



Effect of iliotibial band and gastrocnemius activation on knee kinematics

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ABSTRACT

Background: This paper aimed to evaluate the effects of iliotibial band (ITB) activation and gastrocnemius activation on knee kinematics and stability. A quantitative analysis needs to determine the effect of ITB and gastrocnemius activation in each of the six degrees of freedom of the knee joint.

Methods: Four cadaveric knee specimens were tested during squat motions with physiological loads. The quadriceps and hamstring muscles were activated in each situation. The ITB was intermittently activated using an actuator and a cable pulley system. The gastrocnemius was activated anatomically as part of the triceps surae complex together with the soleus and the plantaris muscle. During the squat motion, the Achilles tendon has increased tension which induced muscle activation in the calf muscles thus creating the activated situation.

Results: Introduction of the ITB resulted in a reduced laxity width during extension and an external tibial rotation (2.4°). The femur shifted less posterior in the lateral compartment when the ITB was activated. Activation of gastrocnemius as part of the calf muscles led to an increased laxity width.

Conclusions: Knee stability and knee joint kinematics are affected significantly by the activation of the ITB and the gastrocnemius as part of the triceps surae complex. This points to the importance of muscles and stabilizing tissue structures such as the ITB in the evaluation of knee joint kinematics both in vitro and in vivo.

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1. Introduction

Knee stability is a major problem in osteoarthritis patients [1]. Knee instability is defined as the inability to maintain a position or control movements of the knee joint under different external loads. Patient-reported knee instability was found to be prevalent in a majority (>60 %) of knee osteoarthritis patients [2].

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The iliotibial band (ITB) is not a muscle but rather a fibrous reinforcement of the fascia latae or deep fascia of the thigh [3]. It serves as a muscle attachment site for the tensor fascia latae and the gluteus maximus. Both muscles connect to the hip and the ITB is inserted in the lateral condyle of the tibia, thus making the ITB cross both the hip and knee joint [3].

The gastrocnemius is a bi-articular, two-headed muscle of the leg originating on the lateral and medial sides of the femur, respectively, and inserts into the Achilles tendon [4]. Together with the soleus muscle and the plantaris muscle, it forms the superficial posterior compartment calf muscles known as the triceps surae. The gastrocnemius serves both flexion and stabilization of the knee [5]. Based on the anatomical description, it is hypothesized that the iliotibial band (ITB) and the gastrocnemius affect the stability of the knee joint. A kinematic study on the effect of ITB and gastrocnemius activation could answer this hypothesis.

A kinematic analysis of the effect of ITB on the tibio-femoral kinematics is presented by Merican and Amis [6]. However, Merican and Amis [6] only present the tibiofemoral abduction and external rotation due to ITB activation. The other degrees of freedom in the tibiofemoral joint are not discussed. A full kinematic analysis of the effect of the gastrocnemius on the knee joint kinematics is limited in the current literature. Slater et al. present a study on the activation of the gastrocnemius muscle under different knee joint misaligned squats [7]. However, a description of the rotation and translations in the six degrees of freedom of the knee joint is absent in literature.

In this paper, the effect of ITB and gastrocnemius during squat motions was investigated using a dynamic knee rig. The activated condition was compared with the inactivated situation to assess the difference between both statistically. A quantitative analysis in all six degrees of freedom of the knee joint was performed.

2. Materials and methods

This study was designed to investigate the effect of activation of the ITB and the gastrocnemius muscle on native tibio-femoral kinematics.

For this pilot study, four Thiel-embalmed cadaveric knee specimens were tested. This study was approved by the institutional review board (IRB) by the University of Ghent ethical committee (B 670201421989) and was performed in accordance with the 1964 Helsinki Declaration and its amendments.

The UGent Knee Rig (UGKR) was used as activity simulator in this study (Figure 1). Compared with previous publications on the UGKR [8,9], the UGKR was altered by adding an ankle-foot holder and an ITB actuator. The advantage of the ankle-foot holder is an anatomically correct connection of the gastrocnemius in the ankle in order to result in activation of this bi-articular muscle during the squat motion. To limit the stresses on the Achilles tendon, the ankle was placed at 20° plantar flexion during the squat motion.

