Decreased Frontal Plane Hip Joint Moments in Runners With Excessive Varus Excursion at the Knee

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Knee varus position and motion have been correlated with increased medial knee loading during gait. The purpose of this study is to determine whether runners with excessive varus excursion (EVE) at the knee demonstrate frontal plane knee and hip kinetics that are different from those of runners with normal varus excursion (NVE). Twelve runners with EVE were compared with 12 NVE subjects using three-dimensional kinematics and kinetics. Frontal plane angles and moments were compared at the knee and hip. Runners with EVE had significantly greater abductor moment of the knee \((p = .004)\) and lower peak abductor moment of the hip \((p = .047)\). Runners with EVE demonstrate knee and hip mechanics thought to be associated with increased medial tibiofemoral loading. Further understanding of how changing hip abductor moments may affect changes in knee abductor moments during running may potentially lead to interventions that augment long-term risk of injury.

Keywords: running, clinical biomechanics, gait analysis, hip moment, knee moment

Running is a common physical activity enjoyed by individuals of all ages. The link between physical activity and the development and progression of osteoarthritis (OA) has been investigated with mixed results (Chakravarty et al., 2008b; Cymet & Sinkov, 2006; Loeser & Shakoor, 2003). Some evidence implies that running is not associated with an increased prevalence of OA (Chakravarty et al., 2008b; Loeser & Shakoor, 2003), whereas other research shows that running can increase the risk of knee and hip OA (Cymet & Sinkov, 2006). While running alone may not result in the development of OA, deviations in lower extremity structure and altered mechanics during running may contribute to the development of joint breakdown in the runner.

The medial tibiofemoral compartment of the knee is the most common site affected by OA (Ledingham et al., 1993). It has been proposed that malalignment, either varus or valgus, of the knee is correlated with unicompartmental OA of the knee (Brouwer et al., 2007; Sharma, 2007). However, the evidence is still unclear whether malalignment of the knee always precedes the development of OA or whether the malalignment is the result of knee OA (Brouwer et al., 2007; Cerejo et al., 2002; Sharma et al., 2001). Deviations in lower extremity structure have been related to varus motion during walking in individuals with knee OA (Chang et al., 2004). However, increased knee motion may exist in the absence of static malalignment.

Dynamically, runners who exhibit mechanical characteristics consistent with knee OA may be at greater risk of developing OA. The medial compartment of the knee is more susceptible to cartilage breakdown compared with the lateral compartment, as functional activities such as walking and running require the medial compartment to bear greater loads than the lateral compartment (Hurwitz et al., 2002). This is due to the line of the ground reaction force passing medial to the knee joint center during gait (Johnson et al., 1980). Further, if the knee is in a varus alignment, the ground reaction force passes more medially from the knee joint center, further increasing the load on the medial compartment (Baliunas et al., 2002; Sharma et al., 2001). This large medial load has been associated with high external knee adduction moments (Baliunas et al., 2002; Hurwitz et al., 1998; Koo & Andriacchi, 2007).

Several studies have found that adults with medial knee OA have greater external knee adduction moments (Baliunas et al., 2002; Brouwer et al., 2007; Chang et al., 2004, 2005; Lewek et al., 2004, 2006; Sharma et al., 2001). Specifically, individuals with medial knee OA compared with those without knee OA demonstrate greater external knee adduction moments and these external moments were not correlated with sagittal plane knee angles or moments (Baliunas et al., 2002). Further, it was found that an increasing degree of varus alignment was associated with the progression and development of knee OA (Brouwer et al., 2007). Therefore, runners with varus position and motion may be more likely to develop the disease. During nonpathological walking and running, there is a motion toward knee varus just after heel...
strike (Milner & O’Bryan, 2008; Willson & Davis, 2008). While it has been reported that a varus motion increases the load across the medial knee compartment (Chang et al., 2004), quantitative assessment of excessive varus excursion at the knee has not been defined or compared during walking or running.

There are a number of reasons why excessive varus at the knee may be present during running. Increased forces and moments are necessary in the lower extremities during running to control pelvic and femoral motion. Increased motion in the frontal plane may be related to presence of laxity in passive structures or lack of muscular control of the knee via lateral hip musculature controlling the femur. Since there is little knee musculature that provides direct frontal plane control at the knee, hip frontal plane muscles may play an important role in stabilizing the knee during gait by helping to redistribute load at the knee. During the single-leg stance phase of gait, weakness of the hip abductors may result in pelvic drop therefore shifting the body’s center of mass away from the knee joint center and increasing the external knee adduction moment (Bennell et al., 2007). It has been found that increasing hip abductor moments during walking helped protect against progression of medial knee OA (Chang et al., 2005).

