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ORIGINAL RESEARCH REPORT

Relationship Between Knee Walking Kinematics and Muscle Flexibility in Runners

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Context: Decreased flexibility in muscles and joints of lower extremities is commonly observed in runners. Understanding the effect of decreased flexibility on knee walking kinematics in runners is important because, over time, altered gait patterns can make runners vulnerable to overuse injuries or degenerative pathologies. ***Objectives:*** To compare hamstring and iliotibial-band (ITB) flexibility and knee kinematics in runners and nonrunners. ***Design:*** A descriptive, comparative laboratory study. ***Setting:*** Hamstring and ITB flexibility were measured with the active knee-extension test and the modified Ober test, respectively, in both groups of participants. Three-dimensional (3D) walking kinematic data were then recorded at the knee using a motion-tracking system. ***Participants:*** 18 runners and 16 nonrunners. ***Main Outcome Measures:*** Knee-extension angle (hamstring flexibility) and hip-adduction angle (ITB flexibility). Knee kinematic parameters of interest included knee angle at initial contact, peak knee angles, and knee-angle range in all planes of movement. ***Results:*** The runners had a significantly less flexible ITB than the nonrunners (hip adduction [–] and adduction [+] angles, 3.1° ± 5.6° vs –6.4° ± 4.5°; $P < .001$). The runners demonstrated a greater mean tibial external-rotation angle at initial contact (7.3° ± 5.8° vs 2.0° ± 4.0°; $P = .01$) and a smaller mean peak tibial internal-rotation angle (–1.6° ± 3.0° vs –4.2° ± 3.2°; $P = .04$) than the nonrunners. ***Conclusion:*** This study provides new insight into the relationship between muscle flexibility and 3D knee kinematics in runners. This supports the premise that there is an association between muscle flexibility and transverse-plane knee kinematics in this population.

Keywords: gait analysis, sports rehabilitation, iliotibial band

For many individuals, long-distance running is the sport of choice. This is supported by a search on *Running USA* and popular North American marathon Web sites (eg, Boston, Ottawa, and New York), which reveals a significant increase in the number of participants in these events over the past several years. For example, since 2000, the number of half-marathon finishers in the United States has more than tripled (from 482,000 to 1,610,000), an increase of 234%.[1] The health benefits and accessibility of this sport certainly contribute to its growing popularity. Nevertheless, running has been frequently associated with musculoskeletal injuries,[2–4] the majority being related to the knee[4,5] and overuse.[4,6]

Decreased flexibility of the tensor fascia latae/iliotibial band (ITB) complex and hamstrings has been commonly reported in runners.[7,8] Anatomical and scientific evidence support the potential role of decreased flexibility of these soft tissues in the pathomechanics of overuse knee injuries.[7,9] The ITB takes its origin in the fascial components of the tensor fascia latae, the gluteus maximus, and the gluteus medius muscles.[10,11] Distally, ITB fibers connect to the linea aspera via the lateral intermuscular septum, terminating just proximal to the lateral condyle of the femur.[10,11] ITB fibers also attach to the patella and to the lateral tibial tubercle, known as Gerdy's tubercle. Due to its tibial attachment, ITB tightness can interfere with internal/external tibial rotation and abduction/adduction movement of the knee during walking. Merican and Amis[12] studied the effect of increasing ITB tension on knee kinematics. They concluded that as the ITB tension increased, the tibia was more externally rotated. However, Merican and Amis' data were collected on cadavers and during an open-kinetic-chain movement, and their results cannot be generalized to an in vivo gait-analysis context. Studying the relationship between decreased ITB flexibility and tibial rotation is clinically relevant because there is evidence that runners with ITB syndrome present changes in tibial rotation compared with symptom-free runners.[13] As regards the hamstrings, they pass across the hip and knee. As the hip goes into flexion during the terminal swing phase of gait, decreased flexibility of the hamstrings can reduce the range of knee-extension movement observed during that period. It can therefore be hypothesized that a greater knee-flexion angle at initial contact could be observed. The contact force between the patella and the femur starts

