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Human Skull Base Asymmetry Analysis

Análisis de Asimetría de la Base de Cráneo Humano

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SUMMARY: Since the asymmetry is generally accepted entity which can be detected on human skulls, the goal of this study was to evaluate the presence and degree of skull base asymmetry and analyze it in relation to sex. The study included 60 skulls. Gender identification was estimated according to the external occipital protuberance, mastoid process, supraorbital margin and glabella. The asymmetry was assessed by analyzing the distance from the bilateral foramina (foramen ovale, foramen spinosum, carotid canal, foramen stylomastoideum) to the pharyngeal tubercle. Digital data were processed in the ImageJ software. The skull base asymmetry was found in all samples. Significant difference between the sides was found for the foramen ovale (p=.01). There was no significant difference in the skull base asymmetry with respect to sex. The highest index of asymmetry (7.38 %) was found in carotid canal and the lowest (5.22 %) was detected in relation to the foramen stylomastoideum. By comparing the index of asymmetry between the genders significant difference occurs for the carotid canal (p=.02). Skull base asymmetry was confirmed in our study. Oval foramen showed a significant degree of asymmetry. Knowledge of the variability of the skull base is the basis for an clinical and radiological evaluation of its changes.

KEY WORDS: Humans; Skull base; Craniofacial asymmetry

INTRODUCTION

The first discoveries of craniofacial asymmetry are related to anthropological research carried out in the early 20th Century (Leibrich, 1908; Woo, 1931). The most detailed study was conducted in 1931 and included a morphological analysis of 800 Egyptian skulls. Further research has shown that asymmetry is present in all examined skulls, more notable on the right side compared with the left side (Woo).

Craniofacial asymmetry is defined as an unequal distance of bilateral structures in relation to the central line of the skull or from a corresponding central point (Sutton, 1968). There are different methodologies of craniofacial asymmetry analysis - from direct morphometric measurements to the use of various diagnostic procedures as laser scanners and 3D computed tomography (Choi, 2015). As a reference point for assessing skull base asymmetry, cephalometric studies most commonly used analysis of the sphenoid bone. The development of the sphenoid bone ends in the early period of life and so it remains relatively unchanged during the development of the entire skull (Nakamura *et al*., 1972). The anatomy of the skull base is characterized by the foramina through which significant neurovascular structures pass. Foramen ovale (FO) and foramen spinosum (FS) are located in the middle cranial fossa, on the medial part of the infratemporal surface of the greater wings of the sphenoid bone. The mandibular nerve, accessory meningeal artery, emissary vein, and lesser petrosal nerve pass through foramen ovale (FO) (Standring, 2005). The middle meningeal artery, middle meningeal vein and the meningeal branch of the mandibular nerve pass through foramen spinosum (FS). The carotid canal (CC) and foramen stylomastoideum (FSM) are integral parts of the petrous part of the temporal bone and are localized on its inferior aspect. Through the carotid canal the internal carotid artery passes, while the facial nerve exits the skull through the foramen stylomastoideum (Standring). The aetiology of craniofacial asymmetry is complex and insufficiently understood. Proposed theories vary and range from intrauterine effects on foetal development to pathological forms (bone deficiency disorder, tumors, trauma, infections). Therefore, as in most development anomalies, genetic factors, environmental factors or their combination may be the cause of the skull base asymmetry. The skull continues to remodel as long as the human growth, development and maturation takes place (Enlow & Hans, 1996). However, many consider that skull base asymmetry occurs after the activation of the muscles

