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Cranial Base Angulation in Metopic and Non-metopic Cranial Series

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Metopic skulls possess specific distinctive characteristics in the configuration of the neurocranium. Due to the close developmental interrelation between neuro- and basicranium we assumed that the angulation of the cranial base could differ as well. This study aimed to compare the cranial base angle (CBA) in metopic and non-metopic series. The CBA was investigated in a sample of 246 skulls of contemporary adult males – 93 metopic and 156 non-metopic. Lateral projections were captured using digital radiography, performed on an industrial CT system. CBA was constructed between definite craniometric points and measured digitally. CBA was assessed as basilar kyphosis, normal and platybasia. Distribution by categories did not show significant differences between the series. Thus, despite the close interrelation between the neuro- and basicranium, the preservation of the MS connected with a specific construction of the neurocranium was not found to be related to an alteration of the basicranium expressed by CBA.

Key words: metopism, cranial base angle (CBA), platybasia, basilar kyphosis, digital radiography

Introduction

The metopic suture (MS) lies between the halves of the fetal frontal bone and is the first suture to close physiologically during the first or second year, but its fusion can last until the 8th year as well [11]. Sometimes, however, the halves of the frontal bone failed to fuse and the MS persists in adults, a condition known as *metopism* [4]. It has been established that metopic skulls usually possess a greater inter-frontal and inter-orbital breadth [2, 3], as well as greater frontal curvature [13] compared to the the non-metopic ones. It was also ascertained that the cranial capacity in metopic skulls was slightly smaller [2, 3], as the length and height were reduced, but the breadth remains stationary. Thus, the metopic skulls attain a given capacity by a greater expansion in the forward and a smaller development in the hinder part of the vault. Therefore, the *metopism* could not be explained merely by a supposed expansion of the frontal regions of the hemispheres, but rather as an adjustment of the brain-case as a whole to its contents [3].

The brain is a major factor controlling cranial size, but is less involved as controlling force producing cranial form. Growth of the bones of the skull base has been shown to be an important factor in determining the shape of the skull [10]. According to Lieberman et al. [6], the role of the cranial base in influencing overall cranial shape is essential. It has also been determined that basicranial development is affected by changes in vault shape and vice versa [1]. The cranial base angle (CBA) expresses the orientation of the anterior versus posterior parts of the cranial base in the midsagittal plane and could vary from extreme flexion (kyphosis) to abnormal flattening (platybasia). According to the spatial packing model, since the brain grows on top of the cranial base, a more flexed (or less extended) cranial base helps to accommodate a larger volume of brain without having to change the width and length of the cranial base [8].

Because of the close interrelation between the neuro- and basicranium, and bearing in mind the general distinctions in the configuration of neurocranium in the metopic and non-metopic skulls, we assumed that the angulation of the cranial base could differ as well. However, in the relevant literature we could not find information if the preservation of the MS interacted with the cranial base angulation. Thus, the goal of this study was to compare the CBA in metopic and non-metopic cranial series.

Materials and Methods

Materials

The CBA was investigated in a sample of 246 dry skulls of contemporary adult males from Bulgaria. The skulls belonged to soldiers who died in the wars at the beginning of the 20th century. Their bone remains were preserved in the Military Mausoleum with Ossuary at the National Museum of Military History of Bulgaria. The individuals were fit for service without severe disorders and malformations. The selected sample was distributed into two series: a metopic series consisting of 93 skulls with an entirely preserved MS and a control one including 153 skulls without traces of a MS.

Methods

A digital radiography was performed on an industrial computed tomography system Nikon XT H 225, developed by Nikon Metrology. The software Inspect-X was used to adjust the parameters and manage the capture of the projections. The settings ranged dependent on the density of the specimens: voltage 85-126 kV, 80-140 µA tube current and exposure time of 500-708 ms.

All of the skulls were oriented in lateral view. The projections were captured and saved in TIFF format. To avoid the error in placement of the points on the radiographs, *nasion* and *basion* were marked in advance on the skulls with radio-dense copper markers glued at the points. Due to its internal location, *sella* was subsequently determined and marked directly on the radiographs (**Fig. 1**).

Cranial points (see **Fig. 1**):

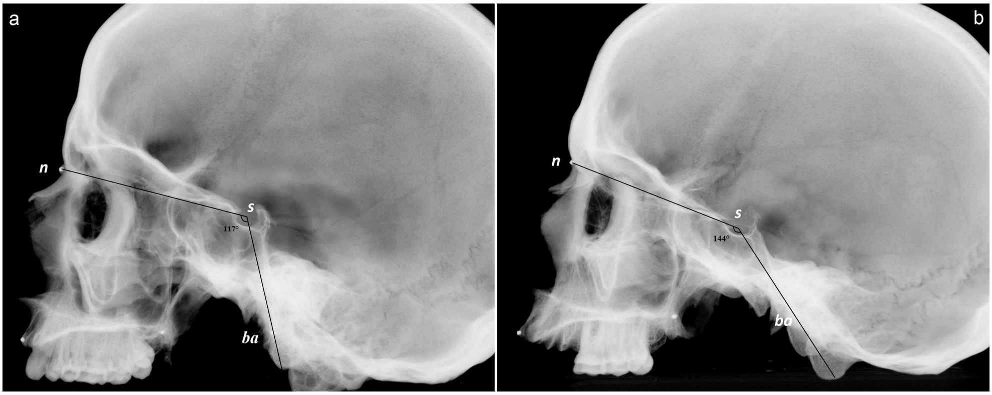

Fig. 1. Cranial base angle: a) basilar kyphosis; b) platybasia

basion (***ba***): the midsagittal point on anterior margin of foramen magnum;

nasion (***n***): the point of intersection between the frontonasal suture and the midsagittal plane;

sella (***s***)**:** the center of sella turcica, independent of contours of clinoid processes.