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at 20°[14] of flexion, and repeatedly contacting the ground in knee flexion can, over time, lead to patellofemoral pain syndrome.[15,16]

Walking is, for most healthy people, the most common functional activity of daily living, and decreased flexibility is frequently observed in runners. Understanding the effect of decreased flexibility on knee walking kinematics is becoming imperative. Over time, decreased flexibility of the hamstrings or ITB can alter the walking kinematic patterns of runners and can make them vulnerable to the onset and progression of chronic injuries or degenerative joint diseases.[17] To our knowledge, the association between the hamstring and ITB flexibility and knee kinematics during walking in a population of runners has not been studied. Therefore, the objectives of the current study were to compare hamstring and ITB flexibility in runners and nonrunners, to compare knee kinematics between both groups during walking, and to measure the association between hamstring and ITB flexibility and knee kinematics. We proposed to investigate the hypothesis that runners have less hamstring and ITB flexibility than nonrunners; runners would present knee walking kinematics that are different from those of nonrunners, thereby exhibiting greater knee-flexion, -abduction, and tibial external-rotation angles during the swing phase and at initial contact than nonrunners; and there would be an association between muscle flexibility and knee kinematics.

Methods

Study Design and Participants

In this descriptive, comparative laboratory study, a sample of 18 runners and 16 nonrunners was recruited on a voluntary basis via word of mouth and advertisements in sports equipment stores and running clubs. Study participants were selected based on the inclusion and exclusion criteria presented in Table 1. Although the runners were considered to be more recreational runners than competitive runners, they all reported having participated in long-distance events (10-km races, half-marathons, or full marathons) on several occasions. All participants were asked to come to the rehabilitation clinic for a clinical assessment (lower limb flexibility measurements) and to have their gait kinematic data recorded. Institutional ethics approval was obtained and all participants signed the consent form.

Data Collection

Descriptive Characteristics and Lower Limb Muscle-Flexibility Measurements. Sociodemographic (ie, age, training history) and anthropometric measurements (ie, weight and height, which we used to calculate the participants' body-mass index) were first collected. These data served to describe the sample of participants. The side to be evaluated was then randomly assigned. Hamstring flexibility was measured by the active knee-extension test.[18] Each participant was positioned supine on a standard examination table, with the pelvis stabilized with a Velcro belt and the evaluated limb flexed at the hip and knee to 90°. We used a goniometer to validate the hip and knee positions. While stabilizing the thigh, the evaluator asked the participant to extend his or her knee as far as possible to measure the knee-extension angle with a goniometer.

To determine the presence or absence of ITB tightness on the evaluated side, the modified Ober test was chosen.[19] Two evaluators were required for this test. Before performing the test, the anterior longitudinal axis of the thigh on the side being evaluated was first identified by drawing a line joining the anterosuperior iliac spine to the midline of the patella. This line served as a landmark for accurate alignment of the movable arm of the goniometer. The participant was positioned on the side opposite the limb being evaluated, with the hip and knee (bottom leg) flexed to 45° and 90°, respectively, to

Table 1 Inclusion and Exclusion Criteria Used to Determine Participant Eligibility for Both Groups

Inclusion criteria	Exclusion criteria
Runners	Confirmed diagnosis of radiological or clinical knee OA.
Age 30–55 y.	Pain >3/10 on visual analog scale when walking.
No confirmed diagnosis of radiological or clinical knee OA.	Pain that makes them consciously change their gait pattern.
Running is or used to be main sport; practice or used to practice running for at least 5 y and at least 32 km/wk.	Claudication.
Able to read and understand the consent form.	Have a pacemaker or a serious cardiac condition.
Nonrunners	Exposed daily to knee overloading patterns at work or in sports other than running.
Age 30–55 y.	Have lower limb wounds.
No confirmed diagnosis of radiological or clinical knee OA.	Present a vestibular, neurological, or any chronic musculoskeletal disorder affecting lower limb function, such as rheumatoid arthritis, sciatica, etc.
Running or other impact sport is not main activity/sport.	
Able to read and understand the consent form.	

