Received: 16.04.2013 / **Accepted:** 28.05.2013
DOI: 10.5137/1019-5149.JTN.8391-13.1

Increased Osseous Thickening of the Inner Surface of the Frontal Bone

Frontal Kemik İç Yüzünde Artmış Kemiksi Kalınlaşma

Figen GOVSA[1], Mehmet Asim OZER[1], Yelda PINAR[1], Murat SEZAK[2]

[1]*Ege University, School of Medicine, Department of Anatomy, Izmir, Turkey*
[2]*Ege University, School of Medicine, Department of Pathology, Izmir, Turkey*

Corresponding Author: Figen GOVSA / E-mail: figen.govsa@ege.edu.tr, fgovsa@yahoo.com

ABSTRACT

AIM: Increased thickening of the internal surface of the frontal bone (ISFB) was investigated, regarding possible pressure application to the brain tissue and the changes in bone marrow structure.

MATERIAL and METHODS: Morphological analysis of the ISFB was carried out in a total of 300 adult skulls.

RESULTS: Type A, defined as normal appearance, has been detected in 243 cranium. In 57 cranium (19%), increased osseous thickening cases with different appearance were observed. The most frequent examples of osseous thickening were present in nodular types (Types B, C) and diffuse types (Types D, E), (29.8%). In fact, an irregular osseous thickening, which is in the form of plaques, was situated on both sides of the origin of sagittal sulcus. Types B and C were seen as small isolated nodules on the ISFB. In the histological analysis of ISFB, it is determined that the endocranium, normally present in a compact bone structure, changed its lamellar and had a nonwoven immature bone structure, in the areas with the characteristic of increased osseous thickening. The thickening of the diploe gap and increasing lamellar bone tissue in the endocranium revealed an increase in vascularization.

CONCLUSION: The nodular and widespread form of increased osseous thickening could apply pressure on to dura mater and the brain tissue.

KEYWORDS: Frontal bone, Osseous thickening, Calvaria, Skull, Endocranium

ÖZ

AMAÇ: Frontal kemiğin iç yüzeyinin (ISFB) artmış kalınlığı beyin dokusuna olası basınç uygulaması ve kemik iliği yapısındaki değişiklikler açısından incelendi.

YÖNTEM ve GEREÇLER: Toplam 300 yetişkin kafatasında morfolojik ISFB analizi yapıldı.

BULGULAR: Normal görünüm olarak tanımlanan Tip A 243 kafatasında saptandı. 57 kafatasında (%19) farklı bir görünüme sahip artmış osseöz kalınlaşma durumu görüldü. Osseöz kalınlaşmanın en sık örnekleri nodüler (Tip B, C) ve difuz tiplerdi (Tip D, E), (%29,8). Hatta sajital sulkus kökeninin her iki tarafında plaklar şeklinde düzensiz bir osseöz kalınlaşma mevcuttu. Tip B ve C, ISFB üzerinde küçük izole nodüller olarak görüldü. Histolojik ISFB analizinde normalde kompakt bir kemik yapısına sahip endokraniyumun artmış osseöz kalınlaşma özelliğine sahip alanlarda lameller yapısını değiştirdiği ve örülü olmayan immatür bir kemik yapısına sahip olduğu görüldü. Endokraniyumdaki diploe aralığı kalınlaşması ve artmış lameller kemik dokusu vaskülarizasyonda bir artışı ortaya koydu.

TARTIŞMA: Artmış osseöz kalınlaşmanın nodüler ve yaygın tipi dura mater ve beyin dokusuna basınç uygulayabilir.

ANAHTAR SÖZCÜKLER: Frontal kemik, Kemiksi kalınlaşma, Kafa kubbesi, Kafatası, Endokraniyum

INTRODUCTION

Generally, when the internal surface of the frontal bone (ISFB) structure is analysed, explicit thickening structure is not recognized. However, in certain case presentations or in many case studies, it is revealed that when the internal surface osseous thickening is observed, it is situated either on the focal point or on the wide area it is covered by (6, 13, 14). On the other hand, changes observed in the ISFB with increased osseous thickening in the process of time were related to the density, shape and agglomeration in larger formations (8, 10, 19). In terms of appearance, osseous thickening could cause either small and isolated nodules or even constant overgrowth of the ISFB.

Many researchers have studied on the shape of the osseous thickening so far (6, 8, 10, 13, 14, 19). In these studies, a variety of factors have been examined but the presence and incidence of osseous thickening in the ISFB were largely associated with hormonal disturbances such as pregnancy osteophytes, acromegaly, Paget's disease, osteoid osteoma, lentiasis ossea or senile hyperostosis (7, 12, 25). The osseous thickening areas of the ISFB were located in the groove of the sagittal sinus (sagittal sulcus) and groove of the middle meningeal artery (sulci arteriosi) (6, 10, 23). Macroscopic as well as microscopic analysis of the osseous thickening areas of the ISFB have been applied to a few cases (8). Only theoretical proposals concerning this bone thickening are available. Thus, there is a need for detailed information.