There are few current studies on the relationship between knee mechanics in healthy runners and factors related to the development of knee OA. The purpose of this study is to determine if runners with excessive varus excursion (EVE) at the knee demonstrate increased knee abductor moment and decreased hip abductor moment when compared with runners with normal varus excursion (NVE).

**Methods**

The subjects in this study were all runners recruited from the university, surrounding communities, and local running clubs. The study included a total of 69 runners ranging in age from 32 to 67 at the time of data collection. There were 41 male and 28 female subjects. To qualify for the study, the subjects ran a minimum of 6 miles (9.7 km) per week for at least 6 months before this study. Exclusion criteria included a history of any cardiovascular or neurological compromise, current lower extremity musculoskeletal injury, or joint replacement or fusion. To determine if subjects were to be excluded, each subject filled out a running and injury history and underwent a lower extremity musculoskeletal examination. The same physical therapist examined all the subjects to attain consistency and decrease measurement errors. Each subject gave their written informed consent for participation in the study. The study was approved by the University and Medical Center Institutional Review Board.

Subjects who were eligible for the study were measured using three-dimensional (3D) running analysis. Retro-reflective markers were placed on the subjects at the following locations: L5-S1 junction, iliac crests, greater trochanters, four markers on each thigh, medial and lateral femoral condyles, four markers on each shank, medial and lateral malleoli, proximal heels, distal heels, lateral heels, 1st metatarsal heads, and 5th metatarsal heads (Figure 1). A standing calibration trial was collected with all the markers on. The markers on bilateral greater trochanters, medial and lateral femoral condyles, medial and lateral malleoli, and 1st and 5th metatarsal heads were removed before the dynamic data were collected. Subjects ran along a 20 m runway as many times as necessary to feel comfortable with the markers in the laboratory environment.

Kinematic data were collected at 240 Hz with an eight-camera Qualisys motion analysis system (Qualisys Inc., Glastonbury, CT). Qualisys software was used to create 3D coordinates for each marker. The subjects were asked to run along the runway at a speed of 3.35 m/s (±5%). Photocells placed 6 m apart were used to measure running speed. A fixed pace was chosen to reduce the effect of speed on differences in lower extremity biomechanics related to running velocity. To record ground reaction forces, two force plates (AMTI, Watertown, MA) mounted in the floor of the runway were used at a sampling frequency of 1200 Hz. A total of 12 successful trials per lower extremity were collected for each subject. A trial was considered successful if the subject...
ran within the given speed range with at least one foot making complete contact with a force plate.

Using Visual three-dimensional software (C-motion Inc., Bethesda, MD), pelvis, thigh, shank, and foot segments were created. This 3D data were filtered using a second-order recursive Butterworth filter with a 12 Hz cutoff frequency. The ground reaction force data were filtered at 50 Hz. These data were time synchronized at the time of collection using the system hardware. Data were further analyzed between heel strike and toe-off and normalized to 100 data points, each representing 1% of the stance phase of running. Joint angles and moments were calculated, defining motion about the X-axis as flexion/extension at the hip and knee, motion about the Y-axis as abduction/adduction at the hip and knee, and motion about the Z-axis as internal rotation/external rotation at the hip and knee. Knee motion was defined as the tibia moving relative to the femur. For the purpose of the current study, all moments are reported as internal joint moments. Internal moments should be considered equal and opposite to external moments.

To establish varus excursion for each subject, the peak knee angle from each subject was subtracted from the initial knee angle during stance. Inclusion in the EVE group was determined as having a varus excursion at least 1 standard deviation greater than the mean varus excursion of the group as a whole. Using this criterion, there were 12 (17%) out of the 69 subjects who had EVE on the right side. A group of 12 age- and gender-matched subjects with NVE was used for comparison (Table 1). Data were then assembled based on the two groups and mean curves were created for each group for knee adduction angle, knee abductor moment, hip adduction angle, hip abductor moment and pelvic drop. Data from the right leg in each subject were compared. Differences in peak knee and hip angles and moments were compared between groups using Student’s t tests (p ≤ .05).

### Results

Data for the groups throughout the stance phase of running are presented in Figures 2–4. Differences in the varus position of the knee were seen throughout the stance phase. Knee varus excursion, \( t (22) = -7.37, p < .001 \), and peak varus velocity, \( t (22) = 3.26, p = .002 \), were significantly different between groups (Table 1). The EVE group landed in varus whereas the NVE group landed in slight valgus at the knee. In fact, the NVE group demonstrated a varus position at the knee only between 10% and 35% of the stance phase (Figure 2).

