CI&gt;80%</td>
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The proximal loop of V3 (PL) is the first lateral extension of V3 in the coronal plane. It is formed by length of vertical section of VA over the interval C1 - C2, which turns ectad giving ascending bend, and then deviates medially under acute angle providing descending bend of the loop (Fig. 2). The value of the angle 1 was in direct proportion with CI. It progressively increased from 67.5±0.75 degree in the dolichocephalic group to 77.1±0.44 degree in the brachycephalic group (Tab. 2). The mean value of the angle 1 (72.5±0.82 degree) belonged to the individuals with mesocephalic shape of skull.

The horizontal part of VA (hVA) starts just after leaving the transverse foramen of the atlas, then the artery turns backward and downward giving a loop and runs in transverse direction medially. The maximum value of the outer diameter of hVA was typical for mesocephalic group (4.1±0.35 mm), while the minimal width was found out in the brachycephalic one (3.57±0.61 mm). Similar tendency is observed in the length measure: the longest hVA belonged to the mesocephalic group (18.15±1.26 mm), and the least value of length had the segment in the brachycephalic one (16.48±1.4 mm).
Table 2. Evaluation of V3 tortuosity according to shape of skull (mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>a1, D</th>
<th>a2, D</th>
<th>a3, D</th>
<th>DD, mm</th>
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<tr>
<td>Dolichocephalic</td>
<td>67.5 ± 0.75</td>
<td>79.6 ± 4.73</td>
<td>116.4 ± 6.38</td>
<td>6.28 ± 0.35</td>
</tr>
<tr>
<td>CI&lt;74.9%</td>
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<tr>
<td>Mesocephalic</td>
<td>72.5 ± 0.82</td>
<td>74.85 ± 2.4</td>
<td>102.5 ± 8.48</td>
<td>5.89 ± 2.12</td>
</tr>
<tr>
<td>CI (75%-79.9%)</td>
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<tr>
<td>Brachycephalic</td>
<td>77.1 ± 0.44</td>
<td>68.8 ± 1.3</td>
<td>98.35 ± 14.8</td>
<td>5.03 ± 1.26</td>
</tr>
<tr>
<td>CI&gt;80%</td>
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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.

The projection of the hVA over the 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 (angle 2) varied in wide range: from 54 to 110 degree. Distribution of the angle 2 according to CI deserves our attention: the maximum value was found in the dolichocephalic group (79.6±4.7 degree), then it decreases in the mesocephalic group (74.85±2.4), reaching the minimal value in the brachycephalic one (68.8±1.3) (Tab. 2). The greater value of the distance from the imaginary horizontal line, drawing through origin and ending of hVA, to the most superior edge of the distal loop, marked as DD, was founded in the dolichocephalic group (6.28±0.35 mm), and the least value of it 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 V3 segment is the oblique part (oV3), which has an oblique direction running up and medially to enter foramen magnum and to pierce the Dura mater. The segment corresponds to the vessel’s extension over interval between the vertebral groove of posterior arch of atlas and inner edge of the foramen magnum. The maximum value of oV3 length found out in the group with dolichocephalic shape of skull (12.9±3.55 mm), while the minimal value was indicated in the brachycephalic group (11.83±1.16 mm). The diameter of oV3 was dominant in the mesocephalic group (3.65±0.86 mm) and nearly equal in the two other groups.

The transition from hV3 to oV3 is marked as a blunt angle between them (angle 3) that varied from 85 to 122 degree. Value of the angle varies inversely as CI (Tab. 2). The maximum degree of angle 3 was found in the dolichocephalic group (116.4±6.38 degree), the minimum value belonged to the
brachycephalic group (98.35±14.8 degree), and its average quantity (102.5±8.48 degree) occupied the middle part of variation range of CI.

DISCUSSIONS

The craniology is one of the most important branches of physical anthropology from time out of mind. It was initiated by Hippocrates, who pointed out the diversity of the head and location of skull sutures in his treatise "On the wounds of head". On the basis of measurements of large number of skulls, Leonardo da Vinci had found close correlation between different parts of the skull by way of geometrical construction. The science “Craniology” was constituted only in the XIX century, when the members of “Society of Anthropology of Paris”, which was founded by Paul Brock in 1859, began to systematize the accumulated knowledge about the variability of different structures of body, including skulls, in connection with variety of races and nationalities. The necessity to arrange the skull’s features from individual observation in types and classes was resolved by Retzius A. (1842), who first applied the principle of classification of the skulls by their sizes (Larsell, 1968). Retzius A. divided all nations over the world into “shot-headed” and “long -headed” groups, afterwards translated to Latin as “brachycephalic” and “dolichocephalic” respectively. Later, Martin (1928) complemented the classification of Retzuss by separating of intermediate type of skull – mesocephalic type. For the first time, Retzius A. used the cranial index to determine the shape of head, named him as “longitudinal-transverse index”. It was computed as ratio of the width of skull (transverse diameter) to its length (longitudinal diameter) as a percentage:

\[
\text{Longitudinal-transverse index} = \frac{\text{Transverse diameter}}{\text{Longitudinal diameter}} \times 100\%
\]

This formula has retained its original appearance and to this day, but the index is renamed to “cranial index”, which we can see in present studies of Salvador et al. (2006), Golalipour et al. (2005), Banister (1995). Meanwhile, the craniological methods are improved by adoption of computed tomography with 3-dimensional characterization of skull morphology employed by Supakit et al. (2010) and Jeffrey et al. (2008) in their studies.

