Iliotibial band tension affects patellofemoral and tibiofemoral kinematics

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\begin{abstract}

The iliotibial band (ITB) has an important role in knee mechanics and tightness can cause patellofemoral maltracking. This study investigated the effects of increasing ITB tension on knee kinematics. Nine fresh-frozen cadaveric knees had the components of the quadriceps loaded with 175 N. A Polaris optical tracking system was used to acquire joint kinematics during extension from 100° to 0° flexion. This was repeated after the following ITB loads: 30, 60 and 90 N. There was no change with 30 N load for patellar translation. On average, at 60 and 90 N, the patella translated laterally by 0.8 and 1.4 mm in the mid flexion range compared to the ITB unloaded condition. The patella became more laterally tilted with increasing ITB loads by 0.7°, 1.2° and 1.5° for 30, 60 and 90 N, respectively. There were comparable increases in patellar lateral rotation (distal patella moves laterally) towards the end of the flexion cycle. Increased external rotation of the tibia occurred from early flexion onwards and was maximal between 60° and 75° flexion. The increase was 5.2°, 9.5° and 13° in this range for 30, 60 and 90 N, respectively. Increased tibial abduction with ITB loads was not observed. The combination of increased patellar lateral translation and tilt suggests increased lateral cartilage pressure. Additionally, the increased tibial external rotation would increase the Q angle. The clinical consequences and their relationship to lateral retinacular releases may be examined, now that the effects of a tight ITB are known.

\end{abstract}

1. Introduction

The iliotibial band (ITB) is a thickening of the deep fascia of the lateral aspect of the thigh. Proximally, it encloses the tensor fascia lata and up to three-quarters (Last, 1948) of the gluteus maximus inserts into it posteriorly. It has several bony attachments: it is anchored to the iliac crest and has a wide attachment to the linea aspera through the lateral intermuscular septum, terminating proximal to the lateral femoral epicondyle (Lobenhoffer et al., 1987; Kaplan, 1958; Terry et al., 1986). It also attaches to Gerdy’s tubercle on the tibia. Recent works have described important connections of the ITB to the patella (Merican and Amis, 2008; Vieira et al., 2007). Clinical studies have suggested that the ITB has an important synergistic role with the anterior cruciate ligament (Kramer et al., 2007; Terry et al., 1993) and that ITB tightness can cause patellofemoral maltracking (Punjillo, 1993; Wu and Shih, 2004) and lateral knee pain (Fairclough et al., 2007; Fredericson and Wolf, 2005).

Despite this, there have been few studies that address the role of the ITB in the biomechanics of the lower limb. These have focussed on its biomechanical role in the hip (Birnbaum et al., 2004; Fetto et al., 1995), to specific conditions (McLeod, 1985; Noehren et al., 2007; Orchard et al., 1996) and its tension characteristics (Matsumoto and Seedhom, 1995). Kinematics studies have been almost exclusively limited to the tibiofemoral joint and in relation to anterior cruciate ligament deficiency (Bull et al., 1999; Noyes et al., 1989; Yamamoto et al., 2006). Kwak et al. (2000) investigated the effect of the ITB on the kinematics of both the tibiofemoral and patellofemoral joints. However, they did not load the vastus lateralis obliquus, which may have an important kinematic effect considering its angle of pull on the patella (Hallisey et al., 1987) and its interaction with the ITB (Merican and Amis, 2008). The knee was tested at fixed flexion angles and so it was not a study of motion. Lastly, although translation and rotation of the patella were detailed, patellar tilt about the longitudinal (proximal–distal) axis of the patella was not reported. Tilting is an essential component of patellar tracking (Grelsamer et al., 1993). It forms the basis of various well-established indices of patellar tracking in clinical imaging (Fulkerson et al., 1987; Grelsamer et al., 1993, 2008; Laurin et al., 1978; Powers et al., 1998; Schutzer et al., 1986) and has been proposed as a radiographic criterion for selection for lateral retinacular release (Ford and Post, 1997; Fulkerson, 2002; Fulkerson et al., 1987).