Figure 3 shows the mean knee moment curve. These data show that the EVE group had a greater peak knee adductor moment \((M = -1.13, SD = 0.28 \text{ N-m/kg})\) compared with the NVE group \((M = -0.78, SD = 0.32 \text{ N-m/kg})\), \( t (22) = -2.89, p = .004 \) (Table 2).

Mean curves for hip moment for the two groups are shown in Figure 4. The EVE group had a significantly lower peak abductor moment \((M = -1.99, SD = 0.50 \text{ N-m/kg})\) than the NVE group \((M = -2.29, SD = 0.31 \text{ N-m/kg})\), \( t (22) = 1.75, p = .047 \) (Table 2).

Finally, there were no significant differences between groups’ hip adduction excursion, \( t (22) = 0.405, p = .345 \), or pelvic drop, \( t (22) = -1.04, p = .156 \) (Figure 5 and Table 2).

### Discussion

Frontal plane knee and hip joint mechanics during running differ in individuals with EVE and NVE. An increase in varus alignment during gait, especially during running when forces are increased, may be associated with joint structure and alignment and potentially increase overall joint laxity (Lewek et al., 2004). This may partially explain the increase in frontal plane knee excursion. It is well supported that a varus alignment of the knee is common in people with medial tibiofemoral OA (Sharma et al., 2001). This is not only the result of having OA, it is often a precursor and cause of developing OA. While none of the subjects in the current study demonstrated symptoms consistent with knee OA, the moments at the knee and hip present in our runners with EVE are consistent with greater frontal plane knee moments observed in the OA population. Prospective evaluation of injury and disease in runners with EVE is necessary to determine whether this particular mechanical deviation is detrimental.

Significantly greater external knee adduction moments in patients with knee OA suggest a possible

<table>
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<th>Table 1 Subject demographics, mean (SD)</th>
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<td>EVE</td>
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<tr>
<td>N</td>
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<tr>
<td>Age (years)</td>
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<tr>
<td>Height (m)</td>
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<tr>
<td>Mass (kg)</td>
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<tr>
<td>Mileage (miles/wk)</td>
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<tr>
<td>Knee varus excursion (degrees)</td>
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<td>Peak knee varus velocity (%s)</td>
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* \( p < 0.05 \) between excessive varus excursion (EVE) and normal varus excursion (NVE).
mechanism for the increased load on the medial compartment of the knee joint (Baliunas et al., 2002). In the current study, none of the subjects were symptomatic and they were similar in respect to height and weight (Table 1). Investigation of normal subjects in the current study demonstrates mechanical characteristics that are consistent with characteristics previously reported in subjects with OA. Based on the data from the current study, subjects with EVE seem to demonstrate a similar increase in knee abductor moments as is often reported in patients with OA (Foroughi et al., 2009). The ability to determine whether this motion results in OA is beyond the scope of the current study. Long-term follow-up in groups of runners with and without EVE is necessary to determine possible causation.

Another factor in reported OA development is a decrease in internal hip abductor moment. Lateral hip musculature has been shown to provide stability in the frontal plane at the knee (Chang et al., 2005). This is important due to the lack of musculature directly responsible for frontal plane knee stability. While there is evidence to support that muscles at the knee do have the capability of providing frontal plane support (Buchanan et al., 1996; Dhafer et al. 2003; Dhafer et al. 2005; Kim et al. 1995), the knee may rely more on muscles at the hip to control frontal plane movement of the femur due to
Figure 4 — Frontal plane hip moments during stance phase; 0% represent heel strike and 100% represents toe-off.

Figure 5 — Frontal plane hip (A) and pelvic (B) angles during stance phase; 0% represent heel strike and 100% represents toe-off.
The fact that this is their primary role. These current data support previous findings that individuals with EVE have decreased hip abductor moment, which may be related partially to decreased activity of hip abductor musculature. While the hip muscles are not the sole structures responsible for control of frontal plane motion of the knee, decreased hip abductor activity may lead to extra tensile stress on the lateral knee structures, thus increasing medial load on the knee joint (Chang et al., 2005).

The EVE group had a 45% increase in peak knee abduction moment compared with the NVE group, associated with a clear difference in knee motion between the two groups. Varus excursion during gait has been associated with a fourfold increase in the progression of medial OA over an 18 month period. Further, varus excursion has been associated with a threefold increase in probability of OA progression in knees that were already varus aligned (Chang et al., 2004). While runners have demonstrated decreased overall incidence of knee OA (Chakravarty et al., 2008b), runners with mechanical deviations have not been specifically analyzed. In the current study, the frontal plane moment is similar between the two groups at heel strike and toe-off. There is disparity in the overall motion at midstance when the vertical ground reaction force is highest. Because running results in larger ground reaction forces when compared with walking, it is reasonable to assume that a resulting higher stress would result in the medial compartment and potentially result in increased risk of OA in runners with EVE. Conversely, the 12 runners in the current study demonstrate no symptoms associated with knee OA. Further prospective analysis of injuries and disease, including OA in runners with various structural and mechanical deviations is necessary.