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 of head- and skull-shape deformity in children. Clinical observations of Albajalan et al. (2010) revealed relation of the obstructive sleep apnoea in adults with the shape of skull-base and individual features of the airways. Studies of Shuvalova (2003) revealed correlation between location of the sigmoid sinus, the stylomastoid foramen and the shape of skull-base.
For the reason of findings, the author offered some special methods of drainage of the major mastoid air cell for the patients with brachycephalic and dolichocephalic shape of skull. Persistent correlation between the shape of the skull and the variability of the venous sinuses, as well as some cerebral veins and arteries, are proved by followers of Shevchenko’s school (Vovk YM et al., 2002; Fominych, 1997; Mashikhina et al., 2009; Stepanenko, 2010). Studies by Korneeva (2007) revealed, what close interrelation of the mesenchymal derivations during antenatal development leads to ascertainment of certain correspondences between the variability of skull and adjacent vascular structures.

Improvement of diagnostic methods and enhancement of techniques and facilities of surgical interventions on the organs of head and neck leads to a new approaches to the issues that once seemed quite famous. Knowledge of the extreme types of variability of the vascular structures of head and neck in relation with the shape of skull is the fundamental principle of choice of the right approach and method of surgical intervention on neck and head. Usability of the cranial index makes this method of variability estimation as a universal tool in the surgical practice that is available in any circumstances and for any segments of the population.

According to our examinations, the mesocephalic shape of skull predominates among the adult Asian population and it was found in 43.8% cases; next in quantity was brachycephalic type (40.6%), and small population group had the dolichocephalic shape of skull (15.6%).

CHARACTERISTICS OF V3 IN THE BRACHYCEPHALIC GROUP

In the literature we did not find any collations of variability of the V3 with respect to the shapes of skull. According to the results we now have at hand, for individuals with brachycephalic type of skull the minimal outer diameter of all segments of V3 as well as the minimal values of length were characterized. On the ground of analysis of V3 width, the posterior cerebral circulation is at the risk of insufficiency in the patients with brachycephalic shape of skull.

The horizontal segment of V3 has more diametrical course in comparison with mesocephalic and dolichocephalic groups that is denoted by the least distance DD in describable group (Fig. 4). In addition, zero-downward deviation of hV3 mainly belonged to the patients with brachycephalic shape of skull. It means that the distance between lower surface of occipital bone and upper edge of the horizontal segment of V3 is the shortest up to the complete absence, posing the threat of iatrogenic injury.

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

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 diameter of the vV3 was the widest in comparison
with other studied groups, as well as width of the hV3 and oV3 parts. The hV3 deviates downward at the middle distance, hereby allowing expose the craniovertebral junction by posterolateral access without threatening of V3 injury (Fig. 4). In terms of the angles estimation, the course of V3 in the mesocephalic group is more bumpless as against of the others groups, whereas the extreme values of α1, α2 and α3 have no correlation with mesocephalic type of skull. 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 DOLICOCEPHALIC GROUP

The length of all segments of V3 and accordingly the total length of the artery was dominant in the dolichocephalic group of patients. The diameter of V3 had intermediate value in comparison with mesocephalic and brachycephalic groups. The distance between lower surface of occipital bone and upper edge of hV3 had maximum value in this group (Fig. 4), so hV3 segment the least subject to injury when in use the posterior surgical approach. But, excessive sagging of the segment can lead to inflection of distal loop during excessive head rotation and severs as important prerequisite for onset of the bow hunter’s syndrome, also known as rotational occlusion of the vertebral artery described in earlier reports (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.

CONCLUSIONS

Thereby, valuable information about the individual variability of the vertebral artery was hidden behind the banal shape of skull. The study showed that the certain anatomical signs of the vertebral artery have close correlation with the variability of skull. The persons with the brachycephalic form of skull 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 given also to the patients of the brachycephalic group, because they have the horizontal part of the VA in close proximity to the base 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 shape of skull have anatomical prerequisite that contribute to the development of the bow hunter’s syndrome.

REFERENCES


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

* the points of cranial landmarks are taken from the Moore-Jansen P.M., et al. (1994).

Figure 2. MR angiography of head and neck: anteroposterior view.

v V3 – 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.
Figure 3. MR angiography of head and neck. The third segment of the left VA is marked.

The extreme 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 characterized 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 ((d) Sheet 32, male, 52 years old, CI=73.8%), and the maximal value of degree – in the brachycephalic patients (Sheet 20. Male, 67 years old, CI=82.7%).
Extreme 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%).