Comparison Between *In Vitro* and Simulated Arthroscopy Electromechanical Measurements of Human Articular Surfaces Using the Arthro-BST

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Purpose*: The original output of the Arthro-BST, the streaming potential integral (SPI) parameter (Abedian-2013), has been recently changed to a new quantitative parameter (QP) which is inversely proportional to the electromechanical activity of cartilage (Sim-2014). The purpose of this study was to investigate whether QP values are reliable for assessing articular cartilage in a clinical context.* ***Materials & Methods****: One closed cadaveric knee joint was obtained from Science Care (Arizona, USA). An orthopaedist opened the joint and defined 12 measurement sites on the distal femur with a permanent marker. The joint was then closed with sutures and arthroscopy was performed. The distal femur was then isolated from the joint and in vitro measurements were performed at matched sites by 4 users (the orthopaedist and 3 engineers). Visual ICRS scoring and histological Mankin scores were obtained for all sites.* ***Results****: An intraclass correlation coefficient (ICC) of 0.85 (95%CI: 0.68–0.95) was calculated among the four users, while an ICC of 0.89 (95%CI: 0.63–0.97) was found between QP values obtained under simulated arthroscopy and in vitro. Strong correlations were found between simulated arthroscopy and in vitro QP values (r=0.83, p=0.0009, N=12, Fig.1). Strong correlations were also obtained between the QP values obtained arthroscopically and the Mankin Score (r=0.84, p=0.0007, N=12, Fig.2a) and the ICRS Scoring (r=0.80, p=0.001, N=12, Fig.2b).* ***Conclusion****: This study revealed strong correlations of QP values obtained in arthroscopy with histological Mankin and visual ICRS scores. In addition to correlation of QP with gold standards, high ICCs suggest that the Arthro-BST could be considered as a powerful tool for articular cartilage assessment in a clinical context.*

Introduction

Compression-induced streaming potentials of articular cartilage can be measured through the electromechanical probe Arthro-BST (Biomomentum Inc., Laval, Quebec). This probe is composed of an array of 37 microelectrodes which records these electric potential signals as a function of time (few seconds). Previously, the software computed streaming potentials integrals (SPI) as their integration for a predefined area of contact[1; 2]. Currently, the analysis of these signals was improved by computing the quantitative parameter (QP) as the area of contact for a predefined streaming potential integral[3; 4]. The new QP output has significant advantages versus the former SPI output including robustness to noise.

The purpose of this study was to investigate whether QP values are reliable for assessing articular cartilage in a clinical context. Intraclass correlation coefficient analysis of QP values obtained *in vitro* between users provides one important characteristic of the electromechanical probe which is its user-independency. Then, an intraclass correlation coefficient analysis and Pearson's correlation analysis will determine agreement of QP values obtained *in vitro* and in simulated arthroscopy. Finally, an indicator of reliability for assessing articular cartilage in a clinical context will be given by an analysis comparing QP values obtained in simulated arthroscopy to gold standards in clinical contexts such as histological Mankin score and macroscopic visual ICRS grading.

Materials & Methods

A fresh cadaveric knee joint was obtained from Science Care (Arizona, USA). An orthopaedist surgically opened the joint in order to define 12 measurement sites on the distal femur with a permanent marker. The surgeon then closed the site with sutures. The cadaveric knee was held in 90° of flexion with a vice in order to use the electromechanical probe Arthro-BST (Biomomentum Inc., Laval, Canada) in conjunction with simulated arthroscopy. Compression-induced streaming potentials were obtained at each of 12 measurement sites by the surgeon. Then, the distal femur was isolated from the joint and *in vitro* electromechanical measurements were obtained at matched sites by 4 users (the orthopaedist and 3 engineers) using the benchtop version of the electromechanical probe. Subsequent to electromechanical measurements, biopsies were extracted at all 12 sites for macroscopic visual ICRS scoring[5] and histological Mankin scores[6].

The Arthro-BST measures compression-induced streaming potentials of articular cartilage[7; 8]. The current output of the probe is the quantitative parameter (QP) which reflects the number of microelectrodes in contact with the cartilage when the sum of streaming potentials reaches 100 mV. This QP is inversely proportional to the electromechanical activity of cartilage.

In this study, raw streaming potentials obtained at the time of measurement were analyzed with the former and current algorithm to extract the SPI and QP respectively. The intraclass correlation coefficient (ICC) was calculated among the four users and between both output values obtained in simulated arthroscopy and *in vitro*. Pearson's correlation coefficient (*r*) was also calculated using SPI and QP values obtained in both configurations of the electromechanical probe. Relationships between both output values obtained in simulated arthroscopy, histological ICRS score and macroscopic ICRS score were assessed by parametric correlation analysis using the Pearson's correlation coefficient (*r*). All statistical analyses were performed with SAS version 9.3 (SAS Institute Inc., Cary, NC).