Abbreviations: OA, osteoarthritis.

stabilize the pelvis. Evaluator 1 stood behind the participant and grasped the upward-facing leg at the knee. He then moved the tested hip into abduction and extension, keeping the knee extended so that the hip was in neutral position. Evaluator 1 stabilized the iliac crest with the other hand while pushing downward and upward and then allowed gravity to lower the evaluated leg into adduction by dropping it until the movement stopped or until he felt a downward pelvic tilt. Evaluator 2 stood in front of the participant and used a goniometer to determine whether ITB tightness was present. The fixed arm of the goniometer was aligned with both anterosuperior iliac spines, and the moveable arm was aligned with the line representing the anterior longitudinal axis of the thigh. Evaluator 2 then measured the angle of hip abduction or adduction. Neutral position at the hip was defined as 0°. Kendall et al[19] suggest that normal ITB flexibility will allow the thigh to drop slightly below 10° with the knee extended, but no objective data are available to support this cutoff value. Based on the procedures used by Gajdosik et al[20] and Reid et al,[21] we decided to use the neutral position to determine the presence or absence of ITB tightness. Therefore, a frontal-plane hip angle above zero (positive value) indicated ITB tightness and an angle below zero (negative value) indicated absence of ITB tightness. The angles of abduction (positive values) or adduction (negative values) were also noted. Finally, all runners had to complete a questionnaire in which they self-reported their training history in terms of frequency (number of days they run per week), distance (number of kilometers they run per week), and running surface (asphalt or dirt surfaces).

Gait Measurements: Velocity, Cadence, and Knee Kinematics. Three-dimensional knee kinematics were recorded while the participants walked barefoot on a regular treadmill. At first, all participants walked for an 8-minute treadmill-walking familiarization session without any equipment. The duration of the treadmill familiarization period was based on Matsas et al,[22] who showed that in adults, the difference observed with time/distance parameters and kinematic parameters between treadmill and overground walking gradually disappears after 6 minutes of familiarization on a treadmill. The speed of the treadmill was progressively increased, and the participants were instructed to tell the evaluator when they felt they had reached their preferred natural gait velocity. This gait velocity was noted in the participant's chart and used during data acquisition.

After this familiarization session, we installed a knee sensor-attachment system (KneeKG, EMOVI Inc, Montreal, Canada) on the participant's lower extremity (Figure 1).[23] This equipment was developed to reduce skin-motion artifacts and allows for the measurement of subtle kinematic changes in the frontal and transverse plane, with an accuracy of 2.3° in the transverse plane and 0.4° in the frontal plane.[24,25] Its repeatability has been assessed in interobserver and intraobserver settings and has resulted in intraclass correlation coefficients above .80 for knee rotation in the 3 anatomical planes.[26] This knee sensor-attachment system is composed of a femoral part, clamped noninvasively on the femoral condyles, and a tibial part, placed on the anteromedial side of the tibia and secured with Velcro bands. Electromagnetic motion-tracking sensors (Fastrak, Polhemus, VT, USA) attach to both the femoral and tibial parts (femoral and tibial rigid bodies). A third electromagnetic sensor located on the sacrum via a sacral belt helps identify the hip-joint center, and a fourth sensor serves as a probe to identify anatomical landmarks on the leg. Once installation of the equipment was completed, we instructed the patients to walk for 2 minutes at their comfortable gait velocity, allowing them to get accustomed to the equipment.