The aim of this study was to determine the shape, width and length of the osseous thickening observed in the ISFB as such information are of great importance in helping the professionals detect whether osseous thickening results in a change in the bone structure. The main question to be answered with this study is to investigate, whether osseous thickening or a shift in vascular structures will lead to a change in the process of operational interventions in these areas. Increase in osseous thickening and vascular vein formation could result in a change in operational process as these formations are close to the brain tissue and serve vital functions in the brain area.

MATERIAL and METHODS

A total of 300 adult dry skulls of unknown age and sex obtained from the Turkish population were used to determine the localization of increased osseous thickening of the ISFB. With the software, superior contours of the osseous thickening were manually chosen and their perimeter, form, area, and relations with the sagittal sulcus and sulci arteriosi were evaluated on the right and left sides separately.

The osseous appearance of ISFB was classified into five types according to its shape as Types A - E (Figure 1). Aside from this, the below stated characteristics were taken into consideration while defining the structure of osseous thickening.

measurement of lesion (a: diameter, b: thickness, c: size),

type (types A-E),

appearance (a: isolated, b: wide plaque),

border type (a: clearly demarcated, b: ill defined),

shape (a: round, b: lobular, c: elongated),

location in frontal bone (a: squamous part, b: lateral part, c: orbital surface),

involvement of other bones (a: parietal, b: sphenoid, c: temporal).

Digital calipers sensitive to 0.01 mm have been used for these measurements. A flexible metric protractor has been used for aspect measurements where necessary. Descriptive statistics (mean, minimum, maximum, standard deviation) were evaluated for all the parameters collected from skull measurements. Differences between the data of skull measurements were analysed by Student's t test.

Tissue preparation

Certain steps were followed during the tissue preparation. To begin with, the frontal bone was removed from parts displaying normal and macroscopic involvement with osseous thickening. A diamond blade was used to remove these parts on the bands cut from the left and rights sides of the frontal bones (Figure 4A-C). Then, these parts were trimmed to form blocks with a dimension of 2 cm at maximum. The blocks were infiltrated with a 1:1 mixture of 100% EtOH and methyl metacrylate after they underwent a dehydration process through a graded series of ethanol for 24 hours. Dehydration and infiltration processes were conducted under vacuum at room temperature. Sections as thin as 4-5 μ were cut on a rotary microtome with tungsten for histomorphometric examination. A quality assessment was performed for each section and the three highest quality sections of each bone were analyzed.

RESULTS

Using the macroscopic morphology characteristics outlined above, five types of osseous thickening of ISFB were recognized and named as Types A - E (Figure 1). The most common type was Type A (81%), whereas the rest of osseous thickenings made up 19% (Type E: 5.7%, Type D: 5%, Type C: 4.7% and Type B: 3.6%) (Figure 1).

Type A (Figure 1A, 2A): The ISFB was concave and of normal appearance. In its upper, median part, a vertical sagittal sulcus was found. The sagittal sulcus was determined beginning from the frontal crest. The groove contained the anterior part of the superior sagittal sinus. On both sides of the sagittal sulcus, a smooth surface of the ISFB structure was observed. Several granular foveolae for arachnoid granulations existed near the sagittal sulcus. No abnormal appearance was detected in the ISFB osseous thickening structure. The ISFBs showed impressions of cerebral gyri and small furrows for meningeal vessels. A total of 243 dry skulls belonged to Type A classification (Figure 2A).

Type B (Figure 1B, 2B, C): The specimens of this type had the following characteristics: the bone structures were isolated, were clearly demarcated, had elevated bony islands, were round in shape, single or multiple and were placed unilaterally or bilaterally. They were generally less than 10 mm in size. Location of the formations was seen to be at 2 cm left and right of the sagittal sulcus. 10 specimens on the left (Figure

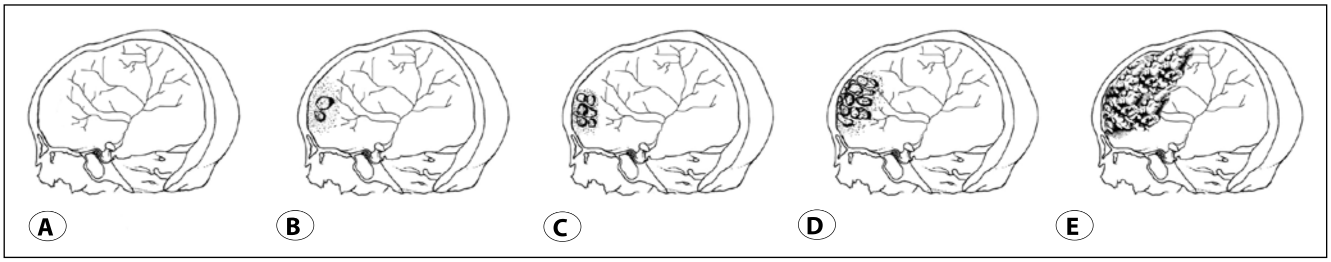

Figure 1: The osseous appearance of internal surface of frontal bone was classified into five types according to its shape as Types A-E. **A)** Normal, Type A, **B)** Type B, **C)** Type C, **D)** Type D, **E)** Type E.

