Combined Mechanical Characterizations Increases Sensitivity in the Assessment of Human Cartilage Degeneration

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INTRODUCTION: We published a recent study showing superior sensitivity of electromechanical and indentation (instantaneous response) assessments versus well-established techniques, including histological Mankin score, to characterize cartilage degeneration [1]. This study aims to determine whether the combination of instantaneous, relaxation and equilibrium mechanical properties and friction measurements (surface integrity) could increase sensitivity to detect cartilage degeneration.

METHODS: To ensure the presence of different degeneration grades, healthy and degenerated cartilage were isolated from human cadaveric (RTI Surgical Inc., FL, USA) and TKR samples, respectively. Four patellas were used because of their high homogeneity throughout their entire surface and importance in joint health [2]. On the entire articular surface, an electromechanical *QP* mapping was first performed using the Arthro-BST [3]. The surface was then graded by an orthopaedic surgeon in accordance with the ICRS grading system [4] to assess cartilage degeneration. Subsequently, an automated indentation mapping [1] was performed at matching positions. Ten osteochondral cores per ICRS grade (0 to 3; 4 being mostly bone was excluded from this study) were then harvested from the patellas. Each core was tested following the sequence previously developed [5] where 12 parameters were extracted (**Fig. 1**). These parameters have been classified as shown in **Table 1**. A multiaxial mechanical tester, Mach-1 v500css (Biomomentum Inc.), was used for all mechanical tests. All statistical tests were done in SAS version 9.3 (SAS Institute Inc., NC, USA).

RESULTS: A general linear model revealed that at least one parameter per category provide high to moderate significant prediction of cartilage degeneration through ICRS grades (**Table 1**). Moreover, the combination which includes a parameter from the instantaneous response and 1 or 2 parameters from the other categories improved model fit (R^2), suggesting increased sensitivity in the differentiation of ICRS grades (**Table 2**).

DISCUSSION: This study established that a combination of different mechanical responses, where one should be an instantaneous response, predicts cartilage degeneration better than a single parameter. These results may reflect the fact that the patellofemoral joint is subjected to both load-bearing and friction [6], corresponding to different modes of cartilage function.

SIGNIFICANCE: There is a lack of gold standard techniques allowing a sensitive distinction of cartilage degeneration stages. This study on the combination of instantaneous response with relaxation, equilibrium response and/or surface integrity parameters could lead to a novel approach of assessing cartilage integrity in studies of cartilage repair or degeneration.

REFERENCES: [1] Sim 2016, J Orthop Res DOI 10.1002/jor.23330 [2] Franke 2011, Mat Sci Eng C 31:789 [3] Sim 2014, Osteoarthritis Cartilage 22:1926 [4] Mainil-Varlet 2003, J Bone Joint Surg Am 85:45 [5] Sim 2016, Transactions of the 62th Annual Meeting of the ORS Poster No. 0527 [6] Hinman 2007, Rheumatology 46:1057

FIGURES AND TABLES:

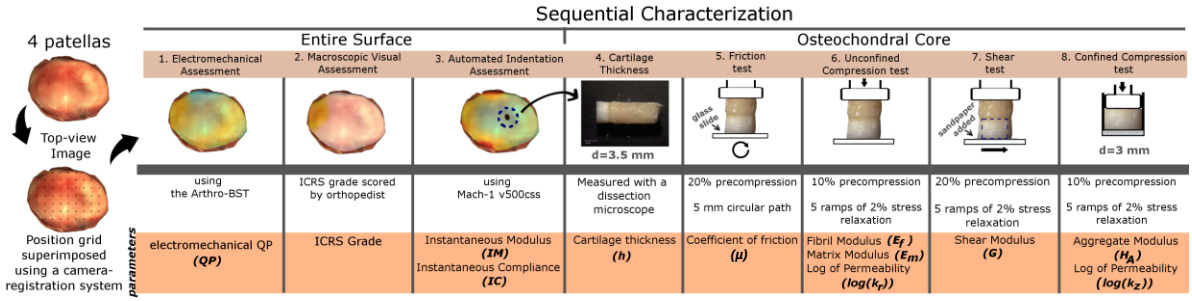

Figure 1. Sequential characterization of entire surface and osteochondral core.

Table 1. Simple General Linear Model Statistical Analysis (only statistically significant parameters are presented)

General Linear Model	model ICRS Grade = $\beta_1(X_1)$		
Test	X_1	β_1	R^2
Instantaneous Response			
Indentation	*log(IM)*	-1.736	0.753 **
Indentation	*IC*	16.715	0.714 **
Electromechanics	*QP*	0.154	0.634 **
Shear	*G*	-4.134	0.484 **
Unconfined Compression	E_f	-0.046	0.199 *
Relaxation Response			
Unconfined Compression	$log(k_r)$	1.088	0.549 **
Equilibrium Response			
Unconfined Compression	E_m	-1.294	0.495 **
Confined Compression	H_A	-0.980	0.193 *
Surface Integrity			
Friction	μ	3.526	0.129 *

** p<0.0001; * p<0.05

Table 2. Multiple Regression Model Statistical Analysis (top 5 best models are showed – higher R^2 and significant parameters)

Multiple Regression Model	model ICRS Grade = $\beta_1(X_1) + \beta_2(X_2) + \beta_3(X_3)$	
$X_{i \text{ where } i=1 \text{ to } 3}$	β_i	R^2
log(IM)	−1.360 **	0.842 **
$log(k_r)$	0.377 *	
μ	1.656 *	
IC	12.697 **	0.824 **
$log(k_r)$	0.438 *	
μ	1.661 *	
IC	12.374 **	0.799 **
$log(k_r)$	0.536 *	
log(IM)	−1.431 *	0.783 **
E_m	−0.422 **	
QP	0.149 **	0.714 **
$log(k_r)$	2.789 *	

** p<0.0001; * p<0.05