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Original Article

Regional variation of bone tissue properties at the human mandibular condyle

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A B S T R A C T

The temporomandibular joint (TMJ) bears different types of static and dynamic loading during occlusion and mastication. As such, characteristics of mandibular condylar bone tissue play an important role in determining the mechanical stability of the TMJ under the macro-level loading. Thus, the objective of this study was to examine regional variation of the elastic, plastic, and viscoelastic mechanical properties of human mandibular condylar bone tissue using nanoindentation. Cortical and trabecular bone were dissected from mandibular condyles of human cadavers (9 males, 54–96 years). These specimens were scanned using microcomputed tomography to obtain bone tissue mineral distribution. Then, nanoindentation was conducted on the surface of the same specimens in hydration. Plastic hardness (H) at a peak load, viscoelastic creep (Creep/P_{max}), viscosity (η), and tangent delta (tan δ) during a 30 second hold period, and elastic modulus (E) during unloading were obtained by a cycle of indentation at the same site of bone tissue. The tissue mineral and nanoindentation parameters were analyzed for the periosteal and endosteal cortex, and trabecular bone regions of the mandibular condyle. The more mineralized periosteal cortex had higher mean values of elastic modulus, plastic hardness, and viscosity but lower viscoelastic creep and tan δ than the less mineralized trabecular bone of the mandibular condyle. These characteristics of bone tissue suggest that the periosteal cortex tissue may have more effective properties to resist elastic, plastic, and viscoelastic deformation under static loading, and the trabecular bone tissue to absorb and dissipate time-dependent viscoelastic loading energy at the TMJ during static occlusion and dynamic mastication.

Introduction

Temporomandibular joint disorder (TMJD) is the second most commonly occurring musculoskeletal symptom, affecting up to 25% of Americans [1]. The TMJ is a synovial joint that has a fibrocartilaginous articular disc located between the cartilage of the articular eminence of the temporal bone and the mandibular condyle [2,3]. As masticatory muscles maintain the integrity of the TMJ, the components of the TMJ are constantly compressed during static occlusion [3–5]. During mastication, muscle contractions associated with TMJ movement can provide cyclic loading in various directions on the articular surface of the joint [4,6,7]. More than 10% of TMJD patients have osteoarthritis, which results from erosion of articular cartilage and degeneration of the bony mandibular condyle under daily loading by static occlusion and dynamic mastication [2,4]. This degeneration can develop when applied loads surpass the mechanical adaptive capacity of the TMJ. As such, it has been suggested that the mechanical properties of the mandibular condyles of the TMJ are the most important factors in determining TMJ osteoarthritis [2,4,8]. However, a lack of knowledge exists about characteristics of mandibular condylar bone tissue.

The mechanical properties of bone have been determined mainly by its elastic modulus and fracture strength using static fracture testing [9]. On the other hand, bone is a viscoelastic material in which mechanical properties change over the duration of static and dynamic loading [10–13]. As such, the viscoelastic ability of the mandibular condylar bone to absorb and dissipate the high impact energy of dynamic mastication is critical to maintain mechanical stability of the TMJ. However, few studies have been performed to investigate the viscoelastic response of mandibular bone to dynamic masticatory loading.

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Bone tissue consists mainly of water, mineral and collagen components, combinations of which determine its mechanical properties [14]. Many studies indicate that tissue mineral distributions play an important role in determining bone properties at the macro level [10,11,15–17]. However, macro level analyses cannot determine the detailed mechanical behavior of bone at the tissue level where microcracks initiate and propagate. Previous studies demonstrated that measured elastic modulus, tissue mineralization and composition of human bone are different between anatomic sites [18,19]. These results suggest that bone tissue properties are adaptive and vary by functional demands corresponding to specific anatomic sites.

In the current study, we hypothesized that the local mechanical properties of human mandibular condylar bone tissue are not uniform. This hypothesis was tested using nanoindentation, a technique that has been widely used to assess elastic modulus and plastic hardness of bone at the tissue level. Recently, it has also been applied to measure viscoelastic properties of bone tissue at various anatomical locations of different species [20–22]. Thus, the objective of this study was to examine regional variation of elastic, plastic, and viscoelastic mechanical properties of human mandibular condylar bone tissue using nanoindentation.