Results

The intraclass correlation coefficient analysis of QP values, obtained *in vitro*, revealed a good agreement between the four users (ICC of 0.85 (95%CI: 0.68–0.95)) which suggest that QP values are user-independent. Using SPI values, the agreement between users is reflected through an ICC of 0.87 (95%CI: 0.71–0.96).

Another intraclass correlation coefficient analysis on QP values, obtained comparing simulated arthroscopy to *in vitro* measurements, shows good agreement between electromechanical properties obtained in the two configurations (ICC of 0.89 (95%CI: 0.63–0.97)). Using SPI values, the agreement between *in vitro* and simulated arthroscopy measurements is lower at 0.64 (95%CI: 0.14-0.88). Moreover, a Pearson's correlation analysis revealed a meaningful correlation between both QP values obtained in simulated arthroscopy and *in vitro* (r=0.83, p=0.0009, N=12, Fig.1). In contrast, a weak correlation between both configurations using SPI values was found (r=0.63, p=0.02).

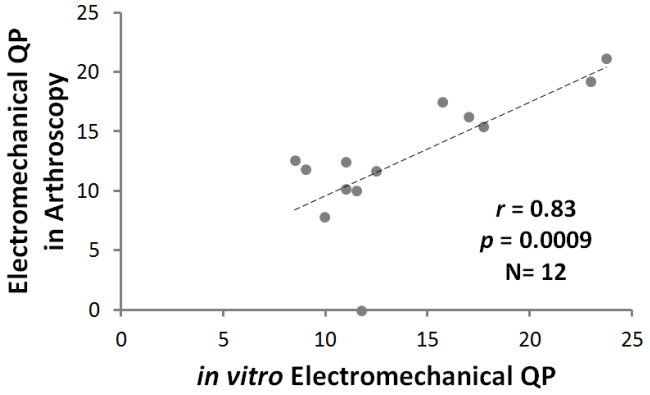

Figure 1. Positive correlation between simulated arthroscopy and *in vitro* electromechanical QP values at 12 positions.

A high QP reveals cartilage degeneration, thus weaker electromechanical properties due to GAG depletion, swelling or loss of cartilage thickness and weakening of the collagen

network. These changes in the cartilage also lead to higher histological Mankin scores and macroscopic visual scoring. Thus as expected, we found strong significant correlations between the QP values obtained arthroscopically and the Mankin Score (r=0.84, p=0.0007, N=12, Fig.2a) and ICRS Scoring (r=0.80, p=0.001, N=12, Fig.2b). However, using the former SPI values, correlations were weak and not significant with the histological Mankin score (r=−0.54, p=0.07, N=12) and moderate and significant with the visual ICRS score (r=−0.60, p=0.074 N=12).

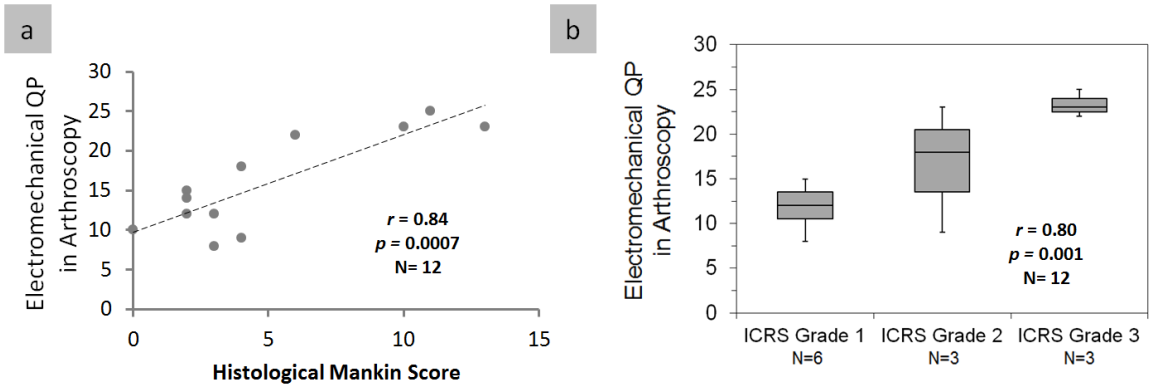

Figure 2. a) Positive correlation between electromechanical QP in arthroscopy and histological Mankin Score b) Positive correlation between electromechanical QP in arthroscopy and ICRS Grade. Boxplots displays median values (central horizontal line), first and third quartiles (box) and 1.5 x interquartile range (bars).