There was also a 15% lower peak hip abductor moment in the EVE group compared with the NVE group. Again, similar patterns are seen at the beginning and end of stance phase in hip joint moment. The EVE group had a decrease in hip moment at midstance when the greatest hip control is required. As previously discussed, hip strength is important for knee frontal plane stability. It is known that malalignment of the knee during stance phase can be detrimental (Brouwer et al., 2007) and that midstance is the most vulnerable and unstable phase of gait for the knee (Baliunas et al., 2002). Excessive varus excursion during midstance demonstrably increases frontal plane knee malalignment in the current study and is consistent with previous findings during walking (Chang et al., 2004).

Interestingly, the EVE group did not demonstrate significantly greater hip adduction excursion or pelvic drop. While not statistically tested, the EVE group appeared to remain more abducted at the hip during the entire stance phase (Figure 5A). While it is expected that a decrease in hip abductor moment would result in greater hip adduction or pelvic drop, the presence of the EVE likely counteracted this hip motion. As the pelvis is dropping slightly from the horizontal during the first 50% of stance (Figure 5B), the distal end of the thigh is moving laterally in the EVE group. This results in a relative abduction at the hip. While the hip kinematic variables were not significantly different, there were differences related to frontal plane joint moments. This suggests that the hip abductors are not solely responsible for hip and pelvis position at midstance. The decrease in hip abductor moment in the EVE group may be related to the position of the moment arm for the vertical ground reaction force relative to the hip. Further, positional data from the trunk were not collected in the current study. Further investigation of how trunk motion, moment arms for the joints, foot position, and center of pressure affect this variable is necessary to fully explain the decrease in hip abductor moment.

Studying the association of running biomechanics to mechanical characteristics of knee OA is important due to the increasing population of active older adults. Running at middle and older ages is associated with reduced disability in later life and it is not associated with accelerated OA (Chakravarty et al., 2008a; Chakravarty et al., 2008b). These findings are encouraging, as the older population continues to be active. However, it is most important to maintain activity in a safe manner. It is important to note that the runners in the current study did not have a diagnosis of or symptoms related to medial knee joint OA. Therefore, a direct relationship between hip abductor moment and knee OA cannot be drawn based on these data. Understanding the relationship between structure and abnormal mechanics in runners, particularly as it relates to EVE is only one factor. Further study of the multifactorial nature of the development of knee OA in older runners is crucial.

In conclusion, runners with EVE displayed greater knee abductor moment and decreased hip abductor moment during running compared with normal runners. These are characteristics that are common with people who have medial tibiofemoral OA. While running may be an important factor in maintaining general cardiovascular

Table 2 Comparison of dependent variables between groups

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<tr>
<th></th>
<th>EVE Mean</th>
<th>SD</th>
<th>95% CI</th>
<th>NVE Mean</th>
<th>SD</th>
<th>95% CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee abduction moment (N·m/kg)</td>
<td>−1.14</td>
<td>0.28</td>
<td>−1.29 to −0.99</td>
<td>−0.78</td>
<td>0.32</td>
<td>−0.96 to −0.60</td>
<td>0.004</td>
</tr>
<tr>
<td>Hip abduction moment (N·m/kg)</td>
<td>−1.99</td>
<td>0.50</td>
<td>−2.28 to −1.72</td>
<td>−2.29</td>
<td>0.31</td>
<td>−2.47 to −2.12</td>
<td>0.047</td>
</tr>
<tr>
<td>Hip adduction excursion (degrees)</td>
<td>4.51</td>
<td>3.08</td>
<td>2.77 to 6.25</td>
<td>4.05</td>
<td>2.23</td>
<td>2.78 to 5.31</td>
<td>0.345</td>
</tr>
<tr>
<td>Pelvic drop (degrees)</td>
<td>−2.18</td>
<td>1.80</td>
<td>−3.19 to −1.16</td>
<td>−1.49</td>
<td>1.25</td>
<td>−2.20 to −0.79</td>
<td>0.156</td>
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and skeletal health in normally aligned runners, EVE may outweigh the benefits. Further research is needed to determine which lower extremity alignments, static and dynamic, may increase or decrease the risk of injury or disease in runners of all ages.

References