2.1. Specimen preparation

Every specimen underwent a full lower limb computed tomography (CT) scan. Based on the CT images, a three-dimensional (3D) model of each bone surface was made using Mimics software (Mimics software R, Materialise, Belgium). A rigid marker set was fixed to the femur and the tibia to allow measurement of the bone position in time using Optitrack Flex 13 cameras (OptiTrack, NaturalPoint, Corvallis, OR, USA). Registration of the bone surfaces was performed with an optically tracked stylus by uncovering the proximal part of the femur, an anterior incision mid-tibia and uncovering the medial malleolus. This procedure ensures the intactness of the knee capsule. The femur was sectioned 95 mm from the femoral hip

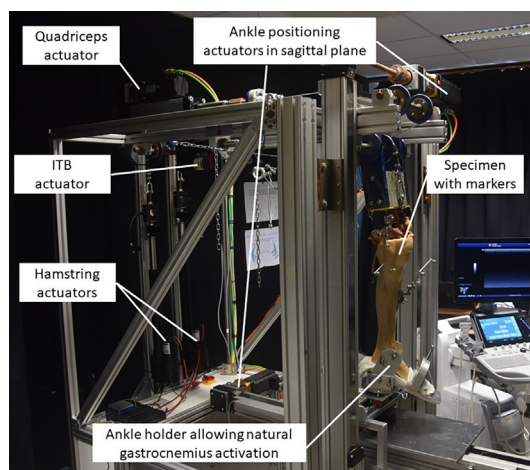


Figure 1. The UGent Knee Rig with the prepared specimen inserted.

centre to pot the femur in a container using resin in order to align the specimen in the UGKR. To ensure a correct anatomical position of the bones in the test set-up, dedicated guides were designed and printed based on the preoperative CT scan [10]. Connection between the cable pulley system and the muscle tendons/ITB was carried out using Ti-Cron™ braided polyester sutures. The semimembranosus and semitendinosus were combined to form the medial hamstring while the biceps femoris formed the lateral hamstring. Note here that due to the transfermoral cut, there was no tension on any of the soft tissue structures acting between the knee joint and the hip joint, unless they were activated using the cable pulley systems. The foot of the specimen was inserted in an ankle-foot holder which allowed for a natural force direction of the gastrocnemius. The ankle-foot holder was designed to allow external varus/valgus load of 6.5 Nm constantly through the range of motion of the squat to test the knee stability under external loads, similar to the method used in Arnout et al. [11].

2.2. Tibio-femoral kinematics

A squat motion was simulated in the UGKR by keeping the hamstring forces constant while varying the quadriceps forces in accordance with a sinusoidal 75 pattern based on numerical simulation software AnyBody, similar to the procedure in Arnout et al. [11]. By approximation, this resulted in a constant vertical ground reaction force, traditionally considered in Oxford test set-ups [12]. Based on the AnyBody simulation of the tensor fascia latae force, a constant ITB force of 75 N was chosen, which can also be found in literature [6]. To preserve integrity of the specimen, a downscaling with factor four was applied to the forces resulting in 75 N for the ITB and 6.5 Nm external varus/valgus load [13]. Hyperextension of the knee joint was avoided by limiting the range of motion in this set-up from 20° to 100° of knee flexion.

Combining the surface registration with an iterative closest point algorithm allows for position tracking of the femur and the tibia in time. The kinematics of the femur relative to the tibia were described according to the framework of Grood and Suntay [14] allowing for evaluation in six degrees of freedom: knee flexion angle (FA), varus/valgus rotation (VV), internal/external rotation (IE), medio-lateral translation (ML), anteroposterior translation (AP) and compression/distraction translation (CD). The three translations were independently calculated for both the medial and lateral compartments of the knee. The knee kinematics were assessed in real time to a 1.0 mm/1.2° of accuracy [11].

A dedicated test protocol was designed to test the two hypotheses of this paper. Therein, each test was repeated twice through the flexion–extension cycles. First, the neutral kinematics were evaluated in different conditions: with/without ITB activation and with/without gastrocnemius activation. The situation with activation of the ITB mimicked the tension in the ITB structure during a squat movement. The inactivated ITB situation mimicked a situation without tension on the ITB structure due to the transfermoral cut in the specimen preparation as performed in previous research on the UGKR. For activation of the triceps surae to which the gastrocnemius belongs, it was assumed that the tension build-up in the Achilles tendon during the performance of a squat motion, induced activation tension in the muscle complex. In order to achieve the condition without gastrocnemius activation, the Achilles tendon was completely resected (Figure 2). This situation does not have a clinical meaning, except for patients with full Achilles tendon ruptures, but it is designed to show the difference between activated and inactivated gastrocnemius muscles. It shows the importance of including the ankle joint in



Figure 2. Cut Achilles tendon to recreate the situation without gastrocnemius activation.

in vitro tests for knee joint kinematics. In each condition, the knee kinematics are again evaluated under external varus/valgus loading conditions. The average over the two repetitions was calculated for each of the four specimens in the test series.