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of mastication (Ras *et al*., 1994; Poikela *et al*., 1997). In a contrary viewpoint, Rossi *et al*. (2003) showed that skull base asymmetry is present at the earliest age, in foetuses, infants and children. In addition, it has been previously determined that the right hemisphere of the brain is more developed compared with the left, and so the skull is mildly rotated in an anti clockwise direction (Woo; Chebib & Chamma, 1981). Brain asymmetry is cited as a potential aetiological factor which can cause morphological changes of the skull. There is no clear boundary between physiological and pathological asymmetry (Shah & Joshi, 1978; Rossi *et al*.) which raises the question regarding the level of asymmetry considered to be "physiological"? Some researchers consider a degree of asymmetry is greater than zero as significant (Lundström, 1961; Shah & Joshi), or if the difference of measured values between the right and the left side is greater than 0.5 mm. As any asymmetry increases there is greater probability that it is approaches a pathological situation. This has clinical significance, especially for maxillofacial and neurosurgeons, when knowledge of morphology and asymmetry of neurocranial structures is of great importance for the successful outcome of microsurgical procedures. The goal of the present research was to determine the presence and level of skull base asymmetry and analyze it in relation to sex.

MATERIAL AND METHOD

The study was conducted at the Department of Anatomy, Faculty of Medicine, University of Novi Sad and included 60 cadaver skulls belonging to the collection of the Department of Anatomy. Only those skulls that had preserved bone structures and openings on their bases were selected. The sex of the skulls was determined according to the size and shape of the external occipital protuberance, mastoid process, supraorbital margin, and glabella (Buikstra & Ubelaker, 1994). All measurements were made by the same examiner. The skulls were positioned in a horizontal position with their bases facing up and the external cranial base was photographed (Digital Olympus sp-560uz with 18x optical zoom). As reference points, four bilateral openings were used (foramen ovale - FO, foramen spinosum - FS, carotid canal – CC, foramen stylomastoideum - FSM) and they were analyzed in relation to the central point identified by the pharyngeal tubercle (PT) (Fig. 1).

Measurements were performed three times and the mean values, expressed in centimeters, were taken as a reference. Digital data were processed in ImageJ software. Since there was no data of the age and anthropometric characteristics of the skeleton, an index of asymmetry (IA)

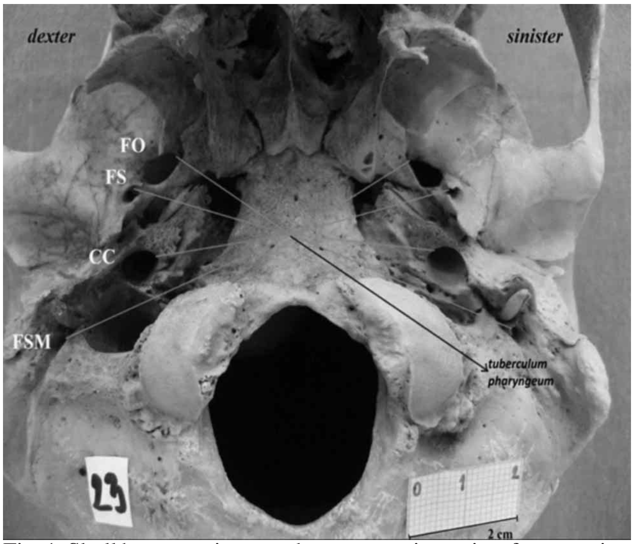

Fig. 1. Skull base openings used as a measuring points for assessing asymmetry. FO – foramen ovale; FS – foramen spinosum; CC – canalis caroticus; FSM – foramen stylomastoideum.

was determined for each skull according to the following formula15:

$$\frac{\text{right side} - \text{left side}}{\text{right side}}$$

Index of asymmetry (IA) (%) Formula x 100

Statistical analysis results are presented as parameters of descriptive statistics (mean value (), standard deviation (SD), minimum and maximum values (Min-Max)). The student's t test was used to determine the difference between the groups. Statistically significant difference was considered if the $p<.05$.

RESULTS

The initial sample consisted of 60 cadaver skulls, 3 of which were excluded due to the presence of damage to their bases leaving a final sample of 26 male skulls and 31 female skulls. A level of asymmetry was detected on the bases of all examined skulls. The highest mean IA was 7.38 % (CC), while the smallest value was 5.22 % (SMF). Table I shows the descriptive statistics and statistical differences in the distance of the observed openings (FO, FS, CC, SMF) compared with the central point between the left and right sides of all examined skull bases. A statistically significant difference was observed in the analysis of foramen ovale ($p=.01$) while the other openings did not show statistical significance of the left, right distances from the pharyngeal tubercle.