The aim of this study was to understand the effects of increasing ITB force on tibiofemoral and patellofemoral kinematics. The hypothesis was that with increasing ITB tension the...
2. Materials and methods

Nine fresh-frozen cadaveric knees with no prior history of knee surgery or disease were used (mean age 62 (SD = 16) range 41–85, M:F 2:7). These were kept moist with normal saline. The knee was prepared on one day, kept overnight in a refrigerator and the kinematic experiment completed the following day. The patellar patellar rotation (external rotation–distal patella moves laterally) when the iliotibial band (ITB) is loaded to 30, 60 and 90 N.

Table 3  
Patellar patellar rotation (external rotation–distal patella moves laterally) when the iliotibial band (ITB) is unloaded (0 N) and the change thereof when the ITB is loaded to 30, 60 and 90 N.

<table>
<thead>
<tr>
<th>Knee flexion</th>
<th>0 N</th>
<th>Difference from 0 N</th>
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<tbody>
<tr>
<td></td>
<td>Actual</td>
<td>Mean S.D.</td>
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<tr>
<td></td>
<td>30 N</td>
<td>60 N</td>
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<td>0.7</td>
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<td>3.4</td>
<td>0.7</td>
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<td>0.3</td>
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<tr>
<td>60</td>
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<td>70</td>
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<td>75</td>
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<td>1.6</td>
</tr>
<tr>
<td>90</td>
<td>7.2</td>
<td>1.9</td>
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(ns—not significant, *p<0.05, **p<0.001, ***p<0.0001 Bonferroni post-hoc test).

The skin and subcutaneous tissue were removed. The deep fascia, retinaculum and ITB were preserved. The attachment of the ITB to the linea aspera and just obtained from the International Institute for the Advancement of Medicine (Jessup, PA, USA), who undertook screening and consent for their use for research. Ethical permission was obtained from the Riverside Research Ethics Committee. The knees were stored at –20° C and thawed a day prior to experimentation. The knee was kept moist with normal saline. The knee was prepared on one day, kept overnight in a refrigerator and the kinematic experiment completed the following day.

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The head of the fibula was transfixed to the tibia by two screws to maintain its anatomical position. An intramedullary sleeve and a rod were cemented into the distal end of the tibial intramedullary rod.

The quadriceps tension pulled the knee into full extension, which was defined as being the point where the tibial rod was aligned parallel to the femoral axis when viewed in the sagittal plane perpendicular to the flexion-extension axis, that is, when the anatomic axes of the two bones were parallel when viewed in a medial-lateral direction. A rod was sometimes necessary to provide an anterior block for the tibial intramedullary rod so that hyperextension was avoided. In this position, the femoral coordinate system was constructed based on points digitised to build the local coordinate system of each bone. The patellar coordinate system was constructed at the (anteroposterior) depth of the geometric centre of the patella and was aligned to the femoral coordinate system. Thus, the knee at 0° flexion defined the zero position for patellofemoral kinematics (Van der Helm and Huiskes, 1990). The tibial coordinate system was defined based on digitising two points on the tibial anatomical axis and the most medial and lateral points of the tibial condyle (Lie et al., 2007). The knee was moved into at least three cycles of flexion–extension, against the extending moment of the quadriceps tension. This was performed manually by a rod held transversely against the anterior surface of the tibial intramedullary rod at a speed of approximately 5–10 s for an extension cycle.

The quadriceps components and the iliotibial tract are tensed by cables, which pass over pulleys to hanging weights (not shown). The kinematics data for the unloaded and progressively loaded ITB were analysed statistically every 5° knee flexion using a two-way repeated-measures analysis of variance, the two bottom of the hole was defined as the geometric centre of the patella for later referencing. The quadriceps was separated into five components: rectus femoris (RF) and vastus intermedius (VI), vastus lateralis longus (VLL), vastus lateralis obliquus (VLO), vastus medialis longus (VML), and vastus medialis obliquus (VMO).

