Image-Derived Movement Biomarkers for Functional Knee Phenotyping

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Summary

With the capability to extract knee movement biomarkers from clinical imaging, functional assessment of the knee will be possible and phenotyping can identify knee movement qualities that may put the knee joint at risk of injury or pathology. A new technology for determination of knee movement characteristics was demonstrated on multiple knees using MRI and anatomical data.

Introduction

Conditions of the knee drive tens of millions of annual visits to the clinic in the US. Osteoarthritis impacts >27 million. There are >790,000 total knee replacements and >100,000 anterior cruciate ligament reconstructions per year. Knee's primary function is to facilitate motion while bearing loads, and a lack of movement capacity can severely decrease quality of life. Movement features are potential risk factors for disease onset and injury. Comprehension of a knee's movements can enable phenotyping and monitoring to support clinical decision making. However, quantification of knee movements remains challenging as conventional approaches are either highly burdensome, need sophisticated equipment for accuracy, and provide only a cross-sectional or gross view of the knee's movement landscape. Imaging (CT or MRI) has become routine in clinical care and provides an opportunity for determination of biomarkers that may be associated with knee joint's function. Recently, we developed a technology to derive knee movement biomarkers solely from clinical imaging [1]: how and how much a knee moves in its entirety, i.e., all of its plausible rotations and translations. Our goal is to demonstrate the feasibility and capabilities of this technology for determination of image-derived movement biomarkers.

Methods

Our patent pending technology [1] uses geometries of bones, cartilage and menisci, and articular contact surfaces obtained from static clinical imaging (in this case MRI). All possible contact pairs on medial and lateral articulations of tibia are matched with their femoral counterparts and for each, optimization aligns contact locations to calculate tibiofemoral joint translations and rotations. The generated set of kinematic configurations are further reduced by removal of outliers (based on z-score). The femoral contact surface's penetration to tibial cartilage and menisci are calculated for each pose using signed-distance function. Filtering is performed first by permissible penetrations of femoral and tibial cartilage surfaces and then by those of femoral and meniscal contact surfaces. The resulting database of tibiofemoral poses is the kinematics space of the knee –a 6D point cloud in 3 rotations and 3 translations. Post-processing transforms the joint poses into clinically meaningful coordinate systems. In this study, determination of the knee kinematics space was demonstrated using MRI of 8 knees from Open Knee(s) [2]. For knee-specific kinematics space to be useful, its dimensionality should be reduced through extraction of movement features. The mean of the kinematics space was used as the characteristic pose and binned averaging over flexion resulted in the characteristic trajectory. Root-mean-squared deviations of each pose from the characteristic trajectory served as a biomarker related to mobility. Metrics were calculated for each degree of freedom: anterior-posterior (AP), medial-lateral (ML) and superior-inferior (SI) translations; flexion-extension (FE), varus-valgus (VV), and internal-external (IE) rotation.

Results and Discussion

The shape, size, and orientation of knee-specific movements indicate the individuality of movement qualities (Figure 1): oks008 leans varus; oks004 exhibits larger movement ranges; all knees move anteriorly and favor internal rotation. Characteristic pose ranges were: -14.1 to -2.6 mm (AP), -2.1°-19.4° (IE), and -4.6°-1.6° (VV). Mobility ranges were: 2.7-5.7 mm (AP), 7.2°-16.8° (IE), and 0.8°-1.6° (VV).

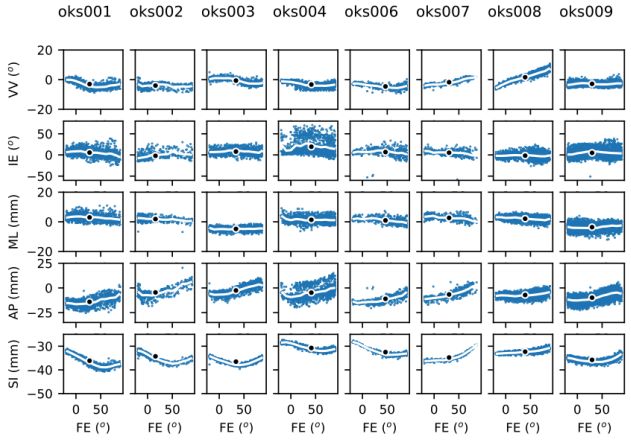

Figure 1: All kinematic poses (blue point cloud) and characteristic pose (black point) and trajectory (white line) for Open Knee(s).

Conclusions

We developed technology to extract knee-specific movement properties from MRI. Image-derived movement biomarkers can have significant utility for discovery and clinical care, when measurements are not possible nor comprehensive.

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References

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[2] Chokhandre S et al. (2023). *Ann Biomed Eng*, 51: 10–23.