2.3. Statistics

The average of the repeated tests was calculated every 1° of knee flexion angle. The neutral kinematics without external VV load were used to evaluate the VV and IE rotation and ML, AP and CD translations in the different conditions. A VV-laxity width was defined using the kinematic patterns under external loading. By subtracting the VV alignment under external varus load from that under the valgus load, the laxity width was obtained. The obtained kinematic parameters were averaged over the four specimens included in the study.

The kinematics with and without ITB and gastrocnemius were compared using paired Wilcoxon signed rank tests. Throughout, a significance level (P -value) of 0.05 was adopted.

3. Results

The results of the kinematics are given in Table 1. Note here that the rotations and translations given are those of the femur with respect to a fixed tibia. In Table 1, the mean (M) and standard deviation (SD) for extension (20–30° FA), mid flexion (55–65°) and deep flexion (90–100°) are given for each test condition.

Comparison between the activated and inactivated situation for the ITB and the gastrocnemius were performed using the paired Wilcoxon signed rank test. The P -value resulting from this test was also given for each phase of the flexion–extension cycle. If $P > 0.05$, there was no statistical significant difference.

To investigate the effect of ITB activation, the kinematic parameters in neutral condition and under external varus/valgus load in function of the knee flexion angle were plotted in Figure 3. Similarly, the effect of the gastrocnemius activation is given in Figure 4. For each rotation and translation, the VV-laxity was the width of the envelopes shown in Figures 3 and 4 for ITB and gastrocnemius, respectively. The average values of the VV-laxity are given in Table 2 for extension (20–30° FA), mid flexion (55–65°), deep flexion (90–100°) for both activations.

4. Discussion

The discussions for the ITB and the gastrocnemius are dealt with separately. The statistical analysis showed in most directions a significant difference when ITB and gastrocnemius were activated (Table 1). During extension and ITB activation, the

Table 1

Kinematic results averaged over all specimens for extension, mid-flexion and deep flexion with varus < 0, valgus > 0, external < 0, internal > 0, lateral < 0, medial > 0, anterior < 0, posterior > 0, compression < 0, distraction > 0.

