Indentation Method to Map Mechanical Properties of Articular Surface to Identify Degenerated Regions

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Introduction: The identification and quantitative grading of early degenerated regions over an entire articular surface remains a challenging quest. The objective of this study was to investigate the ability of a novel technique to automatically characterize mechanical properties of entire human articular surfaces in indentation in order to rapidly and non-destructively discriminate between damaged and healthy articular cartilage regions.

Materials and Methods: Complete articular surfaces from 8 distal femurs of human tissue donors aged 46 to 64 years were obtained from RTI Surgical. Articular lesions were graded with the visual ICRS classification system. Mechanical properties were mapped *ex vivo*, using a novel technique allowing for automated indentation mapping of articular surfaces (Mach-1 v500css, Biomomentum Inc.). Subsequently, the thickness was measured with an adapted version of the needle technique. The instantaneous modulus at each position was obtained by fitting the load-displacement curve (with corresponding thickness) to an elastic model in indentation. 72 osteochondral cores were harvested from healthy (ICRS Grade 0) and osteoarthritis (OA)-like regions (ICRS Grade > 0) and scored with the Mankin histological grading system in which higher scores indicate degraded tissue quality. From those cores, 21 were tested in unconfined compression where mechanical properties were extracted from the stress relaxation curve prior to histoprocessing.

Results: OA-like regions were identified mechanically and were wider than the regions identified by visual assessment (Blue-green regions in Fig. 1A). A strong correlation ($r = 0.84$, $p<0.0001$) was observed between the mechanical properties measured in indentation and in unconfined compression (Fig. 1B) while correlation with the Mankin score was lower ($r = -0.39$, $p<0.0007$). The Safranin O/Fast Green stained section of osteochondral cores (Fig. 2) showed a decrease in the GAG content for decreased instantaneous modulus. Excluding sample preparation time, the completion of each indentation takes 1 minute/position of machine time.

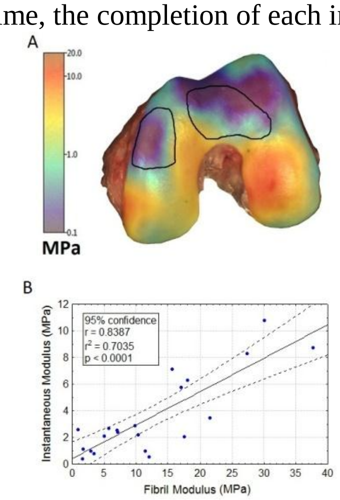

Figure 1: A) Mapping of the instantaneous modulus to identify OA-like articular cartilage. Regions with an ICRS Grade > 0 are circled. B) Significant correlation between the instantaneous modulus and fibril modulus.

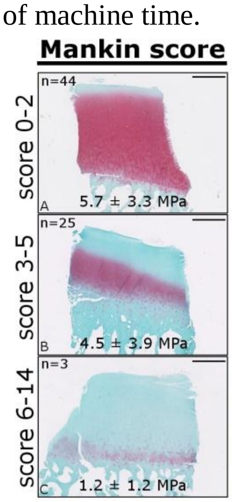

Figure 2: Representative Safranin O/Fast Green stained sections for three groupings (A, B, C) of the Mankin score and the corresponding instantaneous modulus (mean ± SD). Bars = 1 mm.

Conclusions: Our results clearly demonstrate the capabilities of this novel automatic indentation technique to rapidly, objectively and non-destructively map the biomechanical properties of full articular surfaces and to reveal degenerated regions. This automated indentation mapping technique would be of great use in the identification of wear patterns in osteoarthritis progression and in cartilage repair studies.