Ultrasonic Evaluation Reveals Superficial Degeneration of Articular Cartilage - Effect of Cartilage Surface Inclination on Acoustic Parameters

INTRODUCTION

High resolution intra-articular ultrasound imaging provides a potential quantitative technique for the diagnostics of early osteoarthritis (OA). However, an uncontrolled, non-perpendicular incident angle of an ultrasound beam or the natural curvature of the cartilage surface may impair the reliability of the ultrasound measurements [1]. In this study we systematically adjusted the inclination of the articular surface and analyzed the effect on quantitative ultrasound parameters in time and frequency domains. Thereby, we aimed to see whether non-optimal measurement geometry jeopardizes ultrasound diagnostics of early OA.

METHODS

Visually intact (n=2) and mechanically degraded (n=2) osteochondral bovine patella samples and spontaneously fibrillated (n=1) or proteoglycan (PG) depleted (n=1) osteochondral human tibia samples were imaged using a 50 MHz scanning acoustic system (Physical Acoustics Corporation, Princeton, NJ). The surface of each sample was adjusted to known inclination angles (0, 2, 5 and 7 degrees) (Fig. 1A) and five ultrasound scan lines along inclination were analyzed (Fig. 1B). For each scan line, Reflection coefficient (R), Integrated Reflection Coefficient (IRC) and Ultrasound Roughness Index (URI) were calculated as described earlier [2,3]. For reference, the surfaces of the samples were imaged with a scanning electron microscope (SEM) and a light microscope (Fig. 2).

RESULTS

Inclination of the cartilage surface affected all investigated ultrasound parameters (Table 1). When the surfaces of the samples were inclined from 0° to 7°, the values of R and IRC, as an average of all samples, decreased from 2.0% and -34.9 dB to 0.4% and -46.9 dB, respectively. The surface inclination also affected URI. The average values of the URI were 21.2 μm and 29.4 μm at 0° and 7° surface inclination, respectively. The average values for relative changes between the incident angles 0° and 7°, normalized using the range of variation within all measurements of the parameter in the zero angle, were -62.1% for R, -64.3% for IRC and 10.0% for URI.

Surface inclination affected the values of the ultrasound parameters less in the spontaneously fibrillated sample than in the other samples. When the surface was not inclined, all ultrasound parameters discriminated the spontaneously degenerated samples from the intact ones. Further, the ultrasound parameters distinguished the fibrillated sample (Mankin score = 6, i.e. moderate degeneration) from the intact ones even when the degenerated sample was inclined.

DISCUSSION

When determined without surface inclination, the ultrasound parameters distinguished the spontaneously degenerated samples from the intact ones. Further, the fibrillated sample was discerned from the non-inclined intact ones despite the inclination of the degenerated sample surface.

R and IRC decreased significantly as a function of the inclination angle. Interestingly, the decrease was different in the samples with intact or fibrillated surface. In the fibrillated sample, the surface inclination affected the recorded values of R and IRC minimally. This may be explained by the different contributions of specular reflection and scattering, the latter being more dominant in a fibrillated cartilage surface. The relative effect of the inclination of the sample was smaller on the URI than on the reflection parameters. However, changes in the URI were probably due to deterioration of the signal-to-noise ratio and the pulse shape of the ultrasound signal at the higher angles of incidence.

In a point measurement the surface inclination can be minimized by finding the position yielding the maximum reflection amplitude. In a scanning measurement the correction could be done afterwards using the time of flight information. In principle, the correction for minimizing the effect of a variable angle of incidence is possible in clinical measurements. These issues still require more investigation with a wide spectrum of samples showing signs of spontaneous degeneration.

REFERENCES


Table 1: Ultrasound parameters of intact, mechanically degraded and spontaneously degenerated cartilage samples as a function of surface inclination. Inclining affects all parameters. However, the spontaneously fibrillated sample can always be discerned from the intact samples despite its variable inclination.