Ultrasound evaluation of the mechanical injury of bovine knee articular cartilage under arthroscopic control

INTRODUCTION
Local articular cartilage injury can initiate the development of post-traumatic osteoarthritis. Surgical techniques have been developed to repair cartilage injuries. However, objective and sensitive methods are needed for planning the surgery and monitoring the outcome of the treatment. Quantitative ultrasound imaging is potential method for evaluating the integrity of articular cartilage. In this study, the feasibility of ultrasound arthroscopy is evaluated ex vivo in bovine knee joint.

MATERIALS AND METHOD
Bovine knee joints (n = 7) were obtained from a local slaughterhouse (Atria Oy), Kuopio, Finland. Under arthroscopy, the measurement site was first marked at distal central patella and distal femoral sulcus with a curet. Cartilage surface adjacent to the markings was mechanically degraded with a custom made steel brush and ultrasound measurements were conducted at degraded and intact sites. Subsequently, the bovine knee joints were opened and the dynamic stiffness of the cartilage was measured with an arthroscopic indentation instrument (Artscan 200, Artscan Oy, Helsinki, Finland). After the measurements cylindrical osteochondral plugs (dia = 25.4 mm), including the damaged and intact tissue, were extracted from the measurement sites and the samples were prepared for histology.

To determine the histological integrity of the samples, Safranin O stained sections were imaged with a light microscope (Stereomicroscope, Carl Zeiss Microlimaging GmbH, Göttingen, Germany). Subsequently, images were graded using the Mankin scoring by three of the authors and the score values were averaged and rounded to the nearest integer.

A high frequency (40 MHz) clinical IVUS (ClearView Ultra, Boston Scientific Corporation, San Jose, CA, USA) device was used. Signal obtained from the ultrasound device was collected with 250 MHz sampling frequency using a digital oscilloscope (Wave Runner 6051A, Chestnut Ridge, LeCroy Corporation, NY, USA) and stored for the off-line analysis using a custom-made LabView-software (National Instruments Corporation, TX, USA). Reflection coefficient (R), integrated reflection coefficient (IRC), apparent integrated backscattering coefficient (AIB) and ultrasound roughness index (URI) were determined for each measurement site. For determination of the reproducibility all the measurements were repeated three times. The reproducibilities were calculated as a standardized coefficient of variation (sCV (%),

RESULTS
Mechanically degraded tissue exhibited a low-grade cartilage damage (average Mankin score value 2) and the adjacent tissue was nearly intact (average score value 1). Ultrasound reflection (R and IRC) was lower (p = 0.001) in mechanically degraded cartilage than in adjacent tissue. In femoral cartilage, surface roughness (URI) was significantly higher in degraded tissue than in adjacent tissue (p = 0.028) (Table 1). The AIB values measured for degraded tissue were similar to those measured for adjacent intact tissue (p = 0.74 and p = 0.86 for femoral and patellar cartilage, respectively). The mark separating intact and degraded tissue was clearly visible in the ultrasound images (Figure 2). Furthermore, the average depths of the mark measured from the ultrasound images and from histological sections were in good agreement being 0.75 mm and 0.73 mm, respectively.

Significant linear correlations were observed between the cartilage indentation stiffness and R or IRC (r = 0.60, p = 0.022 and r = 0.67, p = 0.009, respectively) in patella. The reproducibility of the ultrasound and mechanical parameters was between 3.7% and 26.1% for all parameters.

DISCUSSION
Similar to previous in vitro study surface reflection parameters (R, IRC) were lower and URI higher for mechanically degraded cartilage than for intact tissue (Table 1). Furthermore, in line with the earlier study significant correlation was detected between cartilage surface reflection and cartilage stiffness. In contrast, the AIB values were similar for intact and mechanically degraded tissue indicating that the mechanical degradation extended only superficial layer of the cartilage. The depth of the cartilage lesion could be reliably measured from the ultrasound images, as also suggested earlier.

To conclude, ultrasound imaging of articular cartilage was applicable in arthroscopic conditions ex vivo and provided valuable diagnostic information on the tissue structural integrity. The development of an arthroscopic tools and procedures that enable more straightforward and reproducible positioning of the ultrasound catheter relative to cartilage surface may improve reproducibility of the arthroscopic measurements.

<table>
<thead>
<tr>
<th>R (%)</th>
<th>IRC (dB)</th>
<th>AIB (dB)</th>
<th>URI (μm)</th>
<th>Stiffness (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femur</td>
<td>Intact</td>
<td>4.1±1.3</td>
<td>61.3±1.0</td>
<td>29.5±3.6</td>
</tr>
<tr>
<td></td>
<td>Degraded</td>
<td>2.0±0.9*</td>
<td>61.4±1.4</td>
<td>24.5±6.1*</td>
</tr>
<tr>
<td>Patella</td>
<td>Intact</td>
<td>6.1±1.2</td>
<td>61.0±0.9</td>
<td>10.7±3.6</td>
</tr>
<tr>
<td></td>
<td>Degraded</td>
<td>2.7±1.4*</td>
<td>61.1±1.5</td>
<td>25.6±14.9*</td>
</tr>
</tbody>
</table>

*p < 0.05, *p = 0.08, Wilcoxon signed rank test for paired samples.

REFERENCES