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Microstructure characterization of the human frontal bone

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ABSTRACT

The frontal bone plays a vital role in supporting and protecting the delicate nervous tissue of the brain. Knowledge of microstructure of the frontal bone is of significant importance for craniocerebral and orthopedic operations. Here, through a combined study of X-ray diffraction (XRD) analysis, optical microscopy, scanning electron microscopy (SEM) and transmission electron microscopy (TEM), we systematically investigate the microstructure of human frontal bone from micrometer to atomic scale. It is found that the frontal bone is mainly composed of hydroxylapatite. At the micrometer scale, the frontal bone appears an obvious layered structure with alternately arranged compacted and loose layers. Down to nanometer scale, the frontal bone in principle consists of a bunch of single-crystalline hydroxylapatite whiskers with an average diameter of ~10 nm.

1. Introduction

The frontal bone is a bone of the skull found in the forehead region, extending from the top of forehead to the tops of eyes. As a part of the skull's cranial bones, the frontal bone not only gives shape to the skull and supports several muscles of the head, but also plays a vital role in supporting and protecting the delicate nervous tissue of the brain [1,2]. A medical emergency will occur if the frontal bone is fractured by blows to the head or falls on hard objects, as brain damage to the frontal lobes is associated with frontal bone fractures. Therefore, knowledge of microstructure of the frontal bone is of considerable significance in many areas of biological and medical sciences, ranging from vital physiological process such as bone growth [3,4] to pathological process such as bone fractures [5,6], which will benefit for the craniocerebral and orthopedic operations. The medical operations of the frontal bone must be performed based on the knowledge of bone structure to reduce operation wound and improve wound healing.

For decades, clinical dissections were carried out to clarify the structure of human bones [7,8]. However, most clinical dissections were performed viewing with naked eyes or an optical microscope, thus offering, at best, structural information at the micrometer scale. TEM has been proved to be very powerful for the microstructure characterizations of biominerals including human bones [9–18], which can offer us microstructural information at the nanoscale or even at the atomic scale. Considering the fact that our knowledge of the microstructure of human frontal bone is still very limited, this study aims to revealing systematically the microstructure of this bone through a combined study of XRD analysis, optical microscopy, SEM and TEM. We found that the frontal bone has a layered structure with alternately arranged compacted and loose layers, which is mainly composed of a bunch of hydroxylapatite nanowhiskers.

2. Experimental details

The frontal bone used in this study was obtained from a medical operation of a 35-year-old female patient. A standard disinfection treatment of the fresh bone was conducted using formalin. Microstructure analyses were performed using XRD, optical microscope, SEM and TEM. For the XRD, a Rigaku RINT-2500 diffractometry with Cu Kα radiation operated at 45 kV and 200 mA was used. Optical microscopy observations were performed using a Nikon Eclipse LV100 optical microscope. SEM observations and SEM-EDS mapping was conducted using a JSM-7800F SEM (JEOL Co., Ltd.). Thin-foil TEM specimens were prepared by first cutting several slices from the frontal bone along the cross-section direction. The bone slices were then prepared into TEM samples through the standard ion-thinning process. TEM microstructure characterizations were carried out using a JEM-2010F TEM (JEOL Co., Ltd.).

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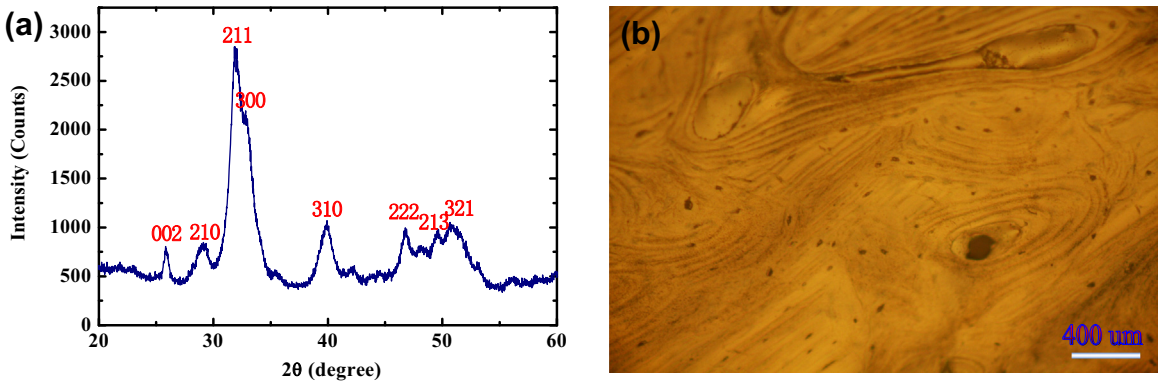

Fig. 1. (a) XRD spectrum of the human frontal bone. (b) Optical micrograph showing the cross-sectional microstructure of the human frontal bone.