Type	Mean $\pm$ SD			P -value compared with inactivated		
Flexion angle	20–30°	55–65°	90–100°	20–30°	55–65°	90–100°
VV rotation (°)						
With ITB	−4.90 $\pm$ 0.21	−6.71 $\pm$ 0.15	−7.30 $\pm$ 0.04	0.168	$\ll$ 0.001	$\ll$ 0.001
With gastrocnemius	−4.88 $\pm$ 0.18	−6.48 $\pm$ 0.13	−7.12 $\pm$ 0.04	0.233	$\ll$ 0.001	0.042
Without ITB or gastrocnemius	−4.81 $\pm$ 0.44	−6.40 $\pm$ 0.10	−7.07 $\pm$ 0.04	–	–	–
IE rotation (°) with ITB	5.21 $\pm$ 2.15	0.95 $\pm$ 0.48	−5.60 $\pm$ 1.05	$\ll$ 0.001	$\ll$ 0.001	$\ll$ 0.001
With gastrocnemius	4.81 $\pm$ 3.21	−0.73 $\pm$ 0.38	−8.00 $\pm$ 1.01	$\ll$ 0.001	$\ll$ 0.001	$\ll$ 0.001
Without ITB or gastrocnemius	1.86 $\pm$ 2.18	−1.53 $\pm$ 0.35	−7.51 $\pm$ 0.76	–	–	–
Medial ML (mm) with ITB	7.88 $\pm$ 0.96	5.96 $\pm$ 0.05	3.57 $\pm$ 0.15	0.022	$\ll$ 0.001	$\ll$ 0.001
With gastrocnemius	7.25 $\pm$ 1.22	5.17 $\pm$ 0.12	2.99 $\pm$ 0.22	0.043	$\ll$ 0.001	$\ll$ 0.001
Without ITB or gastrocnemius	7.66 $\pm$ 1.12	5.56 $\pm$ 0.08	3.45 $\pm$ 0.14	–	–	–
Lateral ML (mm) with ITB	1.89 $\pm$ 2.13	−0.38 $\pm$ 0.05	−2.88 $\pm$ 0.22	0.147	$\ll$ 0.001	$\ll$ 0.001
With gastrocnemius	0.81 $\pm$ 1.23	−1.20 $\pm$ 0.13	−3.77 $\pm$ 0.32	0.027	$\ll$ 0.001	$\ll$ 0.001
Without ITB or gastrocnemius	1.70	$\pm$ 1.89	−0.77 $\pm$ 0.08	−3.19 $\pm$ 0.23	–	–
Medial AP (mm) with ITB	7.63 $\pm$ 1.32	6.90 $\pm$ 0.13	9.26 $\pm$ 0.33	0.002	0.520	$\ll$ 0.001
With gastrocnemius	9.30 $\pm$ 1.16	6.17 $\pm$ 0.10	8.35 $\pm$ 0.48	0.733	$\ll$ 0.001	$\ll$ 0.001
Without ITB or gastrocnemius	9.05 $\pm$ 1.59	6.85 $\pm$ 0.04	8.74 $\pm$ 0.47	–	–	–
Lateral AP (mm) with ITB	3.42 $\pm$ 2.61	8.56 $\pm$ 0.52	17.21 $\pm$ 1.18	$\ll$ 0.001	$\ll$ 0.001	$\ll$ 0.001
With gastrocnemius	6.56 $\pm$ 1.91	9.35 $\pm$ 0.54	18.64 $\pm$ 1.19	$\ll$ 0.001	$\ll$ 0.001	0.638
Without ITB or gastrocnemius	8.01 $\pm$ 1.79	10.73 $\pm$ 0.45	18.65 $\pm$ 1.18	–	–	–
Medial CD (mm) with ITB	24.74 $\pm$ 1.69	25.80 $\pm$ 0.08	25.64 $\pm$ 0.14	$\ll$ 0.001	$\ll$ 0.001	$\ll$ 0.001
With gastrocnemius	24.09 $\pm$ 0.90	25.94 $\pm$ 0.08	26.62 $\pm$ 0.09	$\ll$ 0.001	0.003	$\ll$ 0.001
Without ITB or gastrocnemius	23.73 $\pm$ 1.30	25.86 $\pm$ 0.13	26.11 $\pm$ 0.06	–	–	–
Lateral CD (mm) with ITB	28.00 $\pm$ 1.63	29.79 $\pm$ 0.07	28.66 $\pm$ 0.35	$\ll$ 0.001	$\ll$ 0.001	$\ll$ 0.001
With gastrocnemius	27.04 $\pm$ 1.14	29.77 $\pm$ 0.06	29.36 $\pm$ 0.11	0.021	$\ll$ 0.001	$\ll$ 0.001
Without ITB or gastrocnemius	26.57 $\pm$ 1.48	29.59 $\pm$ 0.09	28.80 $\pm$ 0.28	–	–	–

AP, anteroposterior translation; CD, compression/distraction translation; IE, internal/external rotation; ITB, iliotibial band; ML, medio-lateral translation; SD, standard deviation; VV, varus/valgus rotation.