We recorded the position and orientation of the femur and the tibia using a Fastrak electromagnetic motion-tracking system (Polhemus, VT, USA) at a sampling frequency of 60 Hz. Sensor trajectories were filtered with singular spectrum analysis. The ankle-, knee-, and hip-joint centers and the coordinate system were defined based on the functional and postural approach proposed by Hagemeister et al.[27] Using this method, we first localized the hip-joint center while instructing the subject to circumduct his or her leg. To do so, a third electromagnetic sensor was also fixed over the sacrum with a sacral belt. The center of the femoral head in relation to the pelvis was calculated using an optimization method (least-squares). The lateral and medial femoral condyles were then digitized with a probe. The midpoint was calculated and projected on a functional knee-joint axis obtained during an active open-chain knee-flexion/extension movement. The knee-joint center was then expressed in relation to the rigid body of the femur. We defined the ankle-joint center using the midpoint of the intermalleolar distance,

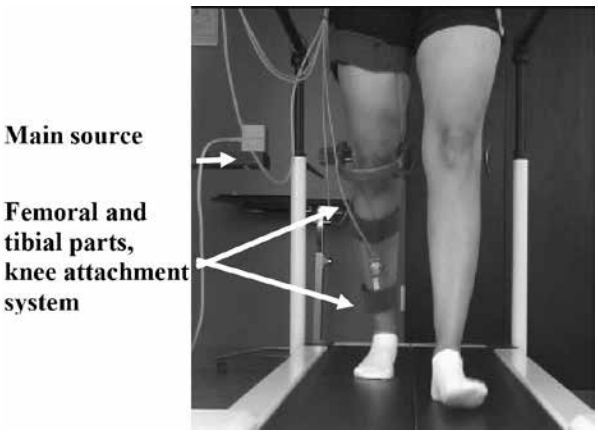


Figure 1 — Illustration of the knee sensor-attachment system that was installed on each participant's knee. This system is composed of a femoral part, clamped noninvasively on the femoral condyles, and a tibial part, fixed onto the medial side of the tibia with Velcro bands. Sensors that are sensitive to an electromagnetic field generated by a main source located on the side of the treadmill are attached to both the femoral and tibial parts. These sensors allow for the recording of the relative position and orientation of the femur and tibia.

which we calculated after digitizing the lateral and medial malleoli. The ankle-joint center was expressed in relation to the tibial rigid body. The joint coordinate system was composed of 3 axes and is defined as follows: The functional sagittal plane was defined during a small-amplitude knee-flexion hyperextension movement, the normal to the sagittal plane was calculated by the vector product of the normal of the frontal plane by the vector joining the hip-joint center to the ankle-joint center, and the neutral position of the knee was defined when the projection of the longitudinal axis of the femur and the tibia in the sagittal plane were best aligned. At that instance, the anteroposterior axis of the tibia and the femur was perpendicular to the normal of the sagittal plane and longitudinal axis. Finally, the mediolateral axis of the femur and the tibia completed each system of orthonormal axes. The functional frontal-plane alignment, corresponding to the frontal-plane angle between the longitudinal axis of the femur and the tibia, was computed when the knee reached 0° of flexion. Afterward, we recorded a 45-second gait trial and saved it for data analysis.

Since no ground-reaction-force information was available, the following procedure was used to identify the beginning of each gait cycle (initial contact). The peak knee-flexion angle was first identified for all the gait cycles. Then, the minimum angle that immediately follows the peak knee-flexion angle was identified. That minimum angle was used to determine the beginning of each cycle. Gait cycles were then normalized to 100 data points (1–100%). An outlier analysis was performed to remove gait-cycle data greater than 2 standard deviations from the mean of all recorded gait cycles. Then a mean pattern was computed from 15 gait cycles for each participant. These cycles were identified from visual inspection. The following parameters were extracted from the kinematic data in all 3 movement planes and used for group comparison: knee-angle value at initial contact, peak and minimal knee-angle values, and angle range (maximum angle minus minimum angle calculated for the entire gait cycle).