Table. I. Parameters of descriptive statistics and differences between right and left side of all examined skulls

n=57	Right side		Left side		*p*
	X̄±SD	Min-M_x	X̄±SD	Min-M_x	
FO (cm)	2.48±0.05	1.98-3.23	2.56±0.05	2.07-3.31	0.01*
FS (cm)	2.85±0.05	2.34-3.48	2.91±0.05	2.24-3.58	0.13
CC (cm)	2.45±0.04	1.81-2.91	2.47±0.04	1.95-2.30	0.68
FSM (cm)	4.19±0.05	3.33-4.80	4.28±0.06	3.77-4.90	0.09

FO – foramen ovale; FS – foramen spinosum; CC – canalis caroticus; FSM – foramen stylomastoideum *p<.05

After dividing the examined sample according to sex, a statistically significant difference was not found in the male or female skulls between right and left side in any of the observed skull based openings (Table II).

By comparing the distance from the examined openings to the PT on both sides of the skulls, between males and females, statistically significant difference also was not evident (Table III).

Table IV shows the index of asymmetry of examined skull bases in relation to sex. The highest measured mean IA in the male skulls group was found in CC (9.71 %), while the smallest (5.27 %) was observed in relation to SMF. Within the female skull group, the highest average IA was 5.17 % (SMF) and the smallest 4.34 % (FS). By analyzing the index of asymmetry of the skull bases of the entire sample, the variation in the distance of the carotid canal from the central point is statistically significant (p=.02).

Table II. The differences between the right and left side of the skull base in relation to the sex.

	Male (n=26)			Female (n=31)		
	Right side X̄±SD	Left side X̄±SD	*p*	Right side X̄±SD	Left side X̄±SD	*p*
FO (cm)	2.49±0.22	2.61±0.05	0.12	2.48±0.09	2.50±0.09	0.86
FS (cm)	2.88±0.06	3±0.052	0.13	2.82±0.07	2.82±0.08	0.98
CC (cm)	2.45±0.05	2.51±0.05	0.38	2.45±0.08	2.42±0.07	0.75
FSM (cm)	4.22±0.05	4.36±0.06	0.10	4.16±0.10	4.19±0.09	0.84

FO – foramen ovale; FS – foramen spinosum; CC – canalis caroticus; FSM – foramen stylomastoideum *p<.05

Table III. Differences between the male and female skulls in relation to the side of the skulls.

	Right side			Left side		
	Male X̄±SD	Female X̄±SD	*p*	Male X̄±SD	Female X̄±SD	*p*
FO (cm)	2.49±0.22	2.48±0.09	0.94	2.61±0.05	2.50±0.09	0.30
FS (cm)	2.88±0.06	2.82±0.07	0.54	3±0.052	2.82±0.08	0.08
CC (cm)	2.45±0.05	2.45±0.08	0.97	2.51±0.05	2.42±0.07	0.28
FSM (cm)	4.22±0.05	4.16±0.10	0.64	4.36±0.06	4.19±0.090	0.14

FO – foramen ovale; FS – foramen spinosum; CC – canalis caroticus; FSM – foramen stylomastoideum *p< .05

Table IV. Index of asymmetry of all examined skulls (n=57) and in relation to the sex

	IA (%)					
	n=57	**Male**		**Female**		***p***
	X̄±SD	**X̄±SD**	**Min-M_x**	**X̄±SD**	**Min-M_x**	
FO (%)	5.69±0.88	6.71±1.52	0.11-17.67	4.51±0.65	0.99-10.29	0.20
FS (%)	6.06±1.04	7.56±1.74	0.52-21.94	4.34±0.84	0.29-10.53	0.11
CC (%)	7.38±1.12	9.71±1.88	0.70-28.67	4.71±0.51	1.75-7.85	**0.02***
FSM (%)	5.22±0.92	5.27±1.23	0.05-18.62	5.17±1.43	0.37-20.51	0.96