2B,C), 6 on the right and 3 were located bilaterally. Type B ISFB, was detected with 19.3% of occurrence.

Type C (Figure 1C, 2D): The specimens of this type were seen as isolated nodular body overgrowths, without discrete margins and had round or lobular shaped structures which were located within the frontal bone. Location of the formations was seen to be at 2 cm right and left lateral of the sagittal sulcus. 10 specimens on the left, 8 on the right (Figure 2D) and 5 were located bilaterally, whole Type C ISFB was detected with 24.5% of occurrence.

Type D (Figure 1D, 3A, B): The specimens of Type D were more extensive in lobular bone overgrowth, and were associated with irregular thickening (Figure 3A,B). A tendency for greater elevation and coalescence was observed. 15 specimens were located bilaterally on the skull. Type D ISFB was detected with 26.3% rate of occurrence.

Type E (Figure 1E, 3C, D): Type E specimens had continuous body overgrowth, with ill-defined margins and their shapes were elongated. The entire region was found to be elevated with sharp, clearly demarcated borders. Type E specimens were flattened, and pancake-shaped with sharp posterior margins (Figure 3C, D). The location of the specimens was seen to be elongated from the orbital roof bordering sagittal sulcus upwards and bilaterally. In 17 bilaterally located samples, Type E ISFB was detected at a rate of 29.8% (Figure 3C, D). Symmetric involvement of the samples was noticeable and the samples of this type formed a different layer in the ISFB.

Extent of involvement (a: lesion diameter, b: lesion thickness, c: lesion size)

It has been reported that the osseous thickening in the ISFB is relatively variable in terms of size and shape and it ranges from small isolated endocranial elevations to extensive diffuse changes. Depending on the case, borders of individual foci could be either well-defined or were difficult to distinguish (Figure 2B-C). Increased osseous thickening and involvement of a greater proportion of the frontal bone determined this difference. The most advanced cases were detected to be either flattened (Figure 3A) or pancake-shaped (Figure 3B) and had sharp posterior margins (Figure 3C). Clustered lobulations (Figure 3D) or a cauliflower shape was observed in some specimens. Furthermore, fine or shallow bony striations were also specified. The extent of involvement led to an increase in the degree of symmetry. This was at most attributed to the extensive osseous thickening of ISFB involvement (Figure 2A-D, 3A-D).

Lesion diameter: The length and the width of the nodular osseous thickening (Types B and C) were found to be as 21.1 ± 2.1 (right), 1.1 ± 1.2 (left) and 1.9 ± 1.2 (right), 1 ± 1.2 mm (left), respectively (Figure 2B, C). The height ranged between 1.09 ± 0.4 mm. The length and width of the diffuse osseous thickening (Types D and E) were found to be as 23.9 ± 3.4 (right), 24 ± 3.3 (left) and 11.9 ± 2.3 (right), 10.7 ± 2.3 mm (left), respectively (Figure 3C, D). The height ranged between 2.5 ±1.09 mm. The head circumference was found to be 67.6 ± 7.9 and 68.3 ± 7.2 mm in the right and left, respectively.

