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IMAGING OF THE WORMIAN BONES USING MICROCOMPUTED TOMOGRAPHY

Abstract: Wormian bones are irregular ossicles of small size and reveal fractal pattern of their edges. Their anatomy was visualized in volumetric reconstructions obtained from a series of micro-CT scans. In visual evaluation Wormian bones showed typical anatomy for the calvarial bones. They revealed three-layer composition: the outer and the inner table of the compact bone intervening with the table of the spongy bone. Microcomputed tomography captured all details of the interdigitation of the edge being incorporated into the lambdoid suture and interlocked between opposing edges of the occipital and parietal bones. This modality provided accurate images which allowed delineating morphological differences between the compact bone and the diploe, including vascular channels.

Key words: Wormian bones, cranial sutures, microcomputed tomography.

INTRODUCTION

Wormian bones are small irregular ossicles that lie between the cranial sutures and fontanelles. The name *os wormianum* was given by Thomas Bartholin for intercalated bones in honor of the Danish anatomist Olaus Worm who described them in 1643. This type of bones, however, had been previously described by Paracelsus who lived in XV century. Wormian bones are also termed as the intrasutural bones or Inca bones if they have a big size [1–3].

The Wormian bones are commonly found in the lambdoid suture but they also occur in other sutures, eg. sagittal or coronal (Fig. 1). Usually, they occur as a normal variant and in the general population their prevalence varies from 8–15% but significant differences between ethnic groups may occur, even up to 80% in a Chinese population [4].

In normal cranial development the Wormian bones are formed due to additional ossification centers. However, their formation may be linked with rapid cranial vault expansion as they appear in great number of hydrocephalic skulls. Formation of Wormian bones could result from metabolic disorders, bone malformations or congenital anomalies of the central nervous system [5, 6]. Their presence is also associated with morphology of cranial sutures and cranial abnormalities [7].

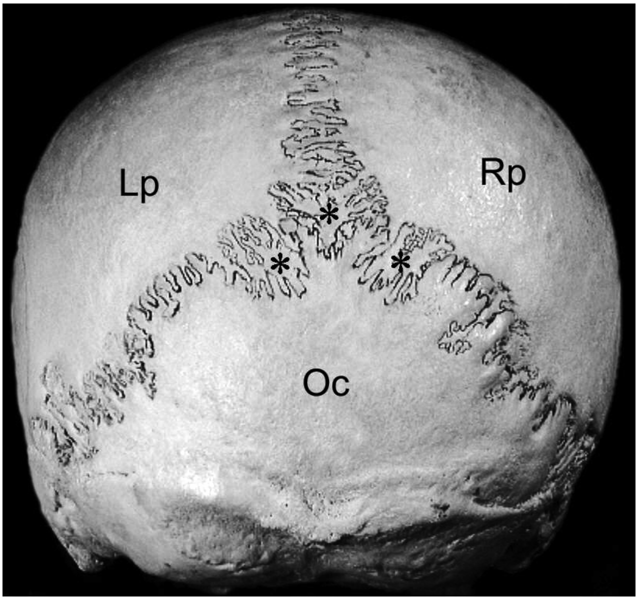

Fig. 1. Examples of the Wormian bones (marked by asterisks) located within the lambdoid suture of the human skull; Oc — occipital bone, Lp — left parietal bone, Rp — right parietal bone.

Clinical significance of the Wormian bones is rather limited to congenital disorders in which they can be treated as markers and used in the primary diagnosis. For instance their higher incidence is typical for the osteogenesis imperfecta, hypothyroidism, cleidocranial dysostosis, progeria, hypophosphatasia, and rickets etc. [8].

Up till now it was not verified whether normal variants of the Wormian bones differ from that Wormian bones which accompany pathological processes. Probably it was caused by lack of accurate imaging techniques which were capable of depicting small morphological details in a range of micros. Invention of micro-CT scanners overcame limitations in imaging small objects and allowed to assess their internal morphology. Thereby, the objective of this study was to reconstruct external morphology of the Wormian bones and depict their inner structure using microcomputed tomography.

MATERIAL AND METHODS

Capabilities of imaging external and internal morphology of Wormian bones by micro-CT scanner were tested on two samples, which belong to the museum cranial collection housed in the Department of Anatomy of the Collegium Medicum, Jagiellonian University. Examined bones were dry specimens therefore they did not require special preparation and fixation for radiological studies performed with the aid of micro-CT scanner.

Isolated Wormian bones from the lambdoid suture of the human skull of an adult individual were subjected to the micro-computed tomography. The samples were scanned with a Skyscan 1172 microtomograph (Skyscan, N.V., Aartselaar, Belgium). The scanner was equipped with the X-ray detector: 11 Megapixel (4024 x 2680 in total; 4000 x 2400 effective), 12-bit digital X-ray camera with 24 x 36 mm field of view. The X-ray source voltage was set to 80 kV and current to 100 µA. The image pixel size was 27 µm. The projection images were acquired over an angular range of 180° with an angular step of 0.5°. Projections were reconstructed using a cone beam reconstruction software (NRECON SkyScan) based on the Feldkamp algorithm.

