Novel Arthroscopic Technique for Measurement of Speed of Sound in Articular Cartilage

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Introduction: Speed of sound (SOS) in articular cartilage is strongly related to the degenerative state of the tissue [1]. Thus, a technique enabling accurate SOS measurement during arthroscopy could have diagnostic value. Multimodality arthroscopy enables simultaneous arthroscopic ultrasound (US) imaging and optical coherence tomography (OCT) [2]. In the present study, a novel multimodal technique for SOS measurement is introduced and evaluated. The technique combines measurement of time-of-flight (TOF) in cartilage using high frequency US and high resolution measurement of cartilage thickness using OCT.

Methods: US (Clear View Ultra, Boston Scientific Corporation, USA) and OCT (Ilumien PCI Optimization System, St. Jude Medical, USA) systems designed for intravascular imaging were applied in this study. US (40 MHz, diam. 1.0 mm) and OCT (axial resolution <20 μm, diam. 0.9 mm) catheters were inserted through an oval shaped instrument channel and the imaging heads of the catheters were aligned adjacent to each other enabling simultaneous imaging of the same anatomical location (Fig. 1). Ten OCT frames covering area of 1×1 mm^2 below the US catheter and ten US scans were acquired simultaneously. For validation of the technique, the SOS in six different materials (elastomers, plastics and glass) were measured using a custom made scanning acoustic microscopy (50 MHz transducer, F_s = 550 MHz) and a caliper (resolution 10 μm). Subsequently, the measured SOS values were compared to those obtained using the multimodality method. The novel technique was further tested *in vitro* by measuring SOS in intact osteochondral samples (n = 25) prepared from equine fetlock joints. Finally, the measurement uncertainty of the technique was investigated using numerical simulations. This was done by systematically varying the US and OCT related measurement error in tissue with variable thickness.

Results: SOS values measured with the multimodality technique correlated significantly (Pearson's correlation: $r = 0.99$, $p < 0.01$) with the values measured with the reference technique, and no systematic bias was found (Fig. 2A). However, significant measurement uncertainty could be detected (Fig. 2B). Mean SOS in equine cartilage samples was 1618 ± 142 m/s and mean thickness of the cartilage in the samples was 0.66 mm. Numerical simulations revealed that with thin equine cartilage resolution of both US and OCT measurements are crucial for the accuracy of the SOS measurement (Fig. 3).

Discussion: Combination of US and OCT creates a possibility to measure local SOS variations in articular cartilage *in vivo*. This would be beneficial as SOS is sensitively related to tissue integrity [1]. The present study introduced a first, clinically applicable prototype of such technique. Evaluation of the technique showed consistent SOS values with those obtained with the reference technique. Furthermore, the SOS values measured for the equine cartilage samples agreed with those in the literature [3]. However, the resolutions of US and OCT measurements were observed to set limits for the accuracy of the technique when measuring thin equine cartilage. Theoretically, the accuracy is better in thick human cartilage, but the limited capability of light and ultrasound to penetrate through cartilage may affect the applicability of the technique. If these technical issues could be solved, the present technique might provide valuable information on cartilage degenerative state during arthroscopy.

Significance: SOS reflects both mechanical and compositional properties of articular cartilage [1,4]. The presented technique, applicable during arthroscopy, enables measurement of SOS in cartilage and could, therefore, be of great benefit in evaluation of cartilage degenerative state. However, technical improvement is needed before clinically applying the technique.