FO – foramen ovale; FS – foramen spinosum; CC – canalis caroticus; FSM – foramen stylomastoideum. *p< .05

DISCUSSION

Symmetry is defined as equality or correspondence in the form of parts that are arranged around the center or axis, on two extremities, or on the opposite sides of the body. In relation to the human skull, the universally accepted and established hypothesis is that it is completely asymmetrical (Shah & Joshi). The "right-left" differences of bilateral structures of the human organism can be the cause of functional or aesthetic problems. From a clinical perspective, the knowledge of the variability in the symmetry of the human body is the basis for precision in diagnostic and therapeutic procedures.

The most common method for estimation skull base asymmetry is the calculation of the distance of bilateral structures to a defined central point or to a central line. The results of the present study showed that a level of skull base asymmetry was present in the whole entire tested sample.

The present results are in agreement with the findings of other anthropological studies (Woo; Rossi *et al*.; Russo & Smith, 2011). In addition, there is much data about asymmetry of the facial skeleton, which was first dealt with by prosthetists, who showed that the left half of the skeleton was larger in comparison to the right side (Lundström). Facial bone asymmetry between the left and right sides was most often evaluated in relation to the upper jaw and zygomatic bone.

In analyzing the difference in the distance between the skull base openings and central point to the left and right, the present study showed a statistically significant difference with respect to FO (p=.01). Similar results were obtained by previous authors who evaluated the distance of FO in relation to a central line and distance was less on the left half of the skull base (Teul *et al*., 2002). Considering that FO has a close topographic relationship with significant neurovascular structures, the study of morphology and morphometry of FO is of particular interest to recent researchers (Patel & Mehta, 2014). In this regard, the results showed that FO varies significantly in shape (oval, round, almond like shape, presence of spines, lumps and bone plates) and its diameter ranged from 2 to 7 mm (Patel & Mehta). In addition, FO may be unilaterally missing or divided into two or three sections (Reymond *et al*., 2005). The clinical significance of the evaluation of the morphological characteristics of the FO is reflected by a percutaneous biopsy of a cavernous sinus tumor is performed through this foramen. Also, one of the pathways of spread of a nasopharyngeal carcinoma is through this foramen (Chong *et al*., 1996). Additionally, the mandibular nerve passes through FO at which site it is the target site for percutaneous trigeminal rhizotomy in the management of trigeminal neuralgia (Nanjappa *et al*., 2013). Anthropological researches have investigated differences in the symmetry of the skull base in relation to sex, but statistically significant differences were not found (Ras *et al*.). Accordingly, although the distance of the skull base openings from the PT was greater in the male group, there were no statistically significant differences found in the current study. The present research compared IA with respect to sex and the results show that a statistically significant difference exists only in relation to CC (p=.02). At the same time, this canal had the highest average IA of the total sample (7.38 %). Russo & Smith indicated that the highest IA (6.6 %) was also obtained in relation to CC, while the lowest was found in relation to the SMF (2.6 %). In the results of the current investigation, the smallest IA also belonged to SMF (5.22 %). In this regard, it is important to note that the internal carotid artery passes through the CC, thereby significantly changing its route (Standring).

