Stepping into the Future of Individualized Osteoarthritis Care: Wearable Sensors

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Purpose: Wearable sensor technology has become an exciting platform for more intelligent assessment of patient function. These novel sensors have the potential to be used alongside current functional tests to provide more quantitative metrics that are relevant to patient-important outcomes in total knee arthroplasty (TKA). Goniometric and inertial wearable sensors are a few of the technologies available to study joint kinematics. While these sensors have been previously used to assess knee joint kinematics (1), limited research is available on pre- and post-TKA sensor measures and correlations to patient-important measures. The purpose of this experiment was to report on the precision, accuracy, and reliability of goniometric and inertial sensors in comparison with 3D motion cameras to determine suitability for future use with TKA patients.

Methods: Motion of the knee joint was simulated using a six degree-of-freedom robot controller and a skin-enclosed, anthropomorphic leg model. Four reflective 3D motion capture markers, two inertial sensors, and an electro-goniometer were attached to the leg phantom to measure knee joint flexion. The goniometer was attached to the lateral side of the leg phantom across a fully extended knee joint. The inertial sensors were attached in line with the goniometric sensor, at proximal and distal positions. The motion capture markers were placed on the lateral side of the phantom on the upper thigh, lower thigh, upper shank, and foot. Sensors were tared in a straight leg position immediately prior to data recording, and sensor data were acquired concurrently. The robot was programmed to simulate knee flexion, and each motion pathway consisted of ten cycles of approximately 115° flexion. The path was repeated at three different speeds, approximately 15, 30, and 50 °/s. Data were processed using GraphPad Prism 7.00, using one-way ANOVA with Tukey’s multiple comparisons correction.

Results: All techniques demonstrated less than ±1° standard deviation in maximum flexion angle within their respective trials. There were no significant differences observed for the peak flexion of the 3D marker angles between speeds. The inertial sensors demonstrated significant decreases in peak flexion from the first speed to both the second and third speeds (both p<0.0001; mean difference: 2.8° and 2.5°), while the second and thirds speeds were not significantly different from each other. One significant difference in peak flexion angles was observed between the second and third speeds for the electro-goniometer (p=0.003; mean difference: 0.4°). Average differences from the goniometric and inertial sensors to the 3D marker angles were all less than ±4°, though the goniometer differed more from the 3D marker angles than the inertial sensors. Instances of missed and incorrect data, timing inconsistencies, and deviation from the expected curve were observed for the inertial sensors.

Conclusions: Both the goniometer and the inertial sensors were deemed to be acceptably precise with their less than ±1° standard deviation within tests. While the variation of the two sensor types was under ±4° from the motion capture camera data, the accuracy of the sensors have room for improvement. The goniometric sensor was found to be much more reliable than the inertial sensors in its data collection, although evidence of crosstalk may have been observed that reduced its accuracy at higher angles (2). Moving forward, efforts to improve accuracy will include creating custom calibration motion sets for the sensors, and hardware and software upgrades for the inertial sensors. The wearable sensors demonstrated great potential for precise data collection in further human tests and for future use in TKA studies.