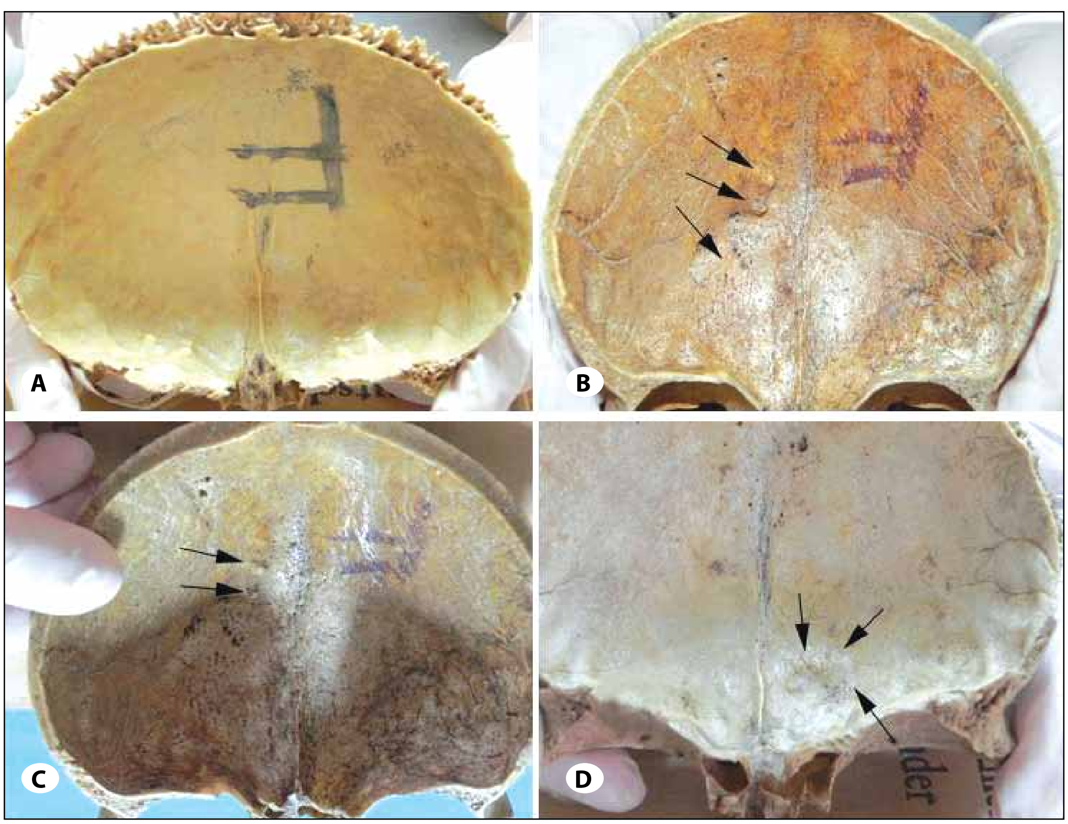

Figure 2: Skullcap showing changes of thickening of inner table of frontal bone. **A)** normal, **B-C)** unilateral multinodular (Type B), **D)** unilateral wide plaque osseous thickening ↑ (Type C).

The head area was measured as 231.9 ± 53.3 and 214.9 ± 45.1 mm^2 in the right and left, respectively.

Lesion size In Type B and C, unilateral and bilateral, single, double and triple bone expansions were found (Figure 2B, D). In the samples of Type D and E, as the lesion covered a wide space, was continuous and was a lobulational sample, the amount may not be considered meaningful (Figure 3A-D). Macroscopic evaluation of the calvaria revealed extensive osseous thickening of ISFB unilaterally (Figure 2B-D) and bilaterally (Figure 3A-D) in the frontal bone. Both left and right halves of the frontal bone showed areas of irregular thickening covering the anterior half of the inner table (Figure 3).

Appearance (a: isolated, b: continuous plaque):

In the analysed cases, Type B and C were seen in the form of isolated areas (Figure 2B-C, 3A-B) whereas cases classifed as Type D and Type E, it was noticed that they were in the form of continuous and plaque areas in appearance (Figure 2D, 3C-D).

Border type (a: clearly demarcated, b: ill defined)

Again, in the analysed cases, in terms of border type, Type B and C were present in the form of clearly demarcated area (Figure 2B-C, 3A-B). On the other hand, Type D and Type E were noticed to be in the form of ill defined surface (Figure 2D, 3C-D).

Shape (a: round, b: lobular, c: elongated)

When the analysed cases were evaluated in terms of their shapes, in Type B and Type C cases it was noticed that 8% were round (Figure 2B-C), 5% were lobular (Figure 2D; 3A,B) and 6% were elongated shapes (Figure 3C,D).

Location in frontal bone (a: anterior part of the frontal squama, b: posterior part of the frontal squama, c: orbital surface);

We found that 5% of the cases were located in the anterior part of the frontal squama (Figure 2D), 4% in the posterior part of frontal squama (Figure 2B-C), 4% in both the anterior and posterior (Figure 3A) and 6% in the orbital roof (Figure 3C-D).

In some cases, it was found that bony formations of ridges and grooves were aligned perpendicularly and obliquely to the midsagittal plane. They were funnel-shaped and had a tendency to converge towards a focal point close to the sagittal sulcus. Large blood vessels were found on the grooves and they drained into the sagittal sulcus. No matter how extensive the osseous thickening was even in the most severe cases, it did not cross suture lines. It was revealed that the skull midline and sagittal sulcus were persistently free of extensive osseous thickening of the ISFB. While the borders of the unaffected central region extended posteriorly, they diverged and reached the maximum separation at the bregmatic area (Figure 2C). Posteriorly, it was the sulci arteriosi that served as a limiting factor. This was because of the fact that extensive osseous thickening in the ISFB did not traverse this vessel (Figure 3C-D). When the bone formations in the ISFB were analysed, it was observed that the location was adjacent to the sagittal sulcus covering the formation ranging between 0 mm (Figure 3A-C) - 20 mm (Figure 2B). Also, it was noticed that these formations did not cross over sulci arteriosi. This irregular thickening continued laterally and terminated 10 - 70 mm anterior to the sulci arteriosi (Figure 3).

Involvement of other bones (a: parietal, b: sphenoid; c: temporal)

In none of the cases, bony protrusions present at frontal region, crossed over the parietal, sphenoid and temporal regions. Only in two cases, the observed changes manifested on outer lamina and covered the cranial bones.