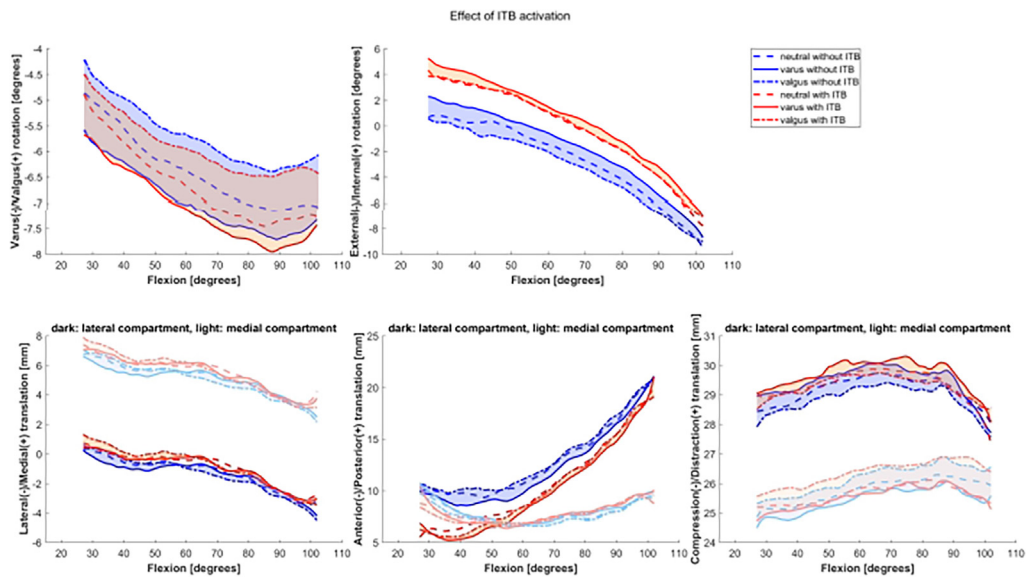


Figure 3. Effect of iliotibial band (ITB) activation on the tibio-femoral kinematics.

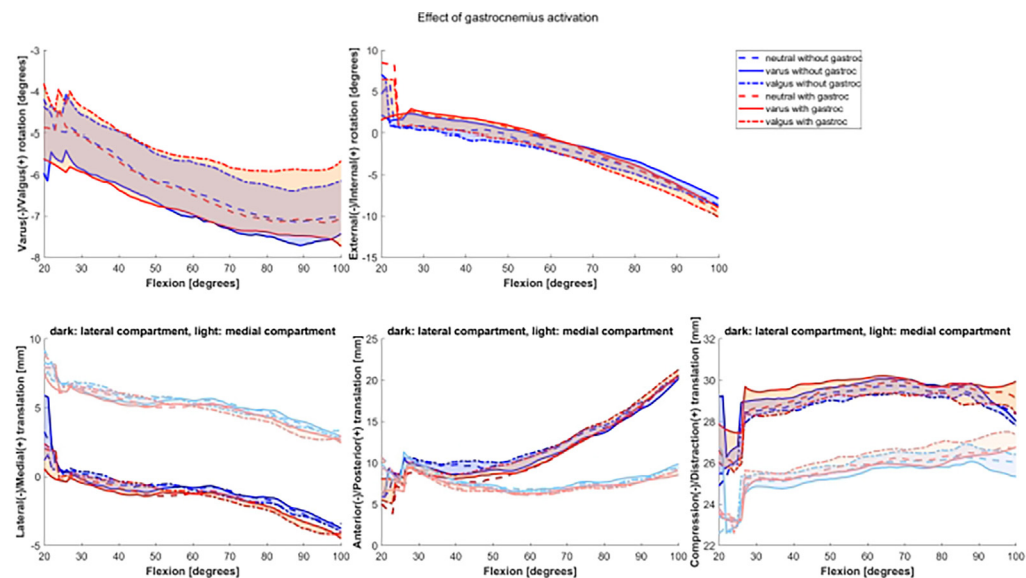


Figure 4. Effect of gastrocnemius activation on the tibio-femoral kinematics.

Table 2

Varus/valgus (VV) rotation laxity in extension, mid-flexion and deep flexion.

Type	M $\pm$ SD		
Flexion angle	20–30°	55–65°	90–100°
VV laxity (°)			
With ITB	1.28 $\pm$ 0.39	1.16 $\pm$ 0.04	1.42 $\pm$ 0.08
With gastrocnemius	1.69 $\pm$ 0.25	1.39 $\pm$ 0.07	1.71 $\pm$ 0.16
Without ITB or gastrocnemius	1.22 $\pm$ 0.38	1.33 $\pm$ 0.03	1.32 $\pm$ 0.02

ITB, iliotibial band.

VV rotation and lateral mediolateral translation did not show a statistically significant difference. The same was valid for VV rotation and medial AP translation for gastrocnemius activation during extension. During mid-flexion, only the medial AP translation under ITB activation was non-significant. During deep flexion, only the lateral AP translation was non-significant under gastrocnemius activation.