The knee was mounted sideways (lateral aspect upwards) in a test rig by locating the femoral sleeve onto a fixed mounting rod (Fig. 1). The rotation of the femur was adjusted until the most posterior parts of the femoral condyles were aligned in a vertical plane, when the sleeve was locked to the mounting. The components of the quadriceps were each loaded with hanging weights using cables and pulleys; a total load of 175 N was applied (Farahmand et al., 1998b; Senavongse and Amis, 2005; Christoforakis et al., 2006; Amis et al., 2006, 2008).

This was done according to the directions and physiological cross-sectional areas (PCSAs) of the muscles (Farahmand et al., 1998a) relative to the femoral axis: VLL 14 lateral and 0° anterior; VLO 35° lateral and 33° posterior; VML 15° medial and 0° anterior; VMO 47° medial and 44° posterior; and RF+VI 0° lateral and 0° anterior. The quadriceps tension distribution was RF+VI 35%, VLL 33%, VLO 9%, VML 14%, and VMO 9%. The direction of pull of the ITB was 0° lateral and 6° posterior (Bull et al., 1999). The following loads were applied to the ITB by hanging weights: 0, 30, 60 and 90 N. The kinematic measurements were repeated for each ITB tension.

A Polaris optical system (Northern Digital Incorporated, Waterloo, Canada) was used with active optical trackers. An active uniplanar four-marker Polaris tracker was secured to track the specific aspect of the femur. One active tracker with multiple markers (Traxtal Technologies, Toronto, Canada) was secured to the lateral aspect of the patella and another to the tibial tuberosity. A Traxtal probe was used to digitise points used to build the local coordinate system of each bone. The quadriceps tension pulled the knee into full extension, which was defined as being the point where the tibial rod was aligned parallel to the femoral axis when viewed in the sagittal plane perpendicular to the flexion–extension axis, that is, when the anatomic axes of the two bones were parallel when viewed in a medial-lateral direction. A rod was sometimes necessary to provide an anterior block for the tibial intramedullary rod so that hyperextension was avoided. In this position, the femoral coordinate system was constructed based on points digitised on a calibration block such that it was centred and aligned to the anatomical axis and rotationally aligned with the most posterior points of the femoral condyles. The patellar coordinate system was constructed at the (anteroposterior) depth of the geometric centre of the patella and was aligned to the femoral coordinate system. Thus, the knee at 0° flexion defined the zero position for patellofemoral kinematics (Van der Helm and Huiskes, 1990). The tibial coordinate system was defined based on digitising two points on the tibial anatomical axis and the most medial and lateral points of the tibial condyle (Lie et al., 2007). The knee was moved into at least three cycles of flexion–extension, against the extending moment of the quadriceps tension. This was performed manually by a rod held transversely against the anterior surface of the tibial intramedullary rod at a speed of approximately 5–10 s for an extension cycle.

The Polaris system captured the orientation of the trackers attached to the bones and the raw data was processed by Visual3D (C-Motion Inc., MD, USA). During the motion cycle, the software calculated the transformations required to take the femoral segment to the patella and the femoral segment to the tibia by a series of rotations and translations in three orthogonal planes. The default Cardan sequence was flexion–extension, abduction–adduction and internal–external rotation, equivalent to the joint coordinate system of Grood and Suntay (1983). The rotations and translations of the patella and tibia relative to the femur were determined for the last two extension cycles and averaged. The kinematic data for the unloaded and progressively loaded ITB were analysed statistically every 5° knee flexion using a two-way repeated-measures analysis of variance, the two proximal to the lateral femoral epicondyle was not disrupted. The femur and tibia were cut approximately 20 and 15 cm above and below the joint line, respectively. The head of the fibula was transfixed to the tibia by two screws to maintain its anatomical position. An intramedullary sleeve and a rod were cemented into the femur and tibia, respectively, using polymethylmethacrylate. They were aligned to the bone axes by use of rubber spacers and an outrigger alignment rod. A hole was drilled 10 mm deep from the anterior (superficial) surface of the patella, located over the centre of the median ridge using an ACL jig. The drill was kept perpendicular to the bone surface by using a drill block resting on this surface. The