Statistical Analysis

We used descriptive statistics to characterize the group samples and performed Kolmogorov-Smirnov and Levine procedures to verify the normality of the distribution and the homogeneity of the variance of all other clinical and kinematic variables. Based on these results, a Student *t* test assessed group difference in mean values for the flexibility variables. A chi-square test compared the frequency of observed ITB tightness (nominal variable) between groups. A regression analysis was performed with gait velocity as a covariate to test the presence of a group difference in mean values for knee kinematic parameters of interest. Finally, the Pearson correlation coefficient served to estimate the strength of the association between muscle flexibility and knee kinematic variables. Statistical significance was set at $P < .05$.

Results

Descriptive Characteristics and Lower Limb Muscle-Flexibility Measurements

Descriptive characteristics such as age, weight, height, body-mass index, and training history were similar for runners and nonrunners (Table 2). Due to an evaluator-

Table 2 Descriptive Characteristics of the Sample Groups and Their Respective Muscle-Flexibility Measures, Mean (SD)

Characteristic	Runners, n = 18	Nonrunners, n = 16
Age (y)	43.5 (6.0)	44.4 (9.0)
Weight (kg)	70.9 (12.8)	66.0 (13.5)
Height (cm)	1.7 (0.1)	1.7 (0.1)
Body-mass index (kg/m^2)	24.4 (4.6)	23.8 (3.5)
Training history (last month)		
frequency (d/wk)	5.2 (1.1)	N/A
mileage (km/wk)	50.1 (10.9)	N/A
running surface—asphalt (% runners)	79%	N/A
running surface—dirt (% runners)	14%	N/A
Lower limb muscle flexibility		
hamstrings (° knee ext.)	155.8 (14.6)	163.0 (9.0)
iliotibial-band tightness (presence/absence)	11/7*	1/15
iliotibial-band flexibility (° hip adduction [–]/abduction [+])	3.1 (5.6)¶	–6.4 (4.5)

*Significant difference at $\alpha = .05$, $\chi^2 = 9.7$, $P < .001$. ¶Significant difference at $\alpha = .05$, $P < .001$.

related error, the flexibility test results for 1 nonrunner were not included in the statistical analyses. No group difference was found for hamstring flexibility. Chi-square analysis showed that ITB tightness was present more often in runners than in nonrunners ($P = .02$). The ITB of the runners was significantly less flexible than that of the nonrunners (3.1° ± 5.6° for runners vs –6.4° ± 4.5° for nonrunners; $P < .001$).

Gait Measurements: Velocity, Cadence, and Knee Kinematics

We observed no difference between the groups for cadence (51.2 ± 4.1 steps/min for runners vs 52.5 ± 2.4 steps/min for nonrunners), but the runners demonstrated a faster gait velocity than the nonrunners (1.2 m/s ± 0.1 for runners vs 0.9 m/s ± 0.1 for nonrunners; $P < .001$). Figure 2 illustrates the mean angular displacement curves as a function of the gait cycle for runners and nonrunners in the sagittal (flexion/extension), frontal (abduction/ adduction), and transverse (internal rotation/external rotation) planes. The kinematic parameter results are summarized in Table 3. In the sagittal plane, the runners had greater mean peak knee-flexion angles during the stance phase and the swing phase. The group difference was significant when the gait velocity was not included in the regression model ($P < .001$ for peak knee flexion during stance and $P < .001$ for peak knee flexion during the swing phase). However, when gait velocity was controlled, we observed a significant effect of gait velocity on peak knee flexion during the stance phase ($P = .04$) and on peak knee flexion during the swing phase ($P < .001$). However, the group effects were not significant for these variables. No significant group difference was observed for frontal-plane parameters. As regards the transverse-plane parameters, the runners had a greater mean tibial external-rotation angle than the nonrunners at initial contact ($P = 0.01$; Table 3). Moreover, the runners had a smaller mean peak tibial internal-rotation angle during the stance