Conclusion

The purpose of this study was to investigate whether QP values are reliable for assessing articular cartilage in a clinical context. This study revealed strong correlations of QP obtained in arthroscopy with histological Mankin and visual ICRS scores. In addition to correlation of QP with gold standards, high ICCs suggest that the QP values are reliable indicators of electromechanical properties of articular cartilage.

This study confirmed that the current QP analysis of streaming potentials is still user-independent as the former analysis, but it is more robust and reliable than former SPI measurements. Indeed, as can be observed, both output values are user-independent (ICC of 0.85 for QP and ICC of 0.87 for SPI), where the user-independency of SPI values was reported by many previous studies[2; 9; 10]. Indeed, the Arthro-BST has already been shown to be reliable in measuring streaming potentials of equine articular cartilage[9], where an ICC of 0.861 was obtained for inter-user utilization and intra-user ICCs of 0.898 and 0.917 were obtained, indicating excellent agreement between and within users' measurements. Another study measuring the electromechanical properties of human articular cartilage using the Arthro-BST[10] also showed the reliability of the device for multiple users (n=5). The high value of the intraclass correlation coefficient (0.87) demonstrated that the Arthro-BST can provide user-independent cartilage

electromechanical properties. Thus, the current algorithm of the Arthro-BST still provides user-independency for electromechanical properties using the QP values, as expected.

However, the former analysis used the area of contact as trigger to determine the streaming potentials integrals, where the latter analysis uses the streaming potentials integral to determine the area of contact, thus the number of microelectrodes in contact at a certain threshold (100 mV). This current output, QP, is consequently inversely proportional to the former SPI but giving better correlation with gold standards such as histological or macroscopic scores and better agreement between *in vitro* and arthroscopy configurations. The results clearly show that QP values are more robust and reliable than SPI measurements in the arthroscopic environment.

Considering all these results, strong correlations with gold standards and high ICCs, the current computation of QP values suggests that the electromechanical probe could be considered as a powerful tool for articular cartilage assessment in a clinical context.

References

1. Abedian R, Willbold E, Becher C, et al. 2013. In vitro electro-mechanical characterization of human knee articular cartilage of different degeneration levels: a comparison with ICRS and Mankin scores. Journal of biomechanics 46:1328-1334.
2. Becher C, Ricklefs M, Willbold E, et al. 2015. Electromechanical Assessment of Human Knee Articular Cartilage with Compression-Induced Streaming Potentials. Cartilage.
3. Sim S, Chevrier A, Garon M, et al. 2014. Non-destructive electromechanical assessment (Arthro-BST) of human articular cartilage correlates with histological scores and biomechanical properties. Osteoarthritis and cartilage / OARS, Osteoarthritis Research Society:10.
4. Sim S, Chevrier A, Garon M, et al. 2016. Electromechanical probe and automated indentation maps are sensitive techniques in assessing early degenerated human articular cartilage. Journal of orthopaedic research : official publication of the Orthopaedic Research Society.
5. Mainil-Varlet P, Aigner T, Brittberg M, et al. 2003. Histological assessment of cartilage repair: a report by the Histology Endpoint Committee of the International Cartilage Repair Society (ICRS). The Journal of bone and joint surgery American volume 85-A Suppl 2:45-57.
6. Mankin HJ, Dorfman H, Lippiello L, et al. 1971. Biochemical and metabolic abnormalities in articular cartilage from osteo-arthritic human hips. II. Correlation of morphology with biochemical and metabolic data. J Bone Joint Surg Am 53:523-537.
7. Garon M, Legare A, Guardo R, et al. 2002. Streaming potentials maps are spatially resolved indicators of amplitude, frequency and ionic strength dependant responses of articular cartilage to load. J Biomech 35:207-216.
8. Legare A, Garon M, Guardo R, et al. 2002. Detection and analysis of cartilage degeneration by spatially resolved streaming potentials. J Orthop Res 20:819-826.
9. Changoor A, Coutu JP, Garon M, et al. 2011. Streaming potential-based arthroscopic device is sensitive to cartilage changes immediately post-impact in an equine cartilage injury model. J Biomech Eng 133:061005.

10. Garon M. 2007. Conception et validation d'une sonde arthroscopique pour l'evaluation des proprietes electromecaniques fonctionnelles du cartilage articulaire. Ph.D., Polytechnique Montreal, Quebec, Canada.