Obtained stack of micro-CT scans served to reconstruct the bone samples as the 3D image. The bone surface was visualized by the surface rendering method, whereas volume rendering method enabled to visualize object's interior. Further, sections of the sutural bones were performed in the processing software and presented on the computer screen as visual data adequate for morphological analysis. For this purpose we used CTVox SkyScan software (Copyright by Bruker MicroCT) and Medical Volume Explorer (Copyright by Jürgen Abel).

During visual inspection of the Wormian bones reconstructed by the volume rendering algorithm morphology of the compact and spongy layers was analyzed. Particular attention was paid to the location and course of the diploic channels.

RESULTS

Two examined Wormian bones showed highly irregular pattern that was characterized by short projections that extended from their edges. Some of the projections seemed to bifurcate in various directions, whereas the others were singular bony outgrowths. The outlined of their edges reconstructed from the serial scans revealed fractal pattern which is characteristic for the cranial sutures. External appearance of the isolated Wormian bone is presented in Fig. 2.

The Wormian bones being a subject of the current study were composed of inner and outer tables of compact bone that enclosed a layer of cancellous bone which constitute the diploe (Fig. 3). The outer surface of the bones was formed by the compact bone with irregularly located pores. These minute openings penetrated the bone and few of them were the outlets of the diploic channels (Fig. 4). The diploe of the Wormian bones appeared to be abundant in numerous cavities spread across the entire sample. Hence, a singular channels for the diploic veins were noted in both samples.

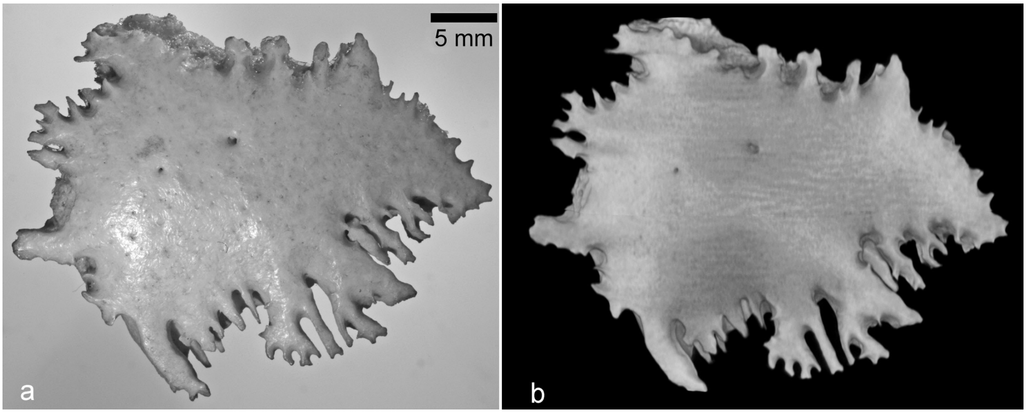

Fig. 2. Digital photography of the Wormian bone (a) and its volume rendering image obtained from a series of micro-CT scans (b). Visible huge coherence in morphological appearance of the bone reconstructed by the volume rendering algorithm towards the natural object.

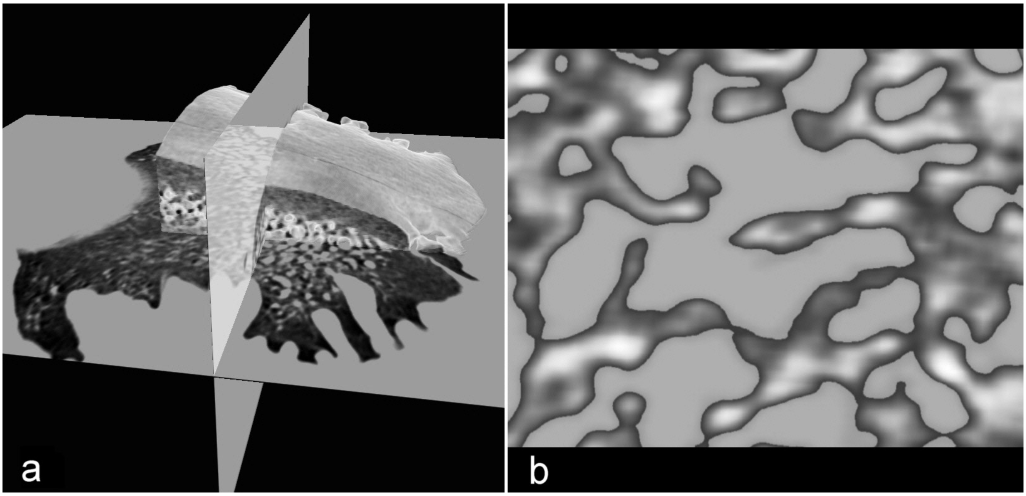

Fig. 3. Multiplanar reconstruction of the inner structure of the Wormian bone (a). Extracted sample of the trabecular microarchitecture shows irregular pattern of the diploe (b). Well visible small cavities and radiated septa are typical for the bones of intramembranous origin.