Histological examination

The histological areas containing both normal and sclerotic thickening were analysed (Figure 4A-D). A detailed investigation has been performed to the layers of the frontal bone. In normal frontal tissue; endocranium, consisting of lamellar layers of compact bone, normal diploe gap and ectocranium, consisting of sclerotic lamellar bone structures have been analysed (Figure 4D). In the histological analysis of the areas with the appearance of increased osseous thickening, there was no evidence of complex tissue appearance denoting a new bone formation or destruction. The ectocranium was noticed to be within the normal margins. In the diploe and medullar areas, there seemed to be a thickening in the mature bone characteristics and the external surface of frontal bone was extensive. A mature Havers system, increase in number of vessels and cell details, was observed regularly. Naturally, there was an increase in the vascularization. When the endocranium, adjacent to the inner surface of the frontal bone was analysed, there seemed to be an irregular formation. In the endocranium, the bone showed nonwoven lamellar tissue characteristic. There was also an increase in the trabecular per unit square and the thickness of the Havers lamellar system in the endocranium. Irregular bone lamellas were noticeable. There were also several gaps extending into the cranial vault (Figure 4D).

DISCUSSION

Despite the fact that the variations in shapes of the ISFB and its incidence have been recognized in previous clinical and anatomical studies, it has been observed that the pattern of the osseous thickening was not as simple as it had been reported by many authors (12-14). While most of these studies were just case presentations, only a few contained comprehensive details. Thus, in existing studies, the results confirm the variability in almost all the measured osseous thickening parameters, including the length and the width, but detailed information considering variety in thickness is seldom (2, 19, 23, 25).

The feature differentiation seen in ISFB is especially in the form of endocranial bone thickening. Terminological differences in relation to the phenomena of endocranial bone thickening (i.e. Morgagni Morel syndrome; Stewart-Morel syndrome; enostosis cranii; endocraniosis; metabolic

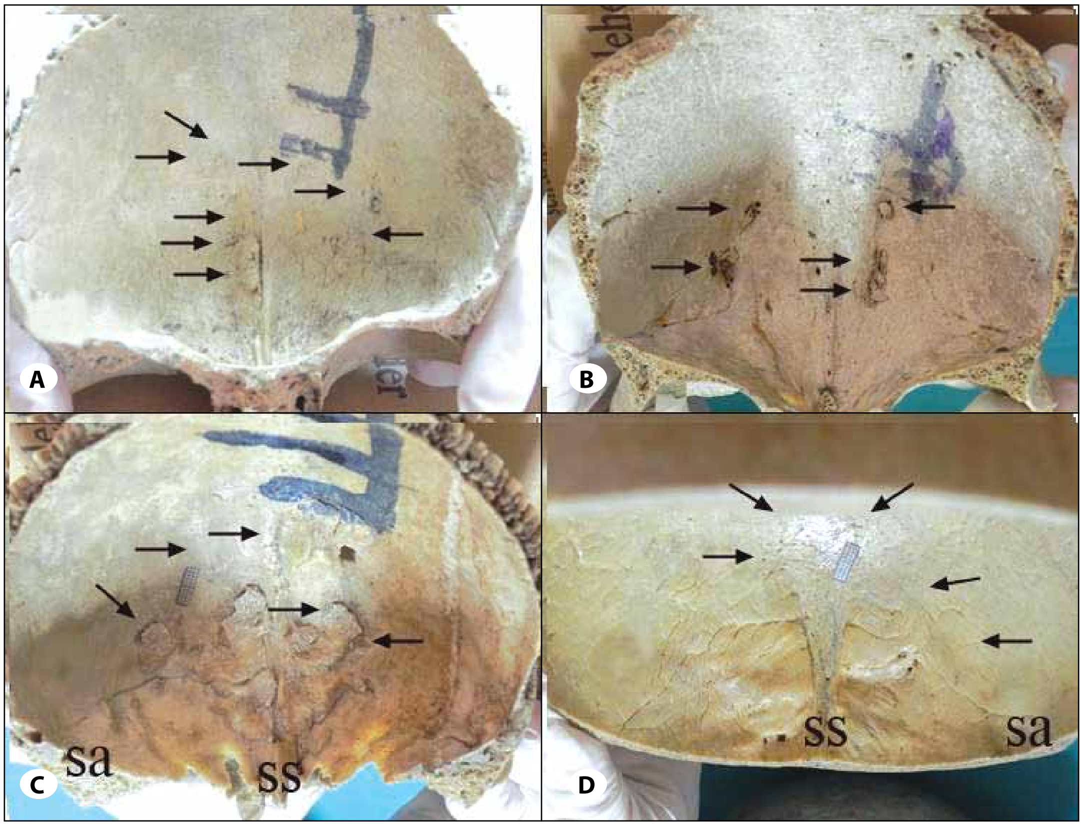

Figure 3: Hypertrophic changes in the form of osseous thickening plaques. **A)** Multinodular within sagittal sulcus, **B)** Bilateral multinodular with scattered location and distant from each other (Type D), **C)** Osseous thickening (Type E) located within sagittal sulcus in the form of bilateral sagittal sulcus inner plaques, **D)** Osseous thickening located between sagittal sulcus (**ss**) and sulci arteriosi (**sa**) in the form of bilateral elongated continous plaques (Type E) osseous thickening ↑.

