Table 1
Correlations among biomechanical risk factors for hip OA progression

		Spinal anterior inclination	Spinal mobility
Cumulative hip loading	*r*	0.14	0.07
	P value	0.33	0.62
Spinal anterior inclination	*r*		−0.23
	P value		0.12

Table 2
Multivariable logistic regression predicting the hip OA progression.

	OR (95% CI)	*P* value	OR (95% CI)* *: Adjustment for age, body weight, and minimum joint space	*P* value
Cumulative hip loading, 10kNm•seconds	1.29 (1.02–1.63)	0.033	1.56 (1.14–2.15)	0.006
Spinal anterior inclination, degrees	1.31 (0.98–1.74)	0.070	1.44 (1.01–2.04)	0.045
Spinal mobility, degrees	0.96 (0.92–0.99)	0.045	0.93 (0.88–0.98)	0.012

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TIBIOFEMORAL JOINT SPACE NARROWING: CAN DYNAMIC JOINT STIFFNESS 2 YEARS AFTER ANTERIOR CRUCIATE LIGAMENT INJURY YEARS PREDICT NARROWING 5 YEARS AFTER INJURY?

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Purpose: Patients with anterior cruciate ligament (ACL) injury experience higher rates of knee osteoarthritis (OA) compared with non-injured individuals. Changes in gait biomechanics are one proposed mechanism for OA development, as small changes in load bearing position shift cartilage loading to regions not adapted to ambulatory loading resulting in gradual degradation. Dynamic joint stiffness (DJS) is a biomechanical measure that captures contributions of both active muscle contraction and passive tissue tension. People with severe knee OA ambulate with higher DJS compared to healthy controls. It is unknown if DJS is predictive of radiographic changes in people after ACL injury. The purpose of this study was to evaluate if DJS measured 2 years after ACL injury predicts minimal joint space width (mJSW) 5 years after ACL injury. We hypothesized that higher DJS 2 years after injury will predict less joint space width (JSW) 5 years after injury.
Methods: As part of a larger longitudinal study, 37 subjects (13 females, age 28.1 ± 11.9 yrs,) completed gait assessment 2 years after injury and radiographs at 5 years after injury. We analyzed participants' walking patterns using an eight-camera motion capture (VICON, Oxford, UK) at 120 Hz and embedded force platform (Bertec Corp, Columbus, OH) at 1080 Hz. We used 39 retroreflective markers on bilateral lower extremities and pelvis. Participants walked overground at a self-selected gait speed maintained ± 5% across trials. Data were processed using commercial software (Visual3D; C-Motion, Germantown, MD). DJS was analyzed during loading response, defined as from the first increase in external knee flexion moment to peak knee flexion. Knee flexion angle was plotted on the X-axis and an increase in the joint angle represents an increase in knee flexion. Knee extension joint moment was plotted along the Y-axis and an increase in moment represents an increase in the net external flexion moment. A larger positive slope indicates higher DJS. Weightbearing posteroanterior (PA) bent knee (30°) radiographs were read by one researcher (JLJ) for mJSW in each compartment. Tibiofemoral JSW in the medial compartment measured from plain radiographs has been shown to be a surrogate for articular cartilage thickness, of particular concern in knee OA. Linear regression was used to test if DJS at 2 years predicted mJSW at 5 years, adjusting for sex, body mass index (BMI), and meniscal involvement.
Results: The median mJSW in this study was 4.6 mm and 5.7 mm in the medial and lateral compartment respectively. Using the IKDC scale for joint space narrowing, 8 subjects had mJSW of less than 4.0 mm, and 1 subject had mJSW less than 2.0 mm in the medial compartment. In the lateral compartment, 5 subjects had mJSW less than 4.0 mm and 1 subject had mJSW less than 2.0 mm. Average DJS of the involved limb at 2 years was 0.050 ± 0.009 and was not predictive of medial or lateral mJSW at 5 years, with unadjusted $R^2 = 0.033$ and 0.022 respectively. Adjusting for sex, BMI, and meniscal involvement, the model remained not significant ($R^2 = 0.107$ and 0.112).
Conclusions: DJS was not a predictor of mJSW in subjects 5 years after ACL injury. Previous studies found a relationship only between severe OA and DJS; we had only 2 subjects with severe OA. Additionally, our cohort had a DJS range of 0.034–0.073, less stiff than previous literature. Limitations of this study included a lack of baseline DJS or JSW measurement. Additionally, our cohort had a very wide age range at time of initial injury (14.1–49.6 years old); previous research was on older adults. It is unknown what affect age has on DJS of the knee during gait. Further research at future time points (for OA progression) or with a more homogenous age sample may provide more insight to the relationship of DJS and JSW.