DISCUSSION

Images play an important role in anatomical study, and without doubt their quality is critical for proper description of the observed structures. Computerized image processing and analysis of the CT scans allows reconstructing spatial organization of the biological objects and recreating realistic 3D models based on volume rendering algorithms [9].

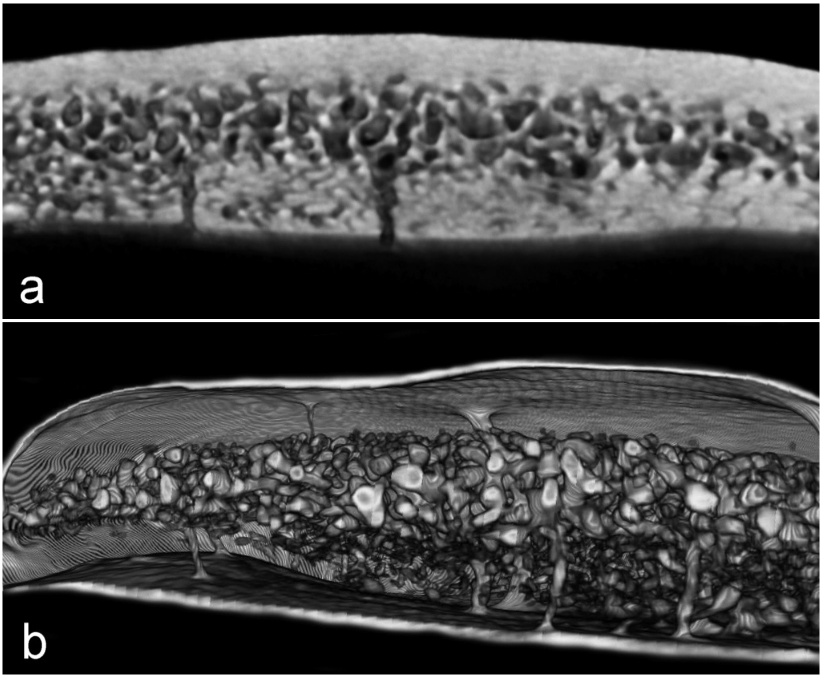

Fig. 4. Cross section of the Wormian bone imagined by the microcomputed tomography using different transfer functions for mapping voxels; a — normal visualization of the bone tissue, b — visualization of the air inside the dry bone enhances recognition of the diploic channels.

Application of various modalities allows to capture both external and internal organization of the biological objects on different scale level (macro and micro). Contemporary radiological methods provide adequate tool for examination of the internal structure of small objects.

Wormian bones are usually small objects because their size does not exceed few centimeters. This geometrical feature compels application of analytic techniques which are capable of visualizing detail structures with high resolution. Microtomography is one of the imaging techniques which can precisely show inner structure of the Wormian bones and may shed new light on their epigenesis or pathogenesis and practical usage in diagnosis [10]. It is known that Wormian bones can develop as a response to the artificial cranial deformations or craniosynostosis [11, 12].

In turn, Parker suggested that the number of Wormian bones increases with the capacity of the skull, and sutural length [13]. Khan *et al.* reported presence of the Wormian bones not only in the lanbdoid suture but also in the coronal, squamosal, and sagittal sutures [14].

Although numerous studies were performed on the Wormian bones, the researchers did not deal with their internal morphology which could have been determined by normal cranial development or altered in the pathological process. Probably this was caused by the lack of appropriate analytic tools or limited number of examined samples which had to be manually dissected. In the current study we examined Wormian bones of the adult individual. However, these bones can be also found in fetuses and infant skulls. Such cases require high resolution techniques which can substitute histological sectioning or clinical imaging by computed tomography or ultrasonography.

Applied in the current study microcomputed tomography offers three-dimensional imaging at the microscopic level, and accurate assessment of the inner structure of the object. This modality allowed to analyze in details morphological properties of the Wormian bones, and revealed precisely their inner anatomy and morphological variation observed between two different samples.

In our study we could clearly differentiate the compact bone from the spongy bone within the examined samples, detect and visualize the course of the diploic channels. Up till now such morphological features were widely attributed to the bones of the cranial vault [15, 16]. Obtained micro-CT data allow to deduce on architecture of the Wormian bones and compare their morphology in 2D and 3D aspect. Therefore this technique should be used in further studies aimed on examination different anatomical variants of the Wormian bones and their relationship with other cranial bones.

CONCLUSIONS

Microcomputed tomography is efficient technique for investigation of the external and internal morphology of the Wormian bones. Volume rendering reconstruction obtained from micro-CT scans is an appropriate technique for three-dimensional presentation of the outer appearance of the Wormian bones, particularly their edges which characterize numerous, irregular interdigitation. Hence, this modality provides accurate and undestructive insight into internal morphology of the osseous structures and can substitute histological sections of the bone tissue.

ACKNOWLEDGEMENTS

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CONFLICT OF INTEREST STATEMENT

None declared.

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