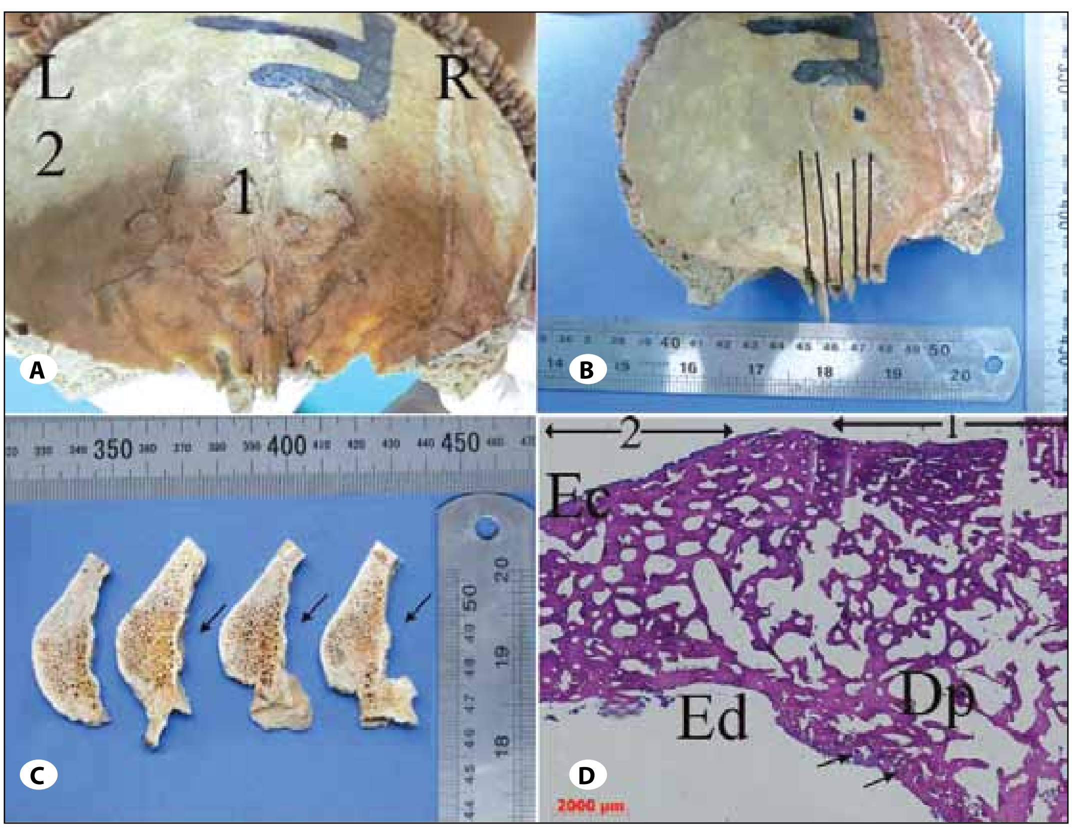

Figure 4: Histological tissue sample of a case with macroscopic investigation of osseous thickening. **A)** The calvaria shows extensive, bilateral remodelling of the right (R) and the left (L) parts of the frontal bone involving more than 60% of the endocranial surface with numerous irregular sharp elevations, **B)** right and left cross-section of the sample, **C)** Macroscopic appearance of 2 cm size sections, **D)** the histology of the sections. **1**. cancellous bone, **2**. compact bone, **Ec**: ectocranium, **Ed**: endocranium, **Dp**: diploe, ↑: gaps, → marked macroscopic thickening.

craniopathy; endostosis cranii) is a clear indicator of the diversity of opinion regarding this medical situation (3, 7, 13, 15). Moreover, the differential diagnosis of extensive osseous thickening in the ISFB ranges from such focal masses as meningioma and endosteal osteoma, subdural and dural calcification and to the diffuse skull process including Paget's disease, acromegaly and fibrous dyplasia (14, 17, 18, 24).

Moore described four different forms of osseous thickening in detail in his research. In line with this, extensive osseous thickening of ISFB was only described as a case where only the frontal bone was affected (13). Another classification of the osseous thickening was also made by Hershkovitz (8). According to this classification, osseous thickening was split into four subtypes including A, B, C and D in terms of appearance, size and the extent of endocranial remodelling. Type D was the most extensive one and it was characterized by constant bone overgrowth, covering more than 50% of the frontal endocranial surface including the entire involved region which was irregularly elevated with sharp and clearly demarcated borders. While the ISFB was displayed in form of prominent bulges, it was separated by grooves and had different depths (13, 20). Being found symmetrically on both sides of the frontal crest, these features did not persist beyond the coronal suture. Bulges were found at the inner lamina and more occasionally in the diploe whereas the thickness of the external lamina did not display a change. Sometimes, calcifications were also observed in the falx cerebri and along the sagittal suture (5).