The CBA was constructed between the line joining nasion (*n*) with the centre of the pituitary fossa (*s*) and the line joining anterior border of the foramen magnum (*ba*) with the centre of the pituitary fossa.

The borderline values of CBA delimiting a normal from flexed and extended base angle were used after Koenigsberg et al. [5]:

1. Basilar kyphosis, an extensive flexion of the skull base, CBA < 125°
2. Normal angulation, CBA between 125-143°
3. Platybasia, an abnormal flattening of the skull base, CBA > 143°

After the CBA was constructed, the angle was digitally measured on the radiographs using ImageJ, a public domain, Java-based image processing program.

Intra- and interobserver reliability was assessed using intraclass correlation coefficient (ICC). The angle was measured twice by two observers as the replicated measurements were performed on a sample of randomly selected 30 projections. The significance of the differences in the distribution of the CBA categories was assessed using chi-square test (χ^2). The comparison between CBA in both series was performed using Independent Samples t-test.

Results

Almost perfect intra- and interobserver reliability (ICC > 0.994) was found for the CBA measurements. Basilar kyphosis was observed with almost equal frequency in both series: 7.53% (7 out of 93 skulls) in the MS series and 7.19% (11 out of 153 skulls) in the control one. A single case of platybasia (1.08%) was observed among the metopic skulls (Fig. 1b). The distribution by categories did not show significant differences between both series ($\chi^2 = 1.69$, k = 2). The CBA did not differ between the series ($p > 0.05$), even the mean values were equal (MS: min 117, max 144, mean 131.67 ± 5.43; Control: min 119, max 144, mean 131.68 ± 5.00).

Discussion

According to our preliminary unpublished data, the configuration of the neurocranium in the metopic and non-metopic series differed significantly, especially in the frontal region. The frontal bone in the metopic skulls tended to be wider, more curved with *bregma* located lower. The sutures allow the skull to change shape and grow during development. They function as signaling centers for bone growth and remain patent postnatally to accommodate cranium expansion [12]. In this point of view, the greater breadth of the frontal bone in the metopic skulls [2, 3] was explicable with the MS preservation which allows growing of the frontal bone in width.

The basicranium differs from the neurocranium and splanchnocranium as it grows mostly from endochondral ossification processes in which the chondrocranium develop *in utero* and is gradually replaced by bone postnatally. The basicranium is also the first region of the skull to reach adult size, and is the structural foundation of many aspects of the craniofacial architecture [6]. The basicranium comprises the central axis of the skull with the brain and neurocranium growing above, and the face growing below, and it provides all the necessary foramina through which the brain connects to the face and the body [8].

Angulation (flexion or extension) of the cranial base affects the relative positions of the three endocranial fossae, and thereby influences a wide range of spatial relationships among the cranial base, brain, face, and pharynx [7]. In phylogenetic aspect, in most mammals the CBA is relatively flat or obtuse, whereas in humans, it is highly flexed. In the non-human primates, the CBA varies considerably, with the ape configuration approximately intermediate between humans and other mammals in terms of the degree of basicranial flexion [8]. Ontogenetically, in gestation the basicranium initially flexes rapidly during the period of rapid hindbrain growth in the first trimester, remains fairly stable during the second trimester, and then extends during the third trimester in conjunction with facial extension, even while the brain is rapidly increasing in size relative to the rest of the cranium. The human cranial base flexes rapidly after birth, almost entirely prior to 2 years of age, before the brain has ceased to expand appreciably [7]. In the same period, the MS usually obliterates. Obviously, despite the interrelation between the developing cranial parts, failed closure of the MS, which give rise to specific configuration on the neurocranium, was not related to a different angulation of the basicranium expressed by CBA. Additional evidence for some degree of independence between the brain and cranial base during development was provided by microcephaly and hydrocephaly, in which cranial base angles tended to be close to the individuals with normal encephalization [7].

It has been established that artificial cranial deformation of an anteroposterior and a circumferential types causes slight but significant increases in the cranial base angulation with respect to the undeformed sample, as the degree of platybasia was greatest in the circumferential type [1]. Platybasia can occur in a variety of congenital disorders like craniofacial anomalies, osteogenesis imperfecta, craniocleidodysostosis and Arnold-Chiari malformation or in acquired diseases like Paget disease, osteomalacia, rickets and trauma [5]. Isolated and mild platybasia is asymptomatic and insignificantly affects the posterior fossa volume. Moderate to severe platybasia is often associated with basilar invagination, a condition in which the caudal part of the occipital bone is displaced inward and upward and the vertebral column and the skull base abnormally approximate each other [9]. Basilar invagination could be primary or congenital and secondary referred to as basilar impression, which is associated with a softening of the skull base as the result of an acquired disease [5]. In our series, a mild platybasia was found in a single case from the MS series and most probably was asymptomatic.

Conclusion

Notwithstanding the considerable distinctions in the configuration of the neurocranium in metopic and non-metopic skulls, there were no significant differences in the basicranial angulation. Thus, despite the close developmental interrelation between the neuro- and basicranium, the preservation of the MS connected with a specific construction of the neurocranium was not found to be related to an alteration in the basicranium expressed by CBA.

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