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DISTINGUISHING BETWEEN KNEE REHABILITATION EXERCISES USING INERTIAL MEASUREMENT UNITS

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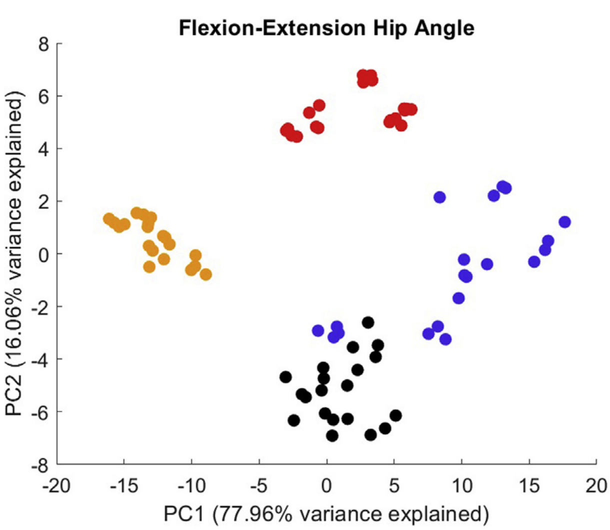
Purpose: Over 90,000 osteoarthritis (OA) related TKR surgeries take place across the UK annually, with patients undergoing regular post-surgery physiotherapy that is reliant on home-based exercise rehabilitation and driven by personalised self-management. With poor patient adherence that is difficult to ascertain, clinicians who are challenged to optimise patient outcomes are unable to determine whether improvements (or lack of) can be attributed to an exercise intervention or (non) adherence. There is a clear need for enhanced forms of objectively monitoring patient adherence to home based exercise rehabilitation, providing valuable biomechanical knowledge to clinicians to guide personalised exercise prescription. This could provide rigorous adherence measurements, optimise the rehabilitation process, reduce NHS burden and improve patient satisfaction. This research aims to determine whether the performance of 4 rehabilitation exercises, routinely prescribed to OA patients following TKR, can be objectively distinguished using inertial measurement sensors (IMU's) placed on the lower limbs.
Methods: 5 healthy participants (4 males, 1 female; mean age 32.6 ± 11.1 years, height 1.79 ± 0.14 m and mass 82.88 ± 15.93 kg) performed a battery of early phase knee rehabilitation exercises based on the Taxonomy for RehAbilitation of Knee conditions (TRAK). Data was collected for multiple exercises with participants wearing a range

of time synchronised biomechanical measurement systems. This study focused on the performance of 1) Knee Flexion in sitting 2) Knee Extension 3) Single Step Down and 4) Sit to Stand, with each participant performing 4 repetitions per exercise and the data collected using lower body IMU sensors. These were placed on the pelvis and bilateral thigh, shank and feet (Xsens, Holland; sampling at 60 Hz). Anthropometric measurements for each participant were combined with IMU data during a static calibration to define the biomechanical model (MVN Studio). 3D hip, knee and ankle joint angles were calculated using the Euler sequence ZXY using the ISB based coordinate system. Joint angle data were processed in Python, with exercise repetitions defined using a detect peaks algorithm. 3D angle data were formatted in Excel, time normalised to 101 points and then Principal Component Analysis (PCA) was performed (Matlab, Mathworks), reducing all joint angle waveforms into new uncorrelated principal components via an orthogonal transformation. Scatterplots of PC1 versus PC2 were used to visually inspect for clustering between the PC values for the 4 exercise groups. A one way ANOVA (SPSS, IBM) was performed on the first 3 PC values (ranked by percentage variance accounted for) for the 9 variables under analysis, with an a priori alpha level of significance set at 0.05. Games-Howell post hoc tests identified variables that were significantly different between exercises.