4.1. Effect of ITB

During extension, the ITB contributed to lateral knee stabilization as stated by Goldblatt and Richmond [3]. This is shown in the VV-laxity parameters in Table 2. The laxity width remained constant during the squat motion when no ITB activation was present. However, there was a clear reduction in laxity during mid-flexion when the ITB was activated (Figure 3).

The VV rotation showed an increased varus rotation when the ITB was activated. This corresponds with the results reported by Merican and Amis [6]. Intuitively, an increase in valgus would be expected but according to Merican and Amis [6] the increased varus rotation can be caused by an exorotation of the tibia with respect to the femur. The same increase in varus rotation is observed during patellar subluxation during the total knee arthroplasty [15].

When the ITB was activated, an external tibial rotation, i.e., internal femoral rotation in Table 1, was seen compared with the inactivated situation. This correlation has been shown in previous studies [16]. An increase in internal tibial rotation when the ITB is absent was shown by Vap et al. [17].

For the ML direction, an activation of the ITB shows a clear medial femoral shift (Table 1, Figure 3).

Anterior translation in the medial compartment remained the same, with or without ITB. However, there was a smaller posterior femoral shift in the lateral compartment when the ITB was activated. This corresponds with the smaller tibial anterior translations after ITB sectioning reported by Noyes et al. [18] and the anterior starting position of the femur with respect to the tibia.

The CD translation was minimally affected by the applied ITB load of 75 N. Both lateral and medial compartments had a mean difference of only 0.5 mm when the ITB was activated (Figure 3).

4.2. Effect of gastrocnemius

Activation of the gastrocnemius had minimal effect on the VV rotation of the knee joint kinematics (Table 1). The effect of the gastrocnemius activation on the VV laxity was smaller in mid-flexion than in extension or deep flexion (Table 2). Generally, activation of gastrocnemius leads to an increased VV-laxity width (Figure 4). In deep flexion, the gastrocnemius is no longer activated but the soleus takes over.

There was an internal rotation when the gastrocnemius is activated in extension and mid-flexion (Table 1).

For the ML direction, an activation of the gastrocnemius showed a clear lateral femoral shift (Table 1). This is linked to the activation of the lateral head of gastrocnemius during a medio-lateral misaligned squat reported by Slater and Hart [7].

There was a smaller posterior femoral shift when the gastrocnemius was activated (Table 1). Slater and Hart [7] also showed an increased gastrocnemius activation during an anteroposterior misaligned squat.

The CD translation was also minimally affected by the applied gastrocnemius load. Both lateral and medial compartments had a difference of only 0.36 mm when the gastrocnemius was activated (Table 1, Figure 4).

4.3. Limitations

There are some limitations in the current study. The applied load of the ITB was held constant at 75 N throughout the squat cycle. This corresponds with similar studies in literature [6]. However, the Anybody simulations show a varying ITB load throughout the squat. Implementing this varying load might provide a more physiological condition.

Activation of the gastrocnemius was limited. The effectiveness of the gastrocnemius is dependent on the angles of both the knee and ankle joints, respectively, following the principle of storage-rendition of elastic energy as with all bi-articular muscles [4,19]. As in this study, the angle of the ankle joint is fixed at 20° plantar flexion, the dependency is reduced to only the knee flexion angle. The flexion moment of the gastrocnemius on the knee is greatest when the knee is fully extended and the greatest reduction in moment occurs between full extension and 15° of flexion angle because the moment arm changes. However, in order to guarantee the intactness of the specimen, this range was not covered in the current study. Between 90° and 100° of flexion angle there is little moment because of the reduction in muscle length. At maximum flexion, only the soleus is effective [5]. However, due to the set-up of this study, the effect of the soleus cannot be excluded from the results. Therefore, the presented results are the effect of the combined gastrocnemius–soleus complex. The activation of the soleus can be seen in Figure 4 with an increased VV-laxity width for VV rotation and CD translation at 90–100° of flexion angle.

5. Conclusion

The iliotibial band and the gastrocnemius muscle have a significant effect on the knee joint kinematics and the knee stabilization. Activation of the ITB resulted in a significantly reduced varus/valgus laxity width and a reduced external tibial rotation during extension in a squat motion. Activation of gastrocnemius leads to an increased varus/valgus laxity width.

This points to the importance of muscles and stabilizing tissue structures such as the ITB in the evaluation of knee joint kinematics both in vitro and in vivo.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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