Materials and methods

Nine fresh human male cadaveric mandibles (75 ± 15 years) were obtained from the Division of Anatomy's Body Donation Program at The Ohio State University. Only male specimens were included to avoid possible complications due to postmenopausal bone loss and compositional changes, which are common in females. There were no records of temporomandibular joint disorders (TMJD) or gross evidence of it on the specimens. All fresh mandibles were unembalmed and were stored at −21°C until utilization. After soft tissue, with the exception of articular cartilage at the TMJ, was removed from the mandibular bone surface, one condyle from each individual mandible was transversely dissected parallel to the occlusal plane using a low speed saw (Isomet, Buehler, Lake Bluff, IL) under irrigation (Fig. 1a). A total of 7 right and 2 left side condyles were randomly obtained for this study.

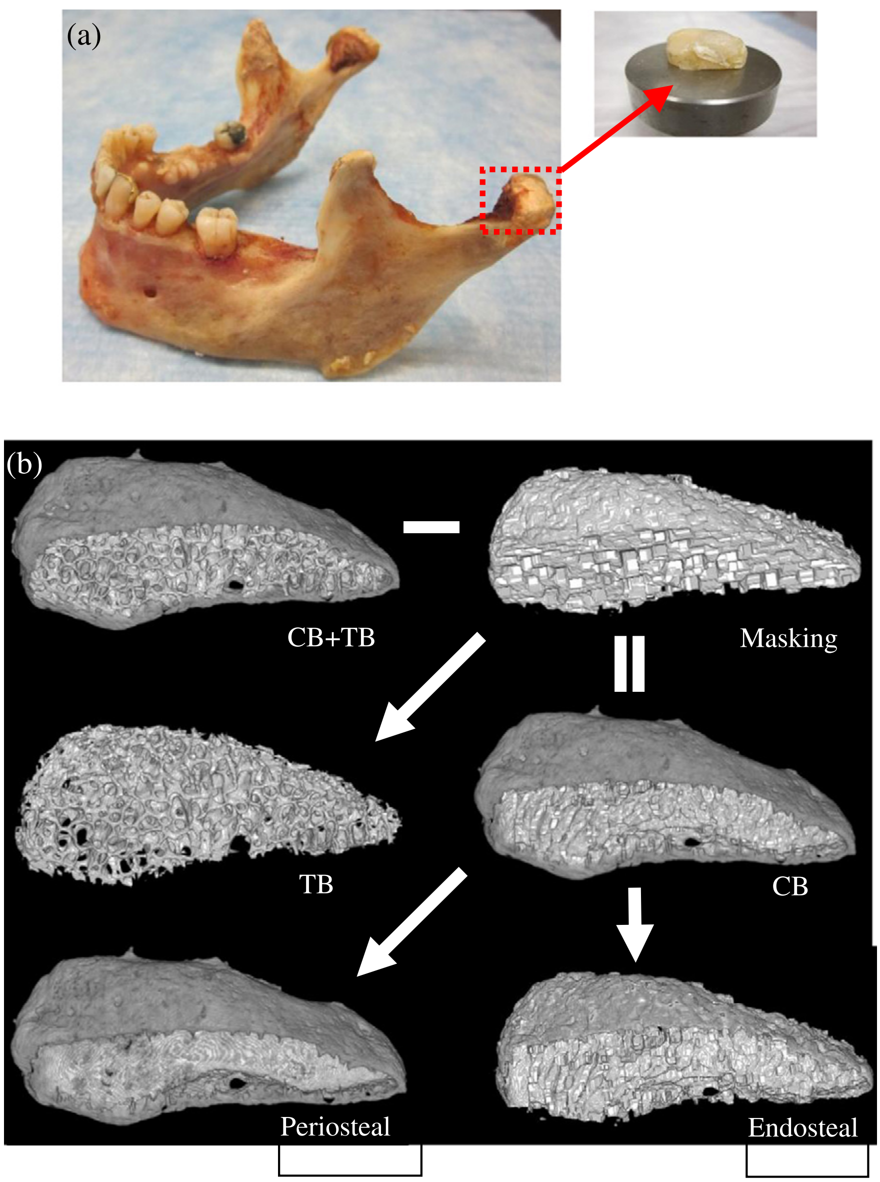

Fig. 1. (a) Isolation of a condyle from a human cadaveric mandible, and (b) the procedure used to identify the condylar centrum in masking region, the trabecular bone (TB) in the centrum, and the cortex (CB). The CB was obtained by subtracting the masking part from the whole condyle. Then, the CB was separated into periosteal and endosteal CBs.