Knee Joint Acoustic Emissions As A Non-invasive Biomarker Of Meniscal Tears

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Overview

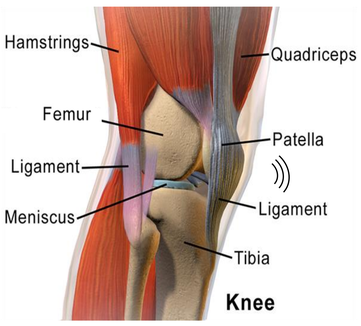

Figure 1. Knee Anatomy

Opportunity: Knees are among the most commonly and most severely injured body parts and current diagnostic tools are expensive, inconvenient and limited to the clinic.

Hypothesis: Acoustical emissions from the joint when properly recorded and analyzed can provide in-depth, quantitative information regarding the underlying physiology of the joint.

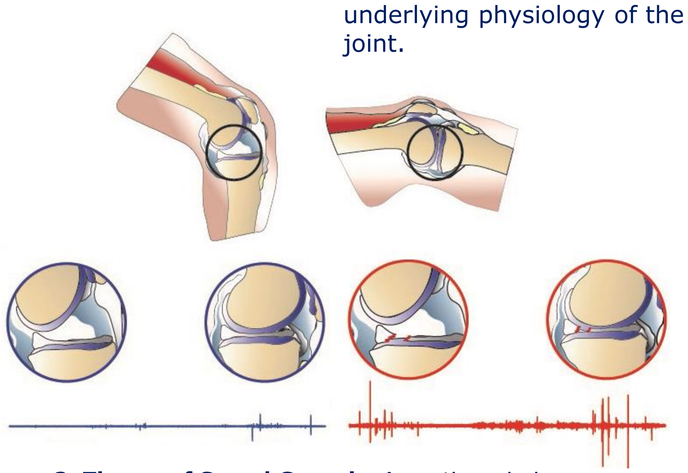

Figure 2. Theory of Sound Genesis. Acoustic emissions are produced by inter-joint friction during articulation that creates vibrations measurable on the surface of the joint using contact accelerometers.

Objectives

Goal: Increase the understanding of the nature and potential applications of joint acoustic emission (AE) recording and analysis. AEs can be measured non-invasively, and if they contain physiologically relevant information could aid in the diagnosis, monitoring, and clinical-decision making of acute musculoskeletal injuries.

In this study, the objective is to determine if acoustic emissions can differentiate between an intact, partially torn, and fully torn lateral meniscus.

Experimental Setup

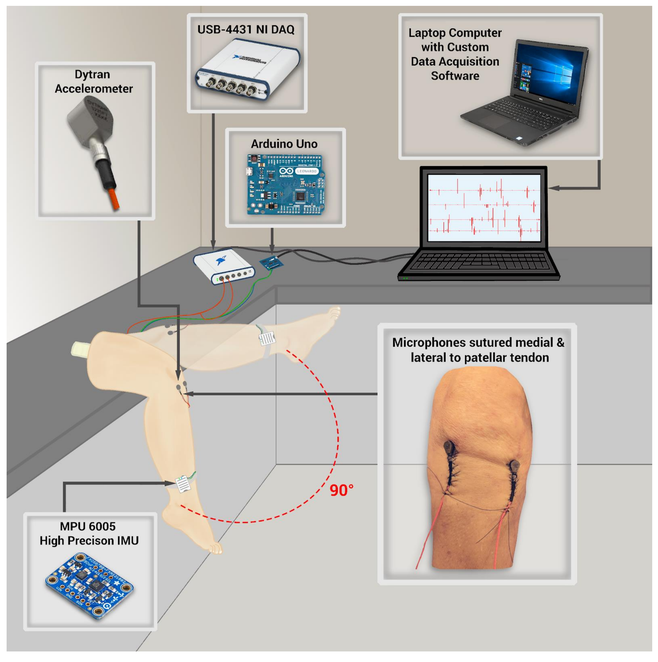

Figure 3. Cadaver sound recording setup. Studies with cadaver legs advance the basic understanding of the joint sounds, their sensing, analytics, and potential applications. In this study, 10 fresh frozen knee specimen were obtained and serially surgically altered in four stages: baseline, sham, partial tear, full tear. The joint acoustic emissions were recorded after each stage of surgery.