### Table 5

<table>
<thead>
<tr>
<th>Knee flexion</th>
<th>0 N</th>
<th>30 N</th>
<th>60 N</th>
<th>90 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>3.4</td>
<td>6.6</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.5</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Difference</td>
<td>3.0</td>
<td>6.6</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Mean</td>
<td>0.6</td>
<td>0.6</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.6</td>
<td>0.6</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

### Table 6

<table>
<thead>
<tr>
<th>Knee flexion</th>
<th>0 N</th>
<th>30 N</th>
<th>60 N</th>
<th>90 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.6</td>
<td>5.6</td>
<td>2.0</td>
<td>1.6</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.8</td>
<td>0.7</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Difference</td>
<td>0.7</td>
<td>4.6</td>
<td>1.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Mean</td>
<td>1.3</td>
<td>1.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D.</td>
<td>1.3</td>
<td>1.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

(ns—not significant, *p<0.05, **p<0.001, ***p<0.0001 Bonferroni post-hoc test).
factors being the range of tibiofemoral flexion angles and the range of ITB tensions. A Bonferroni post-hoc test was used to determine the ITB loading conditions at each knee flexion angle when significant differences occurred, for 30, 60, 90 N ITB tension when compared to the kinematics with the ITB unloaded at each angle of knee flexion, so the Bonferroni correction lowered the alpha value to \( p < 0.0167 \).

The Polaris optical system has an overall volume root mean square error of 0.35 mm for a single marker (Wiles et al., 2004). The Polaris femoral tracker was reported to have mean errors of 0.19 mm and 0.36 (Wiles et al., 2004). The Traxtal patellar tracker was rotated by a known angle and the accuracy was on average 0.03 with a precision 0.03 (S.D.). It was also translated by 3 or 6 mm, 24 times each and the average accuracy was 0.04 mm with a precision 0.03 mm (S.D.). Patellar kinematics was defined as in Fig. 2.

3. Results

Increasing ITB loads caused physically small but statistically very significant changes of the patellofemoral and tibiofemoral kinematics. In relation to the femur, the patella tilted more laterally (lateral patella moves posterior), translated more laterally, rotated more laterally (distal patella rotates laterally) and flexed more, when the ITB was loaded. This occurred in different parts of the flexion cycle for the different components of tracking but in general there was no change in patellar tracking in extension and in the first 15° of flexion (Figs. 3–8). The ITB tension also caused tibial external rotation, up to 13°, along with a small adduction.

For patellar lateral translation, there was no significant change observed between tracking with the ITB unloaded and when the ITB load was 30 N. (Fig. 3). However, with loading to 60 and 90 N, the change of lateral translation was significant \( (p < 0.001) \) for 35–70° and 25° onwards, respectively (Table 1). The increase in lateral translation averaged 0.8 mm (S.D. 0.5) and 1.4 mm (S.D. 1.0) for the 60 and 90 N ITB load, respectively, for the flexion ranges with significant changes (Fig. 3).

Patellar lateral tilt increased earlier in flexion and with less ITB load (Fig. 4). There was a significant lateral tilt with 60 N tension \( (p < 0.001 \text{ for } 25–65°) \) and for 90 N tension \( (p < 0.001 \text{ for } 25–100°) \), respectively (Table 2). The mean increases in patellar tilt in those significant flexion ranges were 1.2° (S.D. 0.7) and 1.5° (S.D. 1.0) for the 60 and 90 N loading conditions, respectively. With ITB loading, the changes in patellar tilt and patellar translation were maximal around 35° to 70° flexion (Fig. 4).