Observed from the embryonic aspect, the first signs of skull-based openings appear in the early period of skull development, around the 12th week of gestation. However, further aetiology of the origin of the skull base asymmetry has not yet been fully clarified. Variations in morphology of the skull base anatomical structures are cited as a consequence of the influence of genetic factors or may occur somewhat later, as a result of the development of the nerve, vascular and muscular structures. The proposed theory about the influence of the masticatory muscles on the facial bones and skull is increasingly disproved by the results of recent research (Rossi *et al*.; Moreira *et al*., 2008). It was thought that the activation of the masticatory muscles lead to the force transmission through the alveolar arches on facial and skull bones. However, Moreira *et al*. has shown that asymmetry of the hard palate is present in early the foetal period and continues during the later growth and development of the individual. In addition, cephalometric radiographic studies highlight the effect of the right hemisphere relative to the left on the development of craniofacial asymmetry. Ultrasonographic visualisation in the early gestation period has showed that brain asymmetry in the foetus was already present (Hering-Hanit *et al*., 2001). Petalia is a type of brain asymmetry and implies the protrusion of one hemisphere of the brain compared with the other. Namely, the right frontal and left occipital petalia is described in humans (Phillips & Sherwood, 2007). It is assumed that cerebral petalia is caused by the functions of the corresponding brain region in the hemispheres. The second component of the brain asymmetry is the "volume torque" and is explained as a difference in distribution of the brain tissue when the right frontal lobe is most commonly wider than the left, and the left occipital lobe is wider than the right. Le May & Kido (1978) pointed out that even the smallest asymmetry of the brain is enough to cause the structural changes of the skull, and the theory of the brain asymmetry may require explanation for the origin of the skull base asymmetry.

Skull base asymmetry was confirmed in our study. Oval foramen showed a significant degree of asymmetry. After more than a century of investigations, the concept of asymmetry in medicine continues to attract the attention of researchers because the knowledge of the variation of morphological and morphometric characteristics of the skull is the base for successful implementation of diagnostic and therapeutic procedures.

RADOSEVIC, D.; MARIC, D. & IVANOVIC, D. Análisis de asimetría de la base de cráneo humano. *Int. J. Morphol., 38(6)*:1566-1570, 2020.

RESUMEN: Debido a que la asimetría detectada en cráneos humanos es aceptada generalmente, el objetivo de este estudio fue evaluar la presencia y el grado de asimetría de la base del cráneo y analizarla en relación con el sexo. En este estudio fueron incluidos 60 cráneos. El sexo fue determinado de acuerdo con la protuberancia occipital externa, el proceso mastoideo, el margen supraorbital y la glabela. La asimetría se evaluó analizando la distancia desde los forámenes bilaterales (foramen oval, foramen espinoso, canal carotídeo, foramen estilomastoideo) hasta el tubérculo faríngeo. Los datos digitales fueron procesados en software ImageJ. La asimetría de la base de cráneo se observó en todas las muestras. Se encontró una diferencia significativa entre los lados para el foramen oval (p = ,01). No hubo diferencias significativas en la asimetría de la base de cráneo con respecto al sexo. El índice más alto de asimetría (7,38 %) se encontró en el canal carotídeo y el más bajo (5,22 %) se detectó en relación con el foramen estilomastoideo. Al comparar el índice de asimetría entre los sexos, se produce una diferencia significativa en el canal carotídeo (p = 0,02). La asimetría de la base de cráneo se confirmó en nuestro estudio. El foramen oval mostró un grado significativo de asimetría. El conocimiento de la variabilidad de la base del cráneo es importante durante la evaluación clínica y radiológica.

PALABRAS CLAVE: Humanos; Base de cráneo; Asimetría craneofacial.

REFERENCES

Buikstra, J. E. & Ubelaker, D. H. (Eds.). *Standards for data collection from human skeletal remains*. Fayetteville, Arkansas Archeological Survey Research Series No. 44, 1994. pp.206.

Chebib, F. S. & Chamma, A. M. Indices of craniofacial asymmetry. *Angle Orthod., 51(3)*:214-26, 1981.

Choi, K. Y. Analysis of facial asymmetry. *Arch. Craniofac. Surg., 16(1)*:1-10, 2015.

Chong, V. F.; Fan, Y. F. & Khoo, J. B. Nasopharyngeal carcinoma with intracranial spread: CT nad MR characteristics. *J. Comput. Assist. Tomogr., 20(4)*:563-9, 1996.