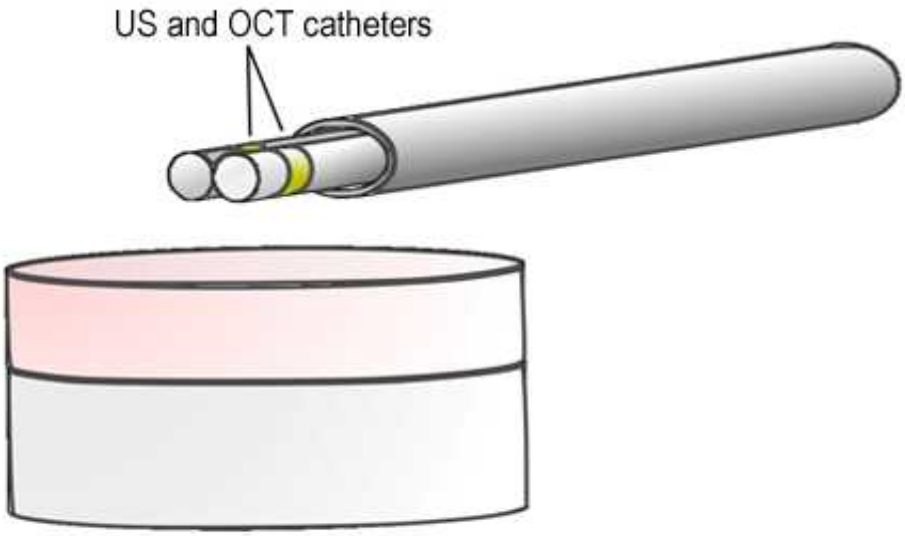

Fig. 1 The measurement setup. Adjacent US and OCT catheters are inserted through an instrument channel enabling simultaneous imaging of the same location.

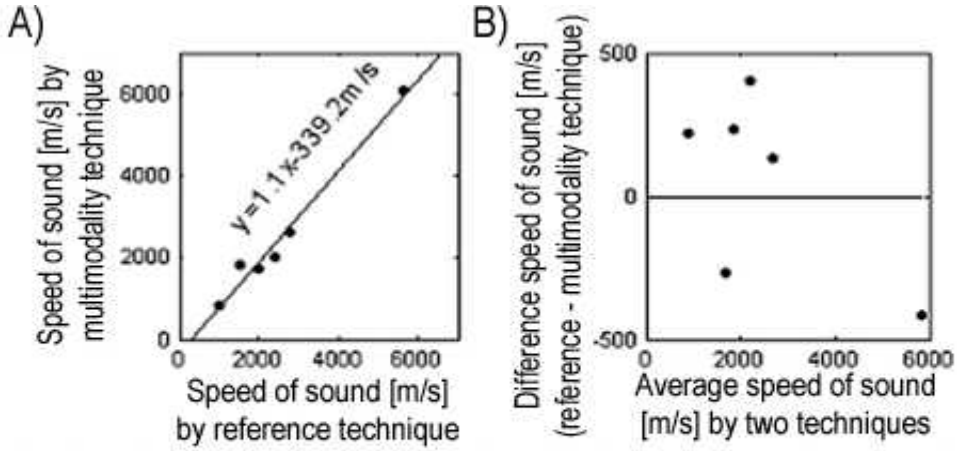

Fig. 2 A) Correlation and **B)** Bland-Altman plots of speed of sound values in elastomer, plastic and glass materials determined with the multimodality and reference techniques.

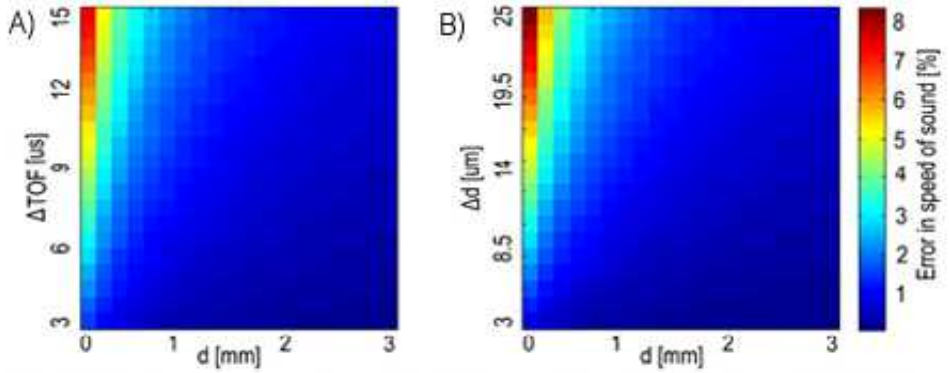

Fig. 3 Simulated effect of sample thickness (d) and resolutions of **A)** US (ΔTOF) and **B)** OCT (Δd) measurements on error in SOS of cartilage with varying thickness.

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