Patellar flexion was also increased significantly by increasing ITB tension, and this effect peaked at 45° knee flexion (Fig. 5). There was an increase in significance of this effect and a wider range of flexion in which this significance occurred with increasing ITB loads (Table 3) \( (p < 0.001 \text{ from } 40° \text{ to } 65° \text{ at } 30 \text{ N tension}; 20–90° \text{ for } 60 \text{ N tension}; 15–100° \text{ for } 90 \text{ N tension}) \).

In contrast, the patella rotated laterally with increasing ITB loads towards maximum flexion reached (Fig. 6). With 30 N ITB load, there was a significant lateral rotation of 0.7° (S.D. 0.4) in the 80–100° range. With further loading to 90 N, this increase was 1.5° (S.D. 0.5) in the significant range of 65–100° (Table 4).

Tibial external rotation increased significantly with ITB loading (Fig. 7). In full extension, however, there was no change. When the ITB was loaded to 30 N, significant increases in external rotation were observed by 30° flexion upwards. For 60 and 90 N load, this was seen at knee flexion of 15° and upwards (Table 5). The increase in external rotation was maximal at 60–75° flexion and was 5.2° (S.D. 2.3), 9.5° (S.D. 3.2) and 13° (S.D. 3.9) for ITB loads of 30, 60, 90 N.

Tibial abduction did not change with increasing ITB load from 0° to 20° flexion (Fig. 8). The tibia was more adducted with
increasing ITB load. This was significant at 45–75° flexion when
the ITB was loaded to 30 N; by 60 N load, it was significant from
30° of flexion onwards (Table 6). The adduction was maximal
between 50° and 60° of knee flexion and with loading to 90 N, it
was 1.4° (S.D. 0.6).

4. Discussion

With increasing ITB loads, the patella tracked and tilted more
laterally in the mid flexion range and rotated more laterally later
in the flexion cycle. Simultaneously, the tibia rotated externally,
with a comparatively small increase in adduction in the mid
flexion range. These findings are in agreement with the hypoth-
esis, except for the tibial adduction in the flexed knee, when
abduction had been expected.

This study has inherent limitations. As with most studies in
vitro, it used elderly knees and it is not known how well their
behaviour extrapolates to the general population. Although care
was taken to tense the individual heads of the quadriceps in a
physiological manner, their relative contributions vary from knee
to knee and the overall tension was limited by tearing the muscle
fibres in these elderly specimens. We do not know the physiologi-
ical loading appropriate for the ITB, but the 30 N ITB load is
equivalent to the ratio of ITB tension to quadriceps tension used
previously (Bull et al., 1999; Kwak et al., 2000; Yamamoto et al.,
2006). For example, Kwak et al. (2000) used 89 N based on
physiological cross-sectional area of the muscle, with 534 N
quadriceps tension, the same 17% ratio. We selected 30 N to
represent the “normal” knee and multiples of this to represent
“pathological” ITB forces. We do not think that even a patholo-
gically tight ITB tension would exceed 50% of the total quadriceps
tension in-vivo, in which case the range of tensions in the study
would cover the clinical scenario. In addition, although the
kinematic changes were small, they were consistent, so post-hoc
application of a power analysis to a representative sample of the
lateral translation data (Lenth, 2006) calculated an 84% power
with 95% confidence. While that is not, strictly, a calculation of the
power of the whole study, it provides an indication in relation to
one of the clinically most important variables. Finally, the

Fig. 4. Lateral tilt of the patella relative to the femur when the ITB is unloaded (0 N) and with loading of the ITB at 30, 60, and 90 N. The graphs below show the difference from the unloaded condition (mean ± S.D., n = 9).

Fig. 5. Patellar flexion relative to the femur when the ITB is unloaded (0 N) and with loading of the ITB at 30, 60, and 90 N. The graphs below show the difference from the unloaded condition (mean ± S.D., n = 9).
experiment replicated ‘open chain’ loading, such as knee extension while sitting; we do not know how the patellar kinematics would be affected by changing to weight-bearing gait analysis.