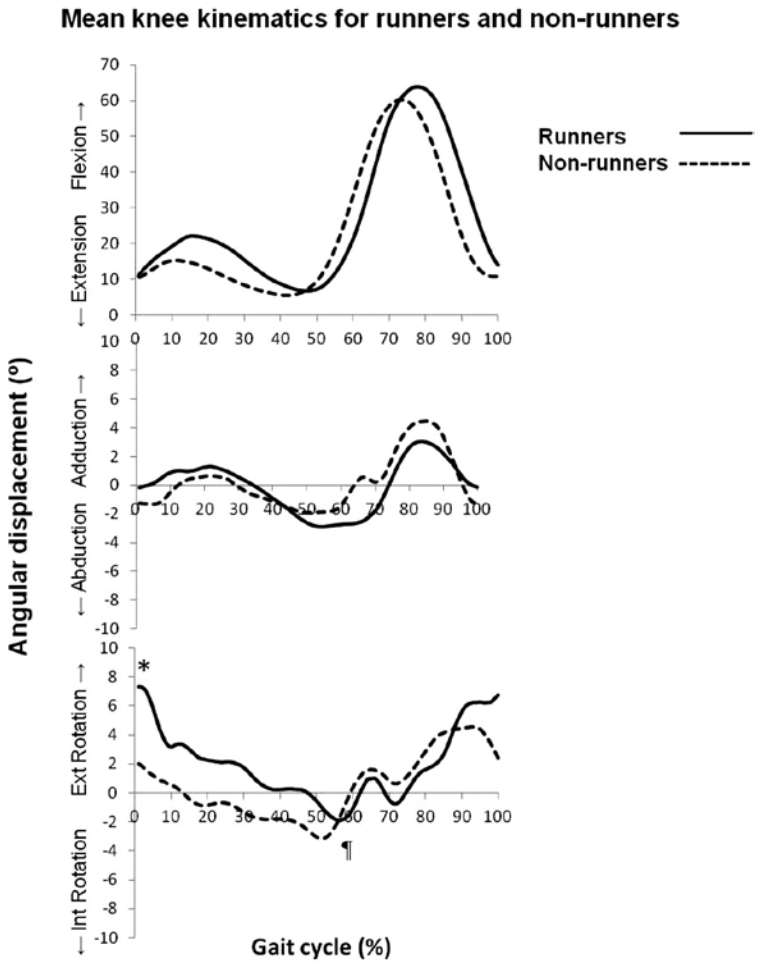


Figure 2 — Graphical representation of mean knee kinematics (computed from 15 gait cycles) for flexion/extension, abduction/adduction, and external/internal angular displacement for both groups. Group differences were significant ($P < .05$) for external/internal-rotation movements at initial contact (*) and for peak internal-rotation angle (¶).

Table 3 Knee Kinematic Parameters for Runners and Nonrunners Recorded During Walking, Mean (SD)

	Runners, n = 18	Nonrunners, n = 16
Sagittal plane (flexion/extension)		
initial contact angle (°)	12.9 (6.2)	10.7 (8.0)
peak knee flexion, stance phase (°)	22.8 (6.4)	15.9 (7.9)
peak knee flexion, swing phase (°)	63.5 (4.7)	52.8 (10.4)
angle range (maximum – minimum; °)	58.2 (7.5)	58.0 (4.1)
Frontal plane (adduction/abduction)		
initial contact angle (°)	–1.2 (5.7)	–0.2 (5.6)
peak adduction, stance phase (°)	1.0 (5.2)	1.6 (5.2)
peak adduction, swing phase (°)	5.7 (7.2)	4.5 (6.9)
angle range (maximum – minimum; °)	10.3(4.7)	10.4 (3.4)
Transverse plane (internal/external rotation)		
initial contact angle (°)	7.3 (5.8)*	2.0 (4.0)
peak internal rotation, stance phase (°)	–1.6 (3.0)¶	–4.2 (3.2)
peak external rotation, swing phase (°)	1.6 (7.2)	2.8 (4.5)
angle range (maximum – minimum; °)	14.0 (5.3)	11.8 (4.4)

*Significant difference at $\alpha = .05$, $P = .01$. ¶Significant difference at $\alpha = .05$, $P = .04$. The group effects observed for initial contact angle and peak internal-rotation angle remained significant when gait velocity was controlled.

phase than the nonrunners ($P = .04$). When gait velocity was controlled, regression analysis showed that it did not explain the difference observed for the transverse-plane kinematic variables.