Results: The PC scatterplot representing the hip flexion-extension waveforms produced the most prominent clustering, with all 4 exercise groups easily distinguishable (Fig.1). Whilst multiple statistically significant differences were found between pairs of exercises for individual PC values, only one PC value was statistically different across all exercise pairings (PC1, knee flexion-extension waveform).

Conclusions: This study demonstrates the potential to objectively distinguish between different knee rehabilitation exercises using IMU sensors and PCA. It would appear that flexion-extension angles at the hip and knee are most suited for accurate exercise classification and require further investigation. Future work will focus on increasing the healthy cohort sample size and generating a post TKR patient cohort to identify whether similar differentiation between exercises can be established in a pathological cohort, and whether there are functional difference between healthy and post-TKR patients that could be used to map patient progress.



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ALTERED MUSCLE SYNERGIES DURING GAIT IN INDIVIDUALS WITH KNEE OSTEOARTHRITIS

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Purpose: While there are well documented differences in gait between symptomatic knee osteoarthritis (OA) as compared to healthy older adults the mechanism for how these altered movement patterns occur are not well characterized. Quantification of synergistic muscle activation patterns in knee OA may provide insight to the altered control of movement that may result from joint pain, inactivity, or changes in joint structure, and contribute to the decline in physical function. It has been proposed that movement may be controlled through synergistic activation of muscle groups working as a single functional unit. Quantification of these groupings (aka muscle synergies) can provide insight into neural control of movement by describing not only which muscles are coactivating, but also how they work together to carry out functional movements. In both cerebral palsy and stroke, fewer synergies were needed to describe movements, compared to healthy or unaffected limbs, suggesting a simplified control pattern due to co-contraction. In addition, differences found in the make-up of the muscle synergies throughout movement tasks suggest less coordinated movement with more severe pathologies. The ***purpose*** of our study is to quantify differences in muscle synergies between individuals with symptomatic knee OA and healthy older adults. We hypothesize that due to cocontraction, there will be fewer muscle synergies in individuals with knee OA compared to healthy older adults, and that the contribution of these synergies will differ throughout the gait cycle.

Methods: After IRB approval, 17 healthy older adults (HA) and 17 symptomatic knee OA were enrolled. Participants walked on a treadmill at a preferred pace and following a 2 minute warm-up EMG was collected at 2000 Hz on 8 leg muscles. EMG signals were then filtered, rectified, and normalized to the gait cycle for 9 total strides for each individual. Mean data for each individual was then concatenated to form one group matrix for OA and one for HA in order to account for individual characteristics within groups in synergy analysis. Muscle synergies were extracted using non-negative matrix factorization (NMF) in both HA and OA. Variance accounted for (VAF = 1-SSE/SSTE) was calculated to determine the number of synergies needed to describe >90% of variance in muscle activation and used to test for differences in complexity of movement between groups. Differences in the contribution of individual muscles to each synergy was determined via visual inspection and then the activation of similar synergies at 0, 30, and 66% of the gait cycle (approx. heel-strike(HS), peak knee flexion(pKF), and toe-off(TO) respectively) were compared using one-way ANOVA's.

Results: To account for >90% variability, 4 synergies were needed in the OA group (VAF = 93.4%), while only 3 were needed in the HA group (VAF = 92.4%). In order to easily compare between groups 4 synergies were used to describe both OA and HA (VAF = 96.9%). At HS, activation of synergy C (Fig.1) for OA (0.10 ± 0.21) was significantly higher compared to HA (0.06 ± 0.04, $P = 0.001$). At pKF, activation of synergy B was significantly higher in OA (0.08 ± 0.04) compared to HA (0.05 ± 0.02, $P = 0.010$). No difference was found between activation of synergies at TO.

Conclusions: In contrast to our hypothesis a greater number of synergies were needed to account for >90% variance in the EMG for the OA group compared to the HA group, suggesting that control patterns in OA are not less complex. The differences in the contributions of the VL, VM and MH to synergy B along with greater activations of synergies B and C at pKF and HS respectively in OA suggests in agreement with the hypothesis that there is greater co-activation of the quadriceps and hamstrings in gait. A strong synergistic relationship between the quadriceps and hamstrings in OA may be related to either pain or joint instability and warrants further analysis to understand the contributing factors.