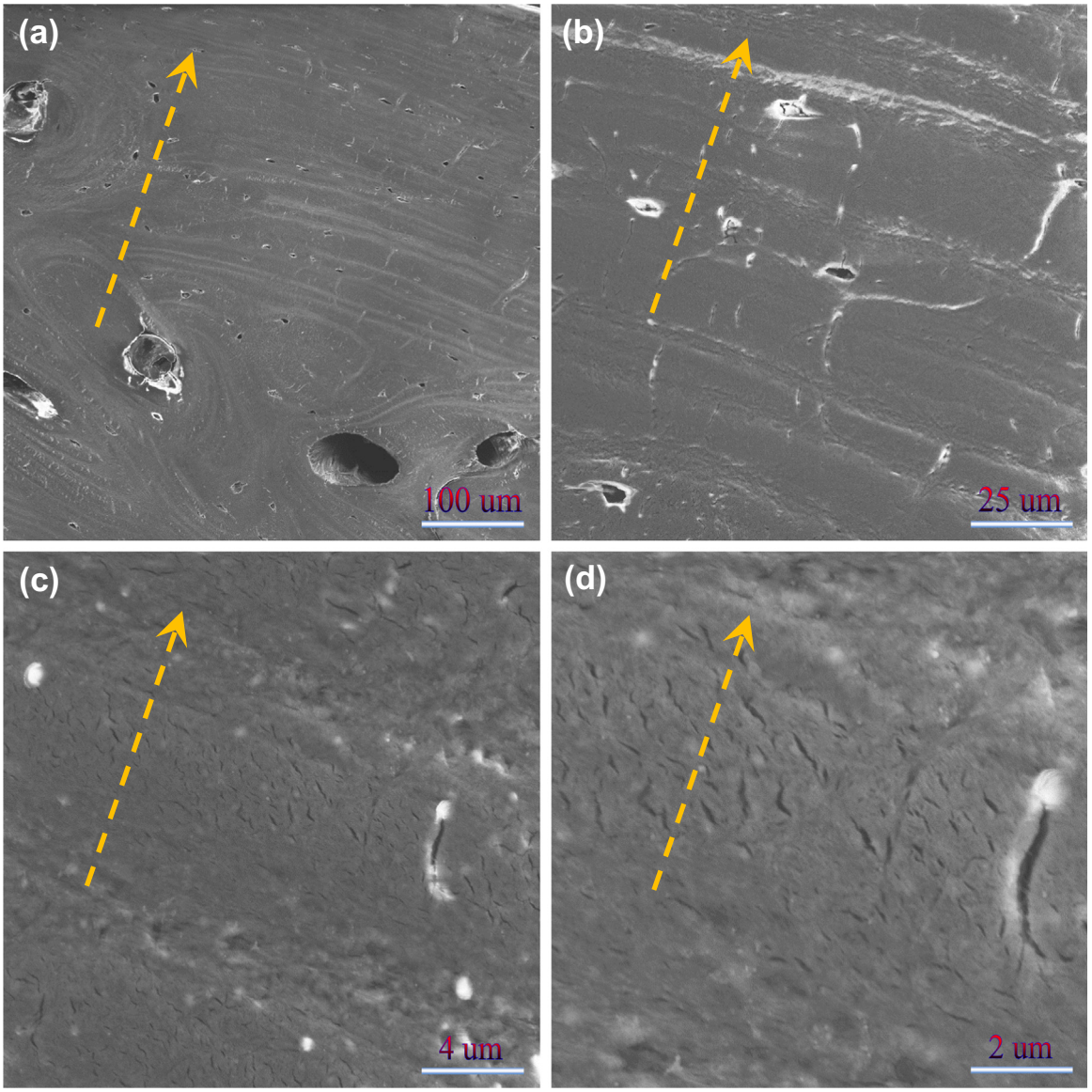

Fig. 2. SEM images showing the cross-sectional microstructure of the human frontal bone. (a)-(b) The cross section of the frontal bone appears obvious layered structure. (c)-(d) The layered structure is composed of alternately arranged compacted layers and loose layers with many cracks.

3. Results and discussion

To determine phase structures of the human frontal bone, we performed XRD analyses and showed the corresponding results in Fig. 1(a). The diffraction peaks from low angle to high angle can be consistently indexed as the {002}, {210}, {211}, {300}, {310}, {222}, {213} and {321} diffractions of the hydroxylapatite ($Ca_5(PO_4)_3(OH)$), implying that the frontal bone is in principle composed of $Ca_5(PO_4)_3(OH)$. No other crystal phase can be detected. The relative broadening of the diffraction peaks suggests