Areas of osseous thickening have not always been associated with hyperostosis frontalis interna (2-5, 11, 15, 21). It was indicated by Talarico et al. that area fraction of lamellar bone showed decrease in regions where extensive osseous thickening was observed in the ISFB (21). Compression of the left precentral gyrus in the location of the motor cortex was observed macroscopically. Nevertheless, it is not clear yet whether the symptoms of subjects including a positive Rhomberg sign are certainly related to the hyperostosis. It is more likely that there is some undetected compression on the postcentral gyrus. This is because of the fact that damage to the posterior white columns is clearly associated with a Romberg sign (21). Therefore, it is of vital importance to recognize the existence of osseous thickening at these regions especially in surgical operations as bone thickening and the changes in the vascularization will probably alter the procedures adopted in the operation.

In a study with osseous thickening, all cases suffered from behavioural disturbances, aggression, or psychiatric disorders (4). Headache, bipolar disorder, and other psychiatric symptomology have been correlated with the presence of cavum septi pellucidi and cavum vergae. Considering osseous thickening cases with respect to the locations is of neurological and psychological importance.

In the literature, three hypothetical models have been presented to explain the endocranial growth. According to the American Model, cancellous bone in the diploe proliferates in such a manner that the ISFB is pushed internally and the calvarial thickness is increased (13, 21). However, in the European Model, a process which occurs in the dura mater and is initiated by enlarging intradural vessels is put forward (13, 21). According to the Global Model which was developed by Hershkovitz et al. (8), there is a four-step process. In the third step of this model, vascularization of new lamellar bone that triggers bone proliferation is observed. It is interesting that a callus that becomes vascularized stimulates bone growth and repair.

With this study, a less detailed subject has been analysed with extensive details. A detailed typology of ISFB has been performed and histological differentiation has been presented. The ISFB, normally, had a concave appearance and median part was found in vertical sagittal sulcus. It was placed bilaterally on both sides of the sagittal sulcus in the form of regular ISFB structure. The osseous thickening of ISFB was recognized to be quite varied in shape and size, ranging from small isolated endocranial elevations (Figure 2A-D) to extensive diffuse changes (Figure 3A-D). Macroscopic evaluation of the calvaria revealed extensive osseous thickening of ISFB bilaterally. Both left and right halves of the frontal bone showed areas of irregular thickening covering the anterior half of the inner table (Figure 3A-D). Bulges on the skull formed radial elevations running symmetrically away from the frontal crest. The most common ones, in Type E cases, bony formations of ridges and grooves were found to be aligned perpendicularly and obliquely to the midsagittal plane. ISFB were showed in the form of prominent bulges, separated by grooves of different depths. These formations were funnel-shaped and tended to converge towards a focal point near the sinus. The osseous elevations were localized in the anterior part of the frontal squama (Figures 3A-D; 4A-D).

There was an irregular thickening which continued laterally and terminated at 10 - 70 mm anterior to the sulci arteriosi. Large blood vessels were found on the grooves and they drained into the sagittal sulcus. The frontal bone might be dominant due to its vascularization. When vascular territories in the calvarium were analysed, it has been indicated that soft and hard tissues of the frontal region constituted a separate angiosome. Diploe venous system of the frontal bone was not dependent on the parietal and occipital regions draining into other calvarial bones and on the grooves between the bony ridges of osseous thickening, and the veins exiting the diploe were found. No matter how extensive the osseous thickening was even at the most severe cases, it did not cross suture lines. It was revealed that the skull midline and sagittal sulcus were persistently free of extensive osseous thickening of the ISFB. Proximity of the locations of the formations to the veins could be attributed to this situation.

In histological analysis, the osseous thickening is characterized by remodelling of the ISFB into a cancellous phenotype (13, 21). Microscopic analysis revealed that a larger proportion of nonwoven mature bone was present in regions of macroscopic hyperostosis. When the area covered by extensive osseous thickening in ISFB is taken into consideration, it is noticed that these formations are close to the frontal lobes.

The most common type, Type E is important in terms of its wide expansion area. As it is a formation that occupies space in the skull and its adjacent location to important areas, it can be a cause of neurological and psychological disturbances.

On the other hand, in the specimens classified as Type E, occasionally there also occur calcifications in the falx cerebri and along the sagittal suture. Bidziński and Glab et al. are the researchers who have reported these results (2, 5). Considering these data, especially wide space involvement of Type E and its frequency (29.8%), can be evaluated as misfortune for these people. However, people with big nodular formations of Type B and Type C can also have focal complaints. Another important point is a need to verify the presence of osseous thickening in the other members of the family tree. Mechanism of occurrence of different types of osseous thickening, if it was constant or nodular, lobular and diffuse transitions are possible, is another subject of research (4, 5, 9). Thus, expansion of the lesion and its growth would cause complaints which would disturb the life quality of the patients. The proposed association between osseous thickening and the psychiatric and neurological complaints will lead to more studies (8-10, 16, 19). Increased bone marrow and endocranial remodelling cause an increase in bone thickening and vein structure in this area. Further research steps planned related to this study is to scan patients with neurological and psychiatric complaints with radiological screening methods with a long-run investigation of ISFB.

