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Elastic properties and apparent density of human edentulous maxilla and mandible☆

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Abstract. The aim of this study was to determine whether elastic properties and apparent density of bone differ in different anatomical regions of the maxilla and mandible. Additional analyses assessed how elastic properties and apparent density were related. Four pairs of edentulous maxilla and mandibles were retrieved from fresh human cadavers. Bone samples from four anatomical regions (maxillary anterior, maxillary posterior, mandibular anterior, mandibular posterior) were obtained. Elastic modulus (EM) and hardness (H) were measured using the nanoindentation technique. Bone samples containing cortical and trabecular bone were used to measure composite apparent density (cAD) using Archimedes' principle. Statistical analyses used repeated measures ANOVA and Pearson correlations. Bone physical properties differed between regions of the maxilla and mandible. Generally, mandible had higher physical property measurements than maxilla. EM and H were higher in posterior than in anterior regions; the reverse was true for cAD. Posterior maxillary cAD was significantly lower than that in the three other regions.

Keywords: elastic modulus; hardness; apparent density; human maxilla; mandible.

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Dental implants have a high success rate overall, but implants placed in the posterior maxilla often fail[2,9]. This difference in clinical performance may be linked to the bone quality in different anatomical regions. A prospective multicenter study[22] reported 23% of maxillary posterior regions had type 4 (poor) bone quality compared with 1–3% in the mandible. Lekholm and Zarb[12] proposed a classification of bone quality (types 1–4) based on the amount of cortical bone and the sparseness of trabecular bone. Numerous studies have attempted to correlate this bone quality classification with implant success rate. This classification is accepted clinically because it is convenient, but it is abstract and subjective. Other quantitative measurements such as bone density and/or stiffness might be more appropriate, providing objectivity for diagnosis, treatment and research.

The material properties of bone and their variations in different types and regions of bone are important for understanding how bone responds and adapts to mechanical environment changes and are essential for accurate numerical modeling. The elastic properties (elastic modulus and hardness) of the bone contacting the implant and the amount of bone (apparent density) surrounding the implant might be important factors determining implant stability and success. Numerous papers have described the physical and mechanical

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properties of bone, especially the long bone in the field of orthopedics. There are limited studies[8,13,16,21] on the quantitative physical properties of human mandibles in relation to anatomical regions. It is difficult to find studies measuring the physical properties of the maxilla, mainly because it is difficult to obtain maxillary test samples with the specific dimensions required for techniques such as the three point bending and compression testing, since available bone is weak and limited in quantity.

The nano-indentation technique applies a micron-level sized indenter tip to the bone surface to measure the elastic properties of bone, thus eliminating the need to prepare bone samples of specific sizes. Since individual trabeculae are typically less than 500 μm thick, it is advantageous to use a technique that allows examination of the elastic properties at the microstructural level. RHO et al.[18] used nano-indentation to measure the elastic modulus (EM) and hardness (H) of individual trabeculae, osteons, and interstitial lamellae in human vertebrae and tibia.

Apparent density can be defined as 'mass of bone tissue divided by the bulk volume of the test specimen, including mineralized bone and marrow space'[14]. Trabecular bone typically varies in porosity (marrow space), and the apparent density concept has been used extensively to define trabecular bone characteristics. A fully mineralized solid matrix of bone, such as cortical bone, is regarded as quite uniform and its density is typically measured.

In the current study, cross-sectioned whole bone samples (3 mm thick, 10 mm long from the crest of alveolar ridge) containing cortical bone shell and inner trabecular bone were used to measure composite (cortical plus trabecular) apparent density (cAD) using Archimedes' principle. It was decided not to measure cortical bone density and trabecular bone apparent density separately because there was not enough cortical or trabecular bone in the maxilla and certain areas of the mandible to make specific-sized samples. There is no known formula to combine cortical bone density and trabecular bone apparent density to obtain a region-specific apparent density.

