FREQUENCY CONTENT OF CARTILAGE IMPACT SIGNAL REFLECTS ACUTE HISTOLOGIC STRUCTURAL DAMAGE

Anneliese Heiner, James Martin, Todd McKinley, Jessica Goetz, Daniel Thedens and Thomas Brown

University of Iowa, Iowa City, IA, USA
email: anneliese-heiner@uiowa.edu web: http://poppy.obrl.uiowa.edu/

INTRODUCTION

Controlled impaction of articular cartilage provides a model for studying cartilage injury associated with post-traumatic osteoarthritis. Typically, cartilage explant specimens are struck with an impactor, and the resulting chondrocyte viability, chondrocyte metabolism, or structural damage is compared to nonimpacted controls. Mechanical measures from the impact itself, such as cartilage loading rate and peak impact force, are also frequently measured.

Determining cartilage impact damage histologically requires appreciable time and expense for specimen preparation. In contrast, mechanical measures from the impact can be quickly determined from the impact force trace.

The purpose of this study was to determine if a relationship could be detected between a new mechanical outcome measure and histologically-apparent cartilage structural damage. The new mechanical measure was a quantification of the frequency response of the impact force trace, namely, the percent of the total signal with high-frequency content. Histologically-apparent cartilage structural damage was evaluated with a histologic scale designed to quantify acute damage.

METHODS

Osteochondral specimens excised from bovine lateral tibial plateaus were each impacted once using a drop tower. The impactor tip was a flat-ended, 5.5 mm diameter brass cylinder with a rounded edge. One of six impact energies was delivered with one of two masses (0.59 or 1.04 kg). An accelerometer measured impact force (Fig. 1a). Each impact force trace underwent frequency analysis by Fast Fourier Transform (Fig. 1b), with a resonant peak at around 5 KHz being digitally filtered out. The amount of high-frequency content in each impact trace was then calculated as the percent of the total signal that was greater than 2 KHz. Two KHz was chosen because the most regular impact traces (such as the impact trace designated as “4%” in Fig. 1) had minimal signal content above that frequency.

Figure 1: Impact traces from bovine osteochondral specimens – a) stress versus time and b) signal versus frequency (inset shows higher-frequency components in more detail). The impact traces shown demonstrate a range of the percent total signal greater than 2 KHz.
Specimens underwent histologic analysis to quantify acute structural damage resulting from the impact. OARSI guidelines for histological preparation were followed. Five-micron-thick sections were selected from the center of the impact site, stained with Safranin-O, digitized on a stepper-motor-driven microscope stage, and reconstructed into high-resolution JPEG images.

Each digitized section was evaluated on a new eight-point scale developed to quantify acute structural damage in terms of articular surface cracking and cartilage crushing (Fig. 2). Articular surface crack damage was given a score of 0, 1, or 2. Cartilage crush scores were assigned independently of, and weighted greater than, the articular surface damage score. Sections were given crush scores of 0, 3, 4, or 5. The articular surface crack score was added to the cartilage crush score to get a total specimen damage score ranging from 0 to 7. Three experienced observers applied the scoring scale to the histological sections on two separate occasions, yielding six separate observations for each specimen. The six scores were averaged to yield a mean value for each specimen.

Kendall’s coefficient of concordance (W) was calculated between the frequency content measure and the specimen-averaged histologic damage score for all data, and for each impact mass separately.

RESULTS AND DISCUSSION

The histologic structural damage score increased with the proportion of high-frequency content in the impact trace (Fig. 3). The coefficients of concordance were 0.864 (p = 0.005) for all data, 0.851 (p = 0.035) for the lower-mass impacts, and 0.927 (p = 0.017) for the higher-mass impacts.

The frequency content measure and the cartilage structural damage score had good concordance, for the data as a whole and for each separate impact mass. This suggests that the frequency content of a cartilage impact signal, specifically the proportion of high-frequency force components, could be used as a surrogate measure of acute cartilage injury. Taking advantage of this relationship could reduce the time and expense of histological processing needed to morphologically assess cartilage damage, for purposes of initial screening when evaluating new impaction protocols.

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