Ultrasound Elastography of Articular Cartilage May Be Affected by Strain-dependent Variation in Ultrasound Speed

Pauno Lötjönen1, Juha Töyräs2, Jukka S. Jurvelin1,3, Heikki J. Nieminen1

1Department of Physics, University of Kuopio, Kuopio, Finland; 2Department of Clinical Neurophysiology, Kuopio University Hospital and University of Kuopio, Kuopio, Finland; 3Department of Clinical Neurophysiology and Nuclear Medicine, Kuopio University Hospital, Kuopio, Finland

lotjonen@hytti.uku.fi

Introduction: In ultrasound (US) elastography of articular cartilage (AC), US measurements are conducted during mechanical deformation of tissue. The displacements of internal strains in tissue are determined by tracking the backscattered US echoes [1], which enables, provided that the acting stress is known, determination of spatial elastic properties of the tissue. Similarly, in mechano-acoustic indentation US is exploited in strain estimation and determination of AC elastic modulus. These methods rely significantly on the constancy of US speed during mechanical compression. However, it has been shown that US speed in AC varies under mechanical compression [2,3] possibly due to the changes in collagen architecture and fluid content. This may, furthermore, induce gross errors to mechano-acoustically determined mechanical AC properties, i.e. strain and elastic modulus [2]. If e.g. strain-dependency of US speed was well-known, compression-related errors in mechano-acoustically determined parameters could possibly be avoided or corrected. However, the strain dependency of US speed under instantaneous compression has not been studied. To clarify this issue, we investigated the strain-dependency of US speed in bovine AC under mechanical compression.

Materials and Methods: Full thickness AC samples (n = 7, dia. = 4100 ± 100 μm) were prepared from lateral upper quadrant of seven visually normal bovine patellae. Subsequent mechano-acoustic measurements were conducted with a custom-made apparatus [4]. The samples were immersed in phosphate-buffered saline (PBS) and positioned between the US transducer (peak frequency: 8.1 MHz, 4.6 - 14.6 MHz, -6dB, M-116, Panametrics, Waltham, MA) and a metallic plate. To secure uniform contact, a 5% pre-strain was applied. After one-hour of relaxation at pre-strain, a sequence of six compression test (strain-rate: 10%/s) was applied at pre-strain at the beginning of the test sequence was 1619 ± 10 m/s. Change in US speed was found to increase as a function of the magnitude of true strain (p<0.05, non-parametric Friedman test, Figure 1) and higher at higher strains. The mean US speed at pre-strain was 1619 ± 10 m/s.

Discussion: The compression-induced change in US speed increased as a function of applied strain. However, the relative error in acoustically determined strain was found to be smaller at higher compressive strains. The change in US speed may be mainly controlled by changes in collagen architecture as no significant fluid flow probably occurs during instantaneous compression [2].

According to the findings of the present study, it may be suggested that higher strains are preferable if strain in full-thickness cartilage is determined acoustically, e.g. in elastography or mechano-acoustic indentation. However, it is not known how the US speed changes spatially under compression. Therefore, it is possible that compression-related errors in determination of strain are significantly different at different tissue depths.

Further studies are required to reveal spatial strain-US speed relations and if compression-related errors in mechano-acoustically determined parameters could be minimized in normal and degenerated articular cartilage.


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Figure 1: Relative change in US speed (mean ± SD) was dependent on the magnitude of applied strain (mean ± SD). Change in US speed was found to increase as a function of the strain (p<0.05). The mean US speed at pre-strain was 1619 ± 10 m/s.

Figure 2: Relative error in acoustically determined strain (mean ± SD) was dependent on the magnitude of applied strain (mean ± SD). The relative error induced in acoustically determined tissue strain was smaller with higher strains (p<0.05).