ACKNOWLEDGEMENTS

No financial conflict of interest exists with any commercial entity whose products are described, reviewed, evaluated or compared in the manuscript. None of the authors has a financial interest in any of the product, devices or drugs mentioned in this article.

REFERENCES

1. Barber G, Watt I, Rogers JA: Comparison of radiological and palaeopathological diagnostic criteria for hyperostosis frontalis interna. Int J Osteoarchael 7:157-164, 1997
2. Bidziński J: Pathological findings in suboccipital decompression in 63 patients with syringomyelia. Acta Neurochir Suppl (Wien) 43:26-28, 1988
3. Calame A: Le syndrome de Morgagni-Morel. Paris: Masson, 1951
4. Devriendt W, Piercecchi-Marti MD, Adalian P, Sanvoisin A, Dutour O, Leonetti G: Hyperostosis frontalis interna: Forensic issues. J Forensic Sci 50:143-146, 2005
5. Glab H, Szostek K, Kaczanowski K: Hyperostosis frontalis interna, a genetic disease?: Two medical cases from Southern Poland. Homo 57(1):19-27, 2006
6. Hajdu T, Fóthi E, Bernert Z, Molnár E, Lovász G, Kovári I, Köhler K, Marcsik A: Appearance of hyperostosis frontalis interna in some osteoarcheological series from Hungary. Homo 60(3):185-205, 2009
7. Henschen F: Morgagni's syndrome: Hyperostosis frontalis interna. Virilismus, obesitas. Gustav Fischer, Jena, 1937
8. Hershkovitz I, Greenwald C, Rothschild BM, Latimer B, Dutour O, Jellema LM, Wish-Baratz S: Hyperostosis frontalis interna: An anthropological perspective. Am J Phys Anthropol 109(3):303-325, 1999
9. Mansilla-Lory J, Amezcua-Guerra LM, Vargas-Rodriquez A, Fernandez-Tapla S, Leboreiro I, Resnick D, Martinez-Lavin M, Villanueva M, Gaytan E, Pineda C: Leontiasis ossea: A paleopathologic case report. J Clin Rheumatol 13:269-272, 2007
10. May H, Peled N, Dar G, Hay O, Abbas J, Masharawi Y, Hershkovitz I: Identifying and classifying hyperostosis frontalis interna via computerized tomography. Anat Rec 293(12):2007-2011, 2010
11. May H, Peled N, Dar G, Cohen H, Abbas J, Medlej B, Hershkovitz I: Hyperostosis frontalis interna: Criteria for sexing and aging a skeleton. Int J Legal Med 125(5): 669-673, 2010
12. May H, Peled N, Dar G, Abbas J, Medlej B, Masharawi Y, Hershkovitz I: Hyperostosis frontalis interna and androgen suppression. Anat Rec 293(8):1333-1336, 2010
13. Moore S: Hyperostosis crani. Springfield: Charles C. Thomas, 1955
14. Nikolic S, Djonic D, Zivkovic V, et al: Rate of occurrence, gross appearance, and age relation of hyperostosis frontalis interna in females. A prospective autopsy study. Am J Forensic Med Pathol 31:205-207, 2010
15. Perau M: Cranial hyperostosis. Springfield: Charles C. Thomas, 1964
16. Ramsthaler F, Kettner M, Gehl A, Verhoff MA: Digital forensic osteology: Morphological sexing of skeletal remains using volume-rendered cranial CT scans. Forensic Sci Int 195:148-152, 2010
17. Resnick D, Niwayama G: Diagnosis of bone and joint disorders. Philadelphia: Saunders, 1988
18. Ruhli FJ, Boni T, Henneberg M: Hyperostosis frontalis interna: Archaeological evidence of possible microevolution of human sex steroids ? Homo 55:91-99, 2004
19. She R, Szakacs J: Hyperostosis frontalis interna: Case report and review of literature. Ann Clin Lab Sci 34(2):206-208, 2004
20. Skrzat J, Brzegowy P, Walocha J, Wojciechowski W: Age dependent changes of the diploe in the human skull. Folia Morphol (Warsz) 63(1):67-70, 2004
21. Talarico EF Jr, Prather AD, Hardt KD: A case of extensive hyperostosis frontalis interna in an 87-year-old female human cadaver. Clin Anat 21(3):259-268, 2008
22. Verhoff MA, Ramsthaler F, Krähahn J, Deml U, Gille R, Grabherr S, Thali M, Kreutz K: Digital forensic osteology-possibilities in cooperation with the Virtopsy® project. Forensic Sci Int 174:152-156, 2008
23. Waclawik AJ: Hyperostosis frontalis interna. Arch Neurol 63:291, 2006
24. Waterval JJ, van Dongen TM, Stokroos RJ, De Bondt BJ, Chenault MN, Manni JJ: Imaging features and progression of hyperostosis cranialis interna. AJNR Am J Neuroradiol 33(3):453-461, 2011
25. Yamakawa K, Mizutani K, Takahashi M, Matsul M, Mezaki T: Hyperostosis frontalis interna associated with hypogonadism in an elderly man. Age Aging 35:202-203, 2006