Introduction
Articular cartilage lesions and degenerative osteoarthritic changes in structure and composition of the cartilage are poorly detected at their early stages with the current non-invasive imaging methods. Arthroscopy enables direct inspection of the surface of the articular cartilage, but the diagnosis is based only on qualitative and subjective visual evaluation and manual mechanical palpation. We have recently introduced an ultrasound arthroscopy application, based on intravascular ultrasound (IVUS) catheter, for arthroscopic evaluation of the integrity of articular cartilage. In this study, we tested whether the method is feasible for diagnosing various types of articular cartilage defects in vivo.

Materials and Method
Seven patients undergoing an arthroscopic surgery of the knee joint were included in the present study. During the normal arthroscopic procedures, an ultrasound examination was carried out using the same anteromedial and anterolateral portals that were used for the surgery. The articular surfaces of the knee joints were classified by the operating surgeons according to the International Cartilage Repair Society (ICRS) grading system. Ethical review board of Northern Savo hospital district has approved these human experiments.

The ultrasound measurement system consisted of a clinical IVUS main unit (ClearView Ultra, Boston Scientific Corporation, San Jose, CA, USA) and catheter (dia. = 1 mm) incorporating a miniature unfocused high-frequency ultrasound transducer (40 MHz, -6 dB bandwidth, 30.1–45.3 MHz). The ultrasound catheter was inserted into the knee joint through shielding tube and directed to the location of interest by aid of an arthroscope. The measurement sites were the central part of the patella, the femoral groove and the central plateau of the tibia. Ultrasound and arthroscopy videos were recorded for later analysis. To calculate quantitative ultrasound parameters, radiofrequency signals were also recorded and digitized at a sampling frequency of 250 MHz using a digital oscilloscope (LeCroy Corporation, Wave Runner 6051A, Chestnut Ridge, NY, USA). The signals were stored for off-line analysis on a laptop computer using a custom-made Labview-software (version 8.2, National Instruments Corporation, Austin, TX, USA). At each measurement site, three successive measurements were conducted and the best measurement (with the best perpendicularity between the articular surface and ultrasound probe) was chosen for calculation of the quantitative ultrasound parameters.

Ultrasound reflection coefficient (R), integrated reflection coefficient (IRC), apparent integrated backscattering (AIB) and ultrasound roughness index (URI) were calculated for each measurement site. Furthermore, cartilage from measurement sites were semi-quantitatively graded from blind-coded ultrasound images by one of the operating surgeons to obtain an “ultrasound score”.

Results
The arthroscopic ultrasound imaging revealed different characteristics of the articular surfaces in the knee joints of the human patients in vivo (Figure 1). In fibrillated cartilage the values of the R and IRC decreased and the value of the URI increased. The ICRS grade and the “ultrasound score” of the 13 example cases were consistent (Spearman’s correlation test, \( r = 0.939, p < 0.01 \)). The value of the “ultrasound score” differed from the ICRS grade in 4 cases out of 13. In all of these 4 cases, the “ultrasound score” was one rank higher than the ICRS grade, thus implicating that the status of the cartilage in those cases was worse when assessed with the ultrasound method than what was estimated during the conventional arthroscopy.

Discussion
Superficial fibrillation of the articular surface visible in the ultrasound image (e.g. Figure 1b) was not always visually detectable through the arthroscope suggesting that the ultrasound provides supplementary diagnostic information to the conventional arthroscopic evaluation. This finding is supported by our earlier study reporting that in laboratory conditions micrometer scale fibrillation can be quantitatively measured with the ultrasound. The cartilage surfaces that were assigned ICRS grades 0 (normal) (Figure 1a) and 1 (nearly normal) (Figure 1b) were distinguishable in the IAUS images. This important finding supports the potential of the ultrasound arthroscopy method to detect early osteoarthritic changes of the superficial cartilage.

To conclude, the ultrasound arthroscopy method served as a diagnostic in vivo method for evaluation of articular cartilage lesions. The method provided quantitative information about the cartilage integrity and thickness not available in conventional arthroscopy. Because the present equipment is already FDA approved for intravascular use, the method can be easily transferred to intra-articular use. The invasiveness of the ultrasound arthroscopy method might restrict its use, but ultrasonic assessment combined with frequently used arthroscopies may enlarge the diagnostic potential of arthroscopic surgery by adding supplementary information on the internal structure of articular cartilage.