The objectives of the current study were to determine whether and how elastic properties (EM and H) and composite apparent density (cAD) differ in 4 anatomical regions of the jawbone (maxillary anterior, maxillary posterior, mandibular anterior, mandibular posterior), and to see whether these physical properties are related.

Material and methods

Sample preparation

Four sets of human edentulous maxilla and mandibles were retrieved from fresh cadavers (dead for < 72 h). All four were males without any known bone disorders. Their mean age was 83.25 (72, 91, 85, 85 years). Different anatomical regions (maxillary anterior, maxillary posterior [left and right], mandibular anterior, mandibular posterior [left and right]) were marked with indelible marker (Fig. 1). Anterior and posterior, 20 mm long, bone blocks represented the central incisor area and molar area, respectively. The midline was used to locate the center of the anterior mandibular and maxillary blocks. The mesial border of the posterior mandibular block was located 3.5 mm distal to the mental foramen midline. The distal border of the posterior maxillary block was located 8.5 mm mesial to the distal surface of the maxillary tuberosity. Each 20 mm long bone block was divided into three sections; one 8 mm middle section and two 6 mm side sections. The 8 mm middle sections were saved for future histomorphometric study. Each 6 mm side section was further divided into two 3 mm slices using a low-speed diamond blade saw (Isomet, Buehler, Lake Bluff, IL, USA), of which one was assigned to the nano-indentation and one to apparent density measurement.

Nano-indentation

For nano-indentation, the bone marrow of each unfixed 3 mm thick bone sample was removed with a water jet and bone was dehydrated with a graded series of alcohol. A total of 48 bone samples (2 samples/block x 6 blocks/cadaver x 4 cadavers) were embedded in photo-polymerizing resin (Technovit 7200 VLC, Kulzer, Germany) under vacuum to provide support for the bone network. After resin embed-

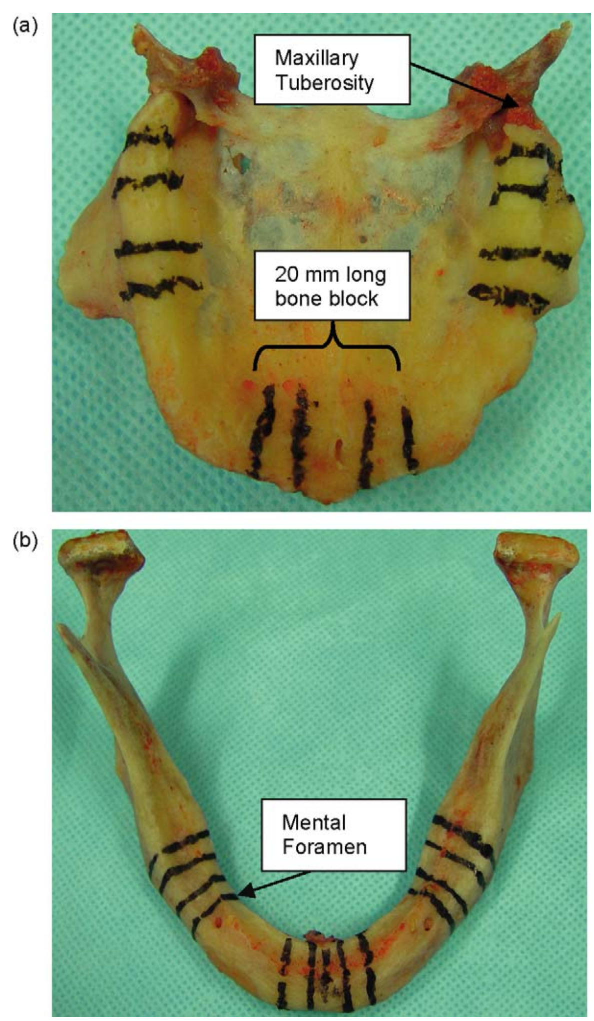

Fig. 1. Marking the anterior and posterior 20 mm long bone blocks in (a) maxilla and (b) mandible.