INTER-RATER ACCURACY AND PRECISION OF MARKERLESS QUANTIFICATION OF 3D TIBIOFEMORAL DISPLACEMENT USING DUAL FLUOROSCOPY

G. Kuntze, G.B. Sharma, D. Kukulski, J. Shank, J.L. Ronsky. Univ. of Calgary, Calgary, AB, Canada; Univ. of British Columbia, Okanagan, BC, Canada

Purpose: Early changes in osteoarthritic (OA) knee cartilage include tissue swelling and softening, which may predispose cartilage to mechanical damage during activities of daily living. Current clinical OA diagnosis relies on radiographic bone morphology change and pain, which can be insensitive to early change. Developing a marker that specifically targets early mechanical tissue changes may advance the current state of OA assessment. Potential candidates for such markers are in-vivo magnitude and rate of tibiofemoral (TF) soft tissue deformation during weight bearing (compression) and unloading (recovery). Respective joint “signatures” for healthy and OA groups may then allow for early OA identification. Dual Fluoroscopy (DF) is an emerging tool with the potential to provide the temporal and spatial resolutions necessary for such assessment. Tissue deformation mechanics may be derived using translation and rotation changes of the femur with respect to the tibia over time. Using a bead tracking technique, similar to radiostereometric analysis (RSA), translation changes of 0.05 mm (1/10th expected maximal cartilage deformation) have previously been accurately detected. It is however unknown if a non-invasive markerless DF approach is sufficiently accurate and precise for quantifying the small changes during weight bearing. The purpose of this study was to establish the Minimum Detectable Displacement (MDD) of 3D femoral translations with respect to the tibia in a custom built DF system using a markerless shape matching image registration approach.

Methods: The DF system consisted of two X-ray tubes (Varian, USA) and generators (EMD, Canada), quad mode image intensifiers (Toshiba, Japan) and high speed digital video cameras (PCO, Germany). DF images were acquired with an entrance field diameter of 228 mm and 0.155 x 0.155 mm² pixel resolution. Dry tibia and femur bones were fixed to a plexiglass frame, where the tibia remained stationary and the femur was placed within the DF system. The frame was placed within the DF field-of-view and did not move during data capture. Ten displacement intervals (0.01-0.1 mm) were imaged with 10 repetitions of each interval. DF calibration was performed using a calibration cube and modified direct linear transform. Images were distortion corrected using a perforated steel grid and XrayProject (Brown University, USA).

3D femur and tibia bone models were generated using segmentation (Amira, USA) of Computed Tomography image sequences (0.21 x 0.21 x 0.31 mm). 3D bone orientations were obtained by three raters using AutoScoper (Brown University, USA) and a markerless shape matching approach. Bone-specific models were positioned to align their visible features to those of the underlying 2D X-ray images. Relative femur and tibia displacements were obtained using the Euclidean distance between bone models. Independent samples t-tests were used to detect MDDs of the moving femur relative to the stationary tibia at each displacement interval. Accuracy and precision were computed as means and standard deviations of the absolute differences of the femur translations compared to the micrometer displacements. Inter-rater reliability values of the femur were computed using intra-class correlation coefficient (ICC). All statistical analyses were performed in SPSS (IBM, USA) and p < 0.05.

Results: Femur displacement measurements were significantly different from tibia (p<0.045) and had greater than 95% confidence in accuracy at micrometer displacements ≥ 0.088mm (accuracy ± precision: 0.022 ± 0.019) (Figure 1). Between raters femur displacement measurements were not significantly for micrometer displacements ≥ 0.055mm and inter-rater reliability across all displacements was 92%.