Quantifying Degree of Injury in a Cadaver Model

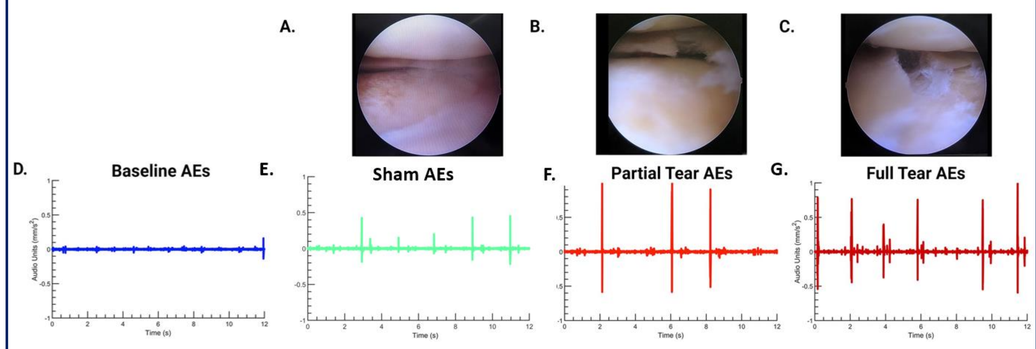

Figure 4. Paired Surgical Images and Acoustic Emissions During Each Stage of the Protocol in a Representative Knee. The sounds were recorded at baseline, after arthroscopically visualizing the meniscus (sham), after a partial thickness tear (~50%) and following a complete tear of the meniscus. Sounds were generated by manually articulating the joint through it range of motion 10 times at a rate of 1 cycle every 4 seconds. Surgeries were performed by Dr. Boyd an orthopedic sports medicine fellow. (n=10).

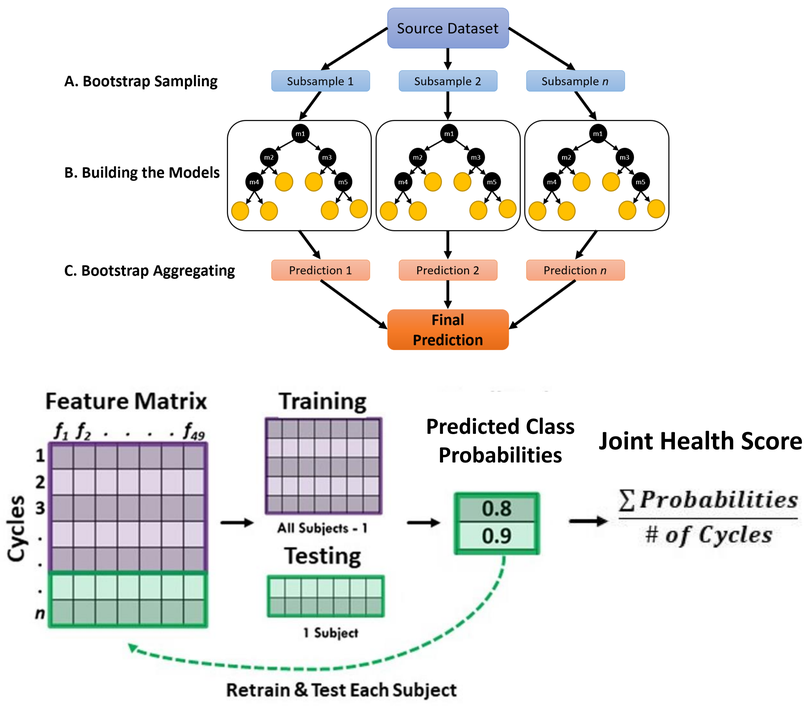

Figure 5. Acoustic Emission Signal Analysis. The resulting AEs were analyzed using machine learning, specifically a bootstrap-aggregated tree model. The output probability of AEs from the model formed the basis for an easily interpretable "Joint Health Score". Leave-one-subject-out cross-validation (LOSO-CV) was performed to assess the robustness of the model.

