Early tibial osteoarthrosis decreases Young’s modulus of subchondral trabecular bone.
A study in humans using scanning acoustic microscopy

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Introduction: Even though osteoarthritis (OA) is one of the three most common diseases and disabling conditions among the elderly (1), the precise etiology of OA remains unclear. OA is a complex joint disease in which microstructural, mechanical and physical/compositional factors plays roles. Previous investigations suggest significantly decreased mechanical properties and deteriorated microstructure in human early OA at trabecular bone apparent levels.

In this study, we turn our focus towards the early OA stage at the trabecular tissue levels by means of validated novel scanning acoustic microscopy (SAM) that measures acoustic impedance, which is a good measure of Young’s modulus of individual trabecular on a minute scale. We hypothesize that there is a decrease in Young’s modulus of subchondral trabecular bone in early stage OA.

Material and methods: Postmortem human subchondral trabecular bone samples from the proximal tibia condyles comprised the material. The specimens were retrieved from early stage OA [female=5, male=6, mean age 73.5 years], and normal age and gender matched proximal tibia [female=5, male=8, mean age 71.8 years] as the control group. Mankin’s criteria were used to define early stage OA and histological analysis was done to confirm changes (2). The bone samples were allocated into 2 groups: OA and normal control groups. The human bone samples were, in all aspects, handled in accordance with the rules of The Danish Ethics Committee.

The axis of the specimen corresponded to the longitudinal axis of the tibia. The harvested bone samples were embedded in epoxy (Epofix, Struers A/S, Denmark) and polished using successively finer diamond paste from 9 to 0.25 micrometer in grain size. The polishing was done to obtain surfaces without scratches and relief larger than 1 micrometer, which was required for acoustic scanning at the ultrasonic signal frequency used.

The specimens were scanned at the SAM2000 acoustic microscope (KSI GmbH, Herborn, FRG) at a signal frequency of 400 MHz. The heart of the scanning acoustic microscope is the lens, which is an ultrasonic transducer and a sapphire rod for focusing. It is the combined action of high signal frequency and the focusing sapphire rod that provides the high spatial resolution. The working principle of the microscope is illustrated in Fig. 1.

![Figure 1. Schematic figure of the acoustic lens. The microscope is truly confocal, e.g. the same lens is used for transmission and collection of reflection ultrasound. Water is used as couplant. The resolution at 400 MHz is approximately 2 micrometer.](image)

We used a simple reflection based method to measure acoustic impedance ($Z$). This method simply quantifies the reflection of ultrasound from the surface of the specimen and $Z$ is a good measure of Young’s modulus on a minute scale in bone (3). Differences in gray-level in pixels in the acoustic images are representative of differences in Young’s modulus (Fig. 2). The brightest color indicates the highest $Z$ value. The images are $1 \times 1$ mm and contain 500 x 512 pixels. The specimens were sampled continuously from a randomly positioned cross section surface. Data are presented as the medians and values their 25- and 75-quartiles. The statistical analyses were done with an F-test with a linear mixed model.

Results: Examples of SAM images of subchondral trabecular bone for OA and controls are shown in Fig. 2.

![Figure 2. Two acoustic images of subchondral trabecular bone of the tibia condyles from the early stage OA (left) and the normal (right). Compared with the normal bone, the early OA subchondral trabecular bone has a lower $Z$ value, as indicated by the darker gray tones.](image)

$Z$ value was significantly higher in the subchondral trabecular bone of the normal condyle (Table 1).

Compared with the normal controls, the amount of bone tissue (A, mm$^2$) in the OA group was significantly higher (Table 2).

![Table 1. Values of $Z$ (medians and 25/75 quartiles) acquired from the condyle of early stage OA and normal subchondral trabecular bone. Values of A (mean and SD) acquired from the condyle of early stage OA and normal subchondral trabecular bone](image)

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<th>OA</th>
<th>Normal</th>
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<tr>
<td>Acoustic impedance ($Z$)</td>
<td>Mrayl ($10^5$ kg m$^{-2}$ s$^{-1}$)</td>
<td>6.67 (5.19/9.27)</td>
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<td>Area (A) ($\text{mm}^2$)</td>
<td>(p=0.032)</td>
<td>1.30±0.35</td>
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Discussion: Our results support the hypothesis that there is decreased acoustic impedance reflecting a decreased Young’s modulus in early OA subchondral trabecular bone, although the amount of bone tissue is increased. These findings are consistent with the previous investigations on the density-mechanical properties associations at trabecular apparent levels (4). The decrease in Young’s modulus and the increase in the amount of bone tissue might suggest quality deterioration in early OA subchondral trabecular bone. Our current study provides further evidences that significantly decreased elastic modulus of the early OA subchondral bone tissue at the trabecular tissue levels.

In elucidating both normal bone function, pathogenesis and structure-function relationship changes in bone diseases, SAM could be useful and thereby may be conducive in evaluating treatments in bone disease.


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