Finally, we found a negative correlation between ITB flexibility and tibial external-rotation angle at initial contact ($r = –.52$, $P < .05$) only for runners. This negative correlation indicates that as the adduction angle measured during the modified Ober test decreased, tibial external-rotation angle at initial contact increased. A positive correlation was also found for runners between ITB flexibility and peak tibial internal-rotation angle during stance ($r = .55$, $P < .05$). This means that as the adduction angle measured during the modified Ober test decreased, peak internal rotation decreased.

Discussion

In this study, hamstring and ITB flexibility and 3-dimensional knee walking kinematics of runners were compared with those of nonrunners. The hypothesis that runners were less flexible than nonrunners and that they had knee gait kinematic profiles that distinguished them from nonrunners was tested. Moreover, the presence of an association between muscle flexibility and knee walking kinematics was investigated.

Lower Limb Muscle Flexibility

A decrease in hamstring and ITB flexibility was anticipated for the runners due to the adaptive response of lower limb muscles to long-term use and repetitive contraction.[8] However, the results of the current study show that this assumption was only partially verified. We found no group difference for hamstring flexibility. It is possible that the running effect was counterbalanced by the fact that the experienced runners in this study were accustomed to stretching their hamstrings more regularly (like most runners do before or after running) than the nonrunners. Unfortunately, this interpretation is merely subjective since no data on stretching habits were collected. The results, however, show that ITB tightness was more frequently observed in runners than in nonrunners and that the ITB was also significantly less flexible in runners. To our knowledge, data on the comparison of ITB flexibility between runners and nonrunners has not been reported in the literature. Harvey[28] compared ITB flexibility between athletes involved in different sports (rowing, basketball, tennis, and running) using the modified Thomas test. They concluded on the presence of ITB tightness in athletes of all sports and reported an overall mean hip-abduction angle of 15.6°. Our results can hardly be discussed in reference to these results because group comparisons were not performed and no control group

data were reported. The mean ITB flexibility reported by Harvey was greater than it was for runners in the current study. However, Harvey used a different method to measure ITB flexibility. The ITB-flexibility data for the nonrunners were similar to those of Gajdosik et al[20] involving healthy asymptomatic participants. A decrease in ITB flexibility among runners may be explained by long-term repetitive eccentric contraction of the abductors needed during the stance phase to avoid dropping the pelvis toward the unsupported leg.[29] Contrary to the hamstrings, ITB stretching may not be part of the stretching routine of our sample of runners, so the stretching effect was not counterbalanced by the running effect. Again, this interpretation is only subjective.

Knee Kinematics

With respect to knee kinematics, we presumed that decreased hamstring flexibility would decrease knee-extension movement during the terminal swing phase of gait, resulting in greater knee flexion at initial contact. This hypothesis was not validated, but it is somewhat consistent with our flexibility findings: hamstring flexibility was not different between the groups, and no association was found between hamstring flexibility and knee kinematics. Published data on the association between flexibility and walking kinematics remain scarce, and most studies involve pathological populations. McMulkin et al[30] also found an absence of correlation between hamstring flexibility and knee kinematics when studying the gait of children with cerebral palsy. This was not corroborated by Cooney et al,[31] who reported a positive association between these 2 variables in the same population. These different conclusions might be related to the method used to measure hamstring flexibility (ie, popliteal angle at first resistance to knee extension vs popliteal angle at the end of available knee-extension range). In a study involving runners, Messier et al[7] concluded that poor hamstring flexibility is related to greater knee-joint load; however, they reported no kinematic data. It is worth mentioning that in the current study, we observed increased knee-flexion angles among the runners, but only during weight acceptance and during the swing phase. However, regression analysis demonstrated that these kinematic changes were attributable to the effect of gait velocity. Similar velocity-dependent changes in sagittal-plane knee kinematics have been reported in the literature.[32]