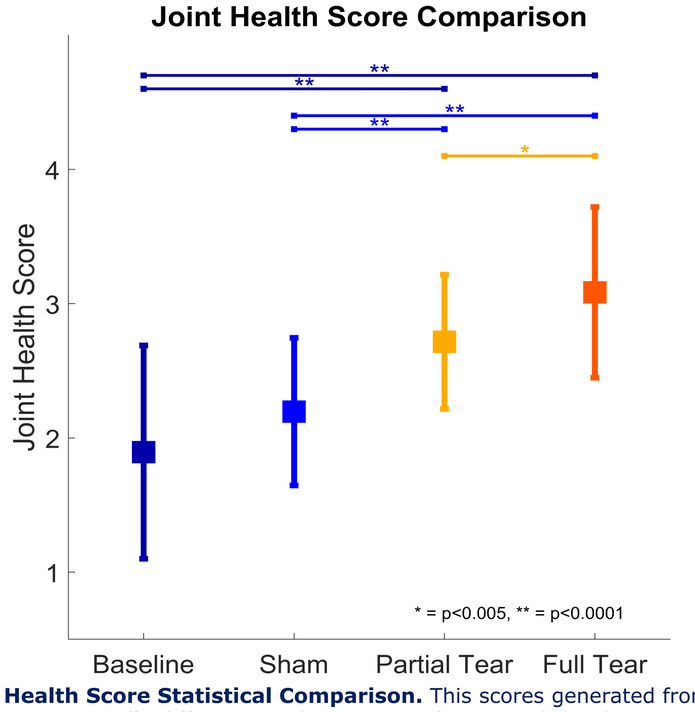

Figure 5. Joint Health Score Statistical Comparison. This scores generated from the tree model were able to statistically differentiate the severity of tears in the cadaver meniscus injury model. Of note, there was no statistical significance between the baseline and sham stages indicating that the surgical approach and associated arthroscopically introduced fluid were not the variables causing the observed change in AEs. (n=10, *= p<0.005, **=p<0.0001).

Results

The baseline, partial tear, and full tear groups were classified at an accuracy rate of 81.0%.

The sensitivity, specificity, and positive predictive value of the model were 77.6%, 93.8%, and 87.7% for classifying individual cycles of movement, respectively.

The baseline and sham stages were not statistically different.

The tear stages were statistically differentiated from the baseline and sham stages ($p<0.0001$)

The partial and full tears' joint health scores were also statistically different ($p<0.005$)

Conclusion

Acoustic emissions generated by knee articulation can be non-invasively measured and interpreted to determine injury status and severity of injury in a cadaver knee model.

The long-term goal of this work is to create a non-invasive tool for quantifying joint health for screening, diagnostic, and longitudinal monitoring purposes.

This study shows for the first time that AE analysis can diagnose and grade lateral meniscus tears in a human cadaver model. The knee is one of the most frequently injured body parts, and diagnosis relies principally on physical exam and imaging - this technique could one day serve a screening tool for triaging possible knee injuries prior to imaging studies.

Future Work

These findings are now being tested in a clinical study on patients with acute knee injuries. So far, 12 healthy controls, 10 patients with meniscus tears, and 6 patients with ACL tears have been recorded. These recordings look promising, but results are pending further recruitment.

Further research should be performed to determine the specificity of these findings. An immediate next step is to perform this same analysis on other types of common knee injuries in a cadaver model.

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Acknowledgements:

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