The ITB moves posteriorly as the knee flexes: in extension it is anterior to the lateral epicondyle but with flexion it moves posterior to it (Kaplan, 1962). This implies that the transverse fibres linking the ITB to the patella are slack in extension and tight in flexion: the implication is that this will correlate with the action of the ITB on the patella. In knee extension, the patella is only partly engaged with the trochlea, so it is relatively vulnerable to maltracking. However, in extension the ITB is acting parallel to the plane of the patella, with little tendency to cause lateral tilt. One would expect that with increasing flexion of the knee, ITB tension would have a larger effect on patellar tracking. Opposing this effect, however, is that with increasing knee flexion, there is a decrease in the angle in the sagittal plane between the quadriceps tendon and the patellar tendon. This increases the proportion of force that acts on the patellofemoral joint, pulling the patella onto the femur and stabilising it (Amis and Farahmand, 1996). Thus, taking into consideration these two opposing effects, a possible explanation can be postulated for why most of the components of patellar kinematics are affected maximally in the mid flexion arc. Patellar kinematics may also be dependent on tibial rotation, because tibial external rotation increases the lateral force vector acting on the patella via the patellar tendon. However, this cannot on its own explain the changes observed; the range of flexion that corresponded to maximal change in tibial external rotation did not correspond to that of maximal change in patellar kinematics.

A previous study of the effect of ITB tension on patellofemoral and tibiofemoral kinematics (Kwak et al., 2000) found similar results despite the differences in methodology noted above, but patellar tilt was not reported. The present study found that ITB tension caused tibial adduction in the flexed knee, while Kwak et al. (2000) found the opposite. The largest kinematic effect of ITB tension was tibial external rotation, caused by the posterior traction on the lateral aspect of the knee. Noting the slope of the lateral plateau, that movement could be expected to induce a secondary rotation into adduction. The results did not support the initial hypothesis that ITB tension would abduct the tibia in the extended knee. That had been expected because the tension

Fig. 6. Lateral rotation of the patella relative to the femur (external rotation–distal patella moves laterally) when the ITB is unloaded (0 N) and with loading of the ITB at 30, 60, and 90 N. The graphs below show the difference from the unloaded condition (mean ± S.D., n = 9).

Fig. 7. External rotation of the tibia relative to the femur when the ITB is unloaded (0 N) and with loading of the ITB at 30, 60, and 90 N. The graphs below show the difference from the unloaded condition (mean ± S.D., n = 9).
acting parallel to the lateral aspect of the knee does impose an abducting moment. However, the quadriceps tension caused an adduction moment, in relation to the centre of the lateral condyle, keeping the tibiofemoral joint surfaces compressed together.

This work has shown that increasing the ITB tension had statistically significant effects on knee kinematics, including increasing lateral tilt and translation of the patella, plus tibial external rotation in flexion. However, many of these changes in kinematics were physically small; we do not know whether the resulting changes in the contact pressure distribution will have clinically significant consequences. It has been shown that similar small changes in patellar kinematics had a significant effect on cartilage contact stresses (Ostermeier et al., 2007), but we do not yet know how these findings will relate to symptoms in patients. It is likely that a knee with dysplastic changes would exhibit larger kinematic changes than those found here in normal knees. These results can help to explain the clinical finding of patellar maltracking and pain as a result of ITB tightness. The method used in this study may be applied to the clinical need for data about the effects of lateral retinacular releases to correct patellar maltracking.

Conflict of interest

The authors confirm that no benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article. There are no potential conflicts of interest (employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding) or financial and personal relationships with other people or organisations that influences or introduces bias in the results and interpretation of this work.

Acknowledgements

Azhar M Merican was supported by the University of Malaya Medical Centre, Kuala Lumpur and the Arthritis Research Campaign (ARC). Knee specimens were funded by a Grant from the ARC. We thank W. Scott Selbie, Ph.D., Director of Research and Development, C-Motion, Inc. for his invaluable help and software support.

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