Conclusions: These findings indicate that 3D bone translations within relevant in-vivo ranges can be observed accurately and precisely using a markerless DF shape matching approach. Femur displacements of ≥ 0.088mm were accurately and reliably detected with respect to set micrometer displacements. The data further indicated good between rater agreement when quantifying femur displacements. Given the above system specifications, the markerless DF approach provides a means for non-invasive in-vivo quantification of TF tissue response to loading and unloading stimuli. Using this approach, further work will be performed to establish the mechanical behaviour of TF soft tissues of healthy and ligament deficient and OA knees. While significant user input is required, compared to RSA type techniques, this non-invasive approach may be more readily applied in a future clinical setting.
modification program (Table 1). This was associated with an average 6.7 degree increase in self-selected toe-out angle (p < 0.001) and 10% reduction in the late stance KAM (p = 0.04). Participants reported that difficulty in achieving the desired toe-out angle significantly decreased over the course of the program. Joint discomfort was reported by five participants (33%) in the hip or knee joints, though none lasted longer than two weeks.

**Conclusion:** Results from the current study provide preliminary evidence as to the benefits of toe-out gait modification training in individuals with medial knee OA. Specifically, these findings suggest that gait modification can significantly improve clinical and biomechanical outcomes relevant to medial compartment knee OA. This study also showed that gait modification can be successfully delivered with minimal difficulty or consequences to other lower limb joints. Future research utilizing more participants and a control group are now needed to best understand the biomechanical and clinical changes following toe-out gait modification.

### Table 1

<table>
<thead>
<tr>
<th>Biomechanical outcomes</th>
<th>Baseline (Week 0)</th>
<th>Follow-up (Week 11)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-selected toe-out angle (°)</td>
<td>4.75 (6.59)</td>
<td>11.41 (6.46) *</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Early stance peak KAM (W/BW*ht)</td>
<td>3.45 (0.82)</td>
<td>3.17 (0.72)</td>
<td>0.12</td>
</tr>
<tr>
<td>Late stance peak KAM (W/BW*ht)</td>
<td>2.87 (0.92)</td>
<td>2.63 (0.84) *</td>
<td>0.04</td>
</tr>
<tr>
<td>KAM impulse (W/BW*ht/sec)</td>
<td>1.33 (0.29)</td>
<td>1.24 (0.34)</td>
<td>0.20</td>
</tr>
</tbody>
</table>

*Indicates significant difference (p < 0.05).

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**MUSCLE ACTIVATION PATTERNS FOLLOWING KNEE JOINT REPLACEMENT DURING THE POSTURAL CONTROL TASK**


**Purpose:** The total knee arthroplasty (TKA) is performed for the purpose of pain reduction and functional improvement for patients with knee osteoarthritis. TKA patients have demonstrated reduced walking velocity and stride length during walking. This performance deficit may originate from impaired balance control resulting from changes in muscle activity. It was reported that patients with ankle instability showed muscle activation patterns different from healthy subjects and that muscle activation patterns of the asymptomatic leg changed than the symptomatic side in patients with patellofemoral pain. However, none of the studies investigated muscle activation patterns of TKA patients during the postural control task. The purpose of this study was to examine the muscle activation patterns of the TKA patients during task of transition from double leg standing position to single leg standing position.

**Methods:** Ten subjects (two men, eight women, mean age 68.9 ± 6.0 years) that four weeks passed after TKA and ten healthy, age-matched control participants (healthy group: one man, nine women, mean age 68.0 ± 5.7 years) participated in this study. Each participant provided informed consent to the potential risks associated with their participation. Subjects performed a transition task from double leg standing position to single leg standing position after a beep sound from an electromyograph (EMG) immediately, and surface EMG signals were recorded using a 8-channel electrode system (Myosystem 1400) at the time. The baseline EMG was calculated by averaging the EMG activity for 100ms interval in a resting position. The onset of EMG activity of each muscle was determined when the EMG amplitude exceeded two standard deviations of the baseline level from a beep sound time. EMG signals of the following muscles were recorded at the both legs in TKA patients and at the dominant leg in control subjects: gluteus maximus, gluteus medius, adductor longus, vastus lateralis, biceps femoris, tibialis anterior and lateral gastrocnemius. Also, Foot switches were attached to the sole of the lower limbs which made elevation done and measured the motor reaction time when a foot left the floor. The motor reaction time was analyzed for the supporting leg only and were averaged across three trials. Two-way analysis of variance was used to compare the onset of muscle activity between groups and compare the onset of muscle activity of each muscle with the motor reaction time in each group. We used the Bonferroni method as an adjustment of the multiple comparisons. The level of significance was set at 0.05.