We did note very interesting findings with respect to transverse-plane knee kinematics. The mean tibial external-rotation angle was greater for runners than nonrunners at initial contact. Runners also demonstrated a decreased peak mean internal-rotation angle during the terminal stance phase. In fact, when looking at Figure 1, we observe that the mean external/internal-rotation curve of the runners during the stance phase is shifted toward external rotation compared with the nonrunner curve. Noehren et al[13] found that runners with ITB syndrome have increased knee internal rotation. However, ITB flexibility was not measured and kinematic data were recorded while running, not walking. The difference in transverse-plane knee kinematics observed for runners in our study can be interpreted in relation to ITB flexibility. Note that the presence of ITB tightness was subjectively observed in two-thirds of the runners, and objective measures show that ITB flexibility was significantly less for runners than nonrunners. Moreover, a moderate association was found between ITB flexibility and tibial rotation angles at initial contact and the terminal stance phase of gait. One of the force vectors of the ITB leads to external rotation of the tibia, especially when the knee moves toward flexion.[12] The passive force created by ITB tightness can induce an external-rotation shift in the position of the tibia relative to the femur that can persist during the stance phase. The effects of daily exposure to this type of walking pattern on the initiation of degenerative pathologies such as knee osteoarthritis or meniscal injuries cannot be discussed here. First, knee kinematics cannot be interpreted in relation to radiological or magnetic resonance imaging findings. Second, although transverse-plane knee kinematics of runners were different from those of nonrunners, they were within normal reference values.[13,33] Most runners in the current study had decreased ITB flexibility, but none of them reported any ITB-syndrome-related signs or symptoms. It is possible that the shift of the tibia toward external rotation prevents slipping of the ITB over the lateral femoral condyle as the knee moves into flexion during the stance phase, preventing repetitive friction and chronic inflammation.[34]

Study Limitations

Although human gait is a cyclic and repeatable activity, every person has a fairly unique gait pattern, leading to intersubject variability in kinematic profiles. This is especially true for frontal- and transverse-plane data. Unfortunately, the sample size did not allow for clustering of the data in more homogeneous gait patterns for these planes. In addition, ankle- and hip-joint kinematics were not recorded, which limits the interpretation of knee kinematics. Moreover, caution must be exercised when interpreting the association between ITB flexibility and transverse-plane knee kinematics. Causality cannot be assumed. Finally, we used a static measure for ITB flexibility, while kinematics is a dynamic measure where viscoelastic properties play an important role. Nonetheless, the current study provides original and useful data, laying the groundwork for future research.

Conclusion

This study provides new insight into the relationship between muscle flexibility and knee kinematics in runners. We hypothesized that runners have decreased muscle flexibility and different knee walking kinematics, and this was partly validated. The runners in our study had a less flexible ITB than the nonrunners, and they demonstrated greater tibial external-rotation angles during the stance phase of gait. Moreover, ITB flexibility and knee

kinematics were correlated. This supports the premise that muscle flexibility is associated with knee kinematics, even in a healthy population. Further investigation is needed to discuss whether the knee kinematic pattern observed in runners in this study can make these sports enthusiasts more vulnerable to overuse or degenerative knee pathologies while they walk.

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N.G. conceived the study, she participated in its design, and she helped with the coordination and the data collection. She drafted the manuscript. A.F. conceived the study and participated in its design. He helped draft the manuscript. NM conceived the study, helped with data interpretation, and helped draft the manuscript. V.O.G. participated in the design of the study, and she performed the statistical analysis and drafted the manuscript. K.T. conceived the study, participated in its design, and helped draft the manuscript. All authors read and approved the final manuscript.

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