Enlow, D. H. & Hans, M. G. *Essentials of facial growth*. Philadelphia, W. B. Saunders, 1996.

Hering-Hanit, R.; Achiron, R.; Lipitz, S. & Achiron, A. Asymmetry of fetal cerebral hemispheres: in utero ultrasound study. *Arch. Dis. Child. Fetal Neonatal Ed., 85(3)*:F194-6, 2001.

Le May, M. & Kido, D. K. Asymmetries of the cerebral hemispheres on computed tomograms. *J. Comput. Assist. Tomogr., 2(4)*:471-6, 1978.

Leibrich, R. *Die asymmetric des Gesichtes and pre Entsichung*. Munich, Bergman, 1908. pp.25.

Lundström, A. Some asymmetries of the dental arches, jaws, and skull, and their etiological significance. *Am. J. Orthod., 47(2)*:81-106, 1961.

Moreira, R. S.; Sgrott, E. A.; Stuker, H.; Alonso, L. G. & Smith, R. L. Palatal asymmetry during development: An anatomical study. *Clin. Anat., 21(5)*:398-404, 2008.

Nakamura, S.; Savara, B. S. & Thomas, D. R. Norms of size and annual increments of the sphenoid bone from four to sixteen years. *Angle Orthod., 42(1)*:35-43, 1972.

Nanjappa, M.; Kumaraswamy, S. V.; Keerthi, R.; Ashwin, D. P.; Gopinath, A. L.; Reyazulla, M. A. & Hemavathi, K. B. Percutaneous radiofrequency rhizotomy in treatment of trigeminal neuralgia: a prospective study. *J. Maxillofac. Oral Surg., 12(1)*:35-41, 2013.

Patel, R. & Mehta, C. D. Morphometry of foramen ovale at base of skull in Gujarat. *IOSR-JDMS 13(6)*:26-30, 2014.

Phillips, K. A. & Sherwood, C. C. Cerebral petalias and their relationship to handedness in capuchin monkeys (*Cebus apella*). N*europsychologia, 45(10)*:2398-401, 2007.

Poikela, A.; Kantomaa, T. & Pirttiniemi, P. Craniofacial growth after a period of unilateral masticatory function in young rabbits. *Eur. J. Oral Sci., 105(4)*:331-7, 1997.

Ras, F.; Habets, L. L.; van Ginkel, F. C. & Prahl-Andersen, B. Three-dimensional evaluation of facial asymmetry in cleft lip and palate. *Cleft Palate Craniofac. J., 31(2)*:116-21, 1994.

Reymond, J.; Charuta, A. & Wysocki, J. The morphology and morphometry of the foramina of the greater wing of the human sphenoid bone. *Folia Morphol. (Warsz.)., 64(3)*:188-93, 2005.

Rossi, M.; Ribeiro, E. & Smith, R. Craniofacial asymmetry in development: An anatomical study. *Angle Orthod., 73(4)*:381-5, 2003.

Russo, P. P. & Smith, R. L. Asymmetry of human skull base during growth. *Int. J. Morphol., 29(3)*:1028-32, 2011.

Shah, S. M. & Joshi, M. R. An assessment of asymmetry in the normal craniofacial complex. *Angle Orthod., 48(2)*:141-8, 1978.

Standring, S. *Gray's Anatomy. The Anatomical Basis of Clinical Practice*. 39th ed. Philadelphia, Elsevier Churchill Livingstone, 2005.

Sutton, P. R. Lateral facial asymmetry-methods of assessment. *Angle Orthod., 38(1)*:82-92, 1968.

Teul, I.; Czerwin´ski, F.; Gawlikowska, A.; Konstanty-Kurkiewicz, V. & Slawin´ski, G. Asymmetry of the ovale and spinous foramina in mediaeval and contemporary skulls in radiological examinations. *Folia Morphol. (Warsz.)., 61(3)*:147-52, 2002.

Woo, T. L. On the asymmetry of the human skull. *Biometrika, 22(3-4)*:324-41, 1931.

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