**Results:** In the comparison between groups, the onset of muscle activity of the vastus lateralis was significantly later in the operation side (0.76 ± 0.36s) and the non-operation side (0.77 ± 0.47s) than the healthy group (0.44 ± 0.12s). There was no significant difference between groups in other muscle activity onset. In the comparison in each group, the entire onset of muscle activity except the vastus lateralis was significantly earlier than the motor reaction time in the operation side of the TKA subjects. The onset of muscle activity of gluteus medius, adductor longus and the tibialis anterior were significantly earlier than the motor reaction time in the non-operation side. In the healthy group, onset of muscle activity of gluteus medius muscle, adductor longus, vastus lateralis, biceps femoris and the tibialis anterior were significantly earlier than the motor reaction time.

**Conclusions:** The results of this study showed that the onset of muscle activity of the vastus lateralis in the operation side and the non-operation side of TKA subjects was later than the healthy group. Also, the muscle that the onset of muscle activity was earlier than the motor reaction time was different from the healthy group in the operation side and the non-operation side of TKA subjects. Horak et al described that the subjects used the posture control strategy due to the hip joint as compensation, when they reduced the somatosensory of the ankle of subjects. We suggest that the TKA patients may use the muscle activation patterns different from a healthy subject compensating the myofunction of the quadriceps femoris in both operation side and non-operation side during postural control task. Because the difference in observed muscle activity pattern may influence posture control after TKA, a further investigation is necessary.

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**PARTIAL WEIGHT BEARING AND CONTINUOUS PASSIVE MOTION FOR REHABILITATION FOLLOWING MICROFRACTURE SURGERY: A MULTISCALE FINITE ELEMENT SIMULATION**

L. Ruggiero, D. Logerstedt, M. Park, S. Adriaenssens, L. Snyder-Mackler, L. Lu, Univ. of Delaware, Newark, DE, USA; 2 Free Univ. of Brussels, Brussels, Belgium

**Purpose:** Continuous passive motion (CPM) and partial weight bearing (PWB) are often applied in rehabilitation after microfracture surgery for cartilage repair. CPM is often used immediately after surgery and is thought to provide lower mechanical loads than PWB. In this study, using a multi-scale finite element analysis (FEA) and an in vitro microfracture system, we propose to compare 1) the mechanical loading profiles at lesion site during PWB and CPM, and 2) the biophysical fields, including stress, strain, fluid pressure, and nutrient transport, in both repaired tissue and surrounding cartilage during PWB and CPM.

**Methods:** PWB and CPM movements were simulated adopting the OpenKnee model in FEBio, based on the MRI imaging of a healthy female knee joint. PWB was modeled as vertical load of 0-400N (~1/2 donor body weight) on the femur (tibia was fixed) while the CPM as a 0-30° flexion, both in quasi-static conditions. The deformation and stress within 20 different cartilage regions (Fig 2C) on the medial condyle head were determined. The cartilage deformation field was further used as input into a tissue scale model (Fig 1C&D), in which the cartilage lesion and surrounding tissue were modeled as nonlinear biphasic materials with strain dependent permeability. The material properties of the lesion were obtained by testing the repaired tissue from an in vitro culture model (Fig 1E). Microfracture was simulated as a bone-cartilage explant, which was cultured with mechanical stimulation for two months. Multiple simulations were performed to compare 1) the effects of PWB and CPM, 2) effect of the lesion size (6-10 mm), and 3) effect of material properties at lesion site to simulate the “healing phase” (from very soft marrow clot to fibrous cartilage).