Subtalar Joint Motion and the Relationship to Lower Extremity Overuse Injuries

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The purpose of this study was to determine if there was a difference between the subtalar joint ratio (transverse plane component to frontal plane component) in subjects with overuse symptoms in the foot compared with subjects with overuse symptoms in the leg and knee. Superior and posterior photographs were taken with the subtalar joint in pronation and supination while the subjects were in a seated position. The ratio of the transverse plane to frontal plane components of subtalar joint motion was calculated. A significant ($p < 0.05$) difference in the subtalar joint ratio existed between subjects with foot overuse symptoms and subjects with leg and knee overuse symptoms.

Overuse injuries caused by repetitive submaximal microtrauma occur frequently in individuals participating in repetitive activities such as walking, running, and jumping.[1-3] These microtraumatic overuse injuries have many causes including training errors, shoe selection, and inadequate lower extremity strength and flexibility.[3,4] Abnormal subtalar joint pronation has also been shown to cause overuse injuries of the lower extremity.[5,6]

During closed-chain subtalar joint supination, the calcaneus inverts and the talus dorsiflexes and abducts, which causes external rotation of the leg. During closed-chain subtalar joint pronation, the calcaneus everts and the talus plantarflexes and adducts, which causes internal rotation of the leg. The subtalar joint can influence motion in the foot and up the kinetic chain because of its triplane axis. Injuries to the foot such as first metatarsophalangeal joint deformities, metatarsalgia, and plantar fasciitis can occur because of excessive subtalar joint pronation. Excessive subtalar joint pronation can also cause leg and knee overuse injuries including Achilles tendinitis, shin splints, compartment syndromes, and stress fractures.[7,8]

The deviation of the subtalar joint axis from the transverse plane can influence the ratio of the frontal plane component to the transverse plane component of subtalar joint motion. Several studies have examined the subtalar joint axis on cadavers or amputated specimens. Manter[9] examined 16 cadaver feet and determined that the average subtalar joint axis deviated 42° from the transverse plane with a range of 29° to 47°. Root et al[10] examined the subtalar joint range of motion on 22 freshly amputated feet. The average subtalar joint axis was found to deviate 41° from the transverse plane with a range of 22° to 55°. Isman and Inman[11] studied the talocrural joint and subtalar joint axes on 46 cadaver feet. The average deviation of the subtalar joint axis from the transverse plane was 41° with a range of 20° to 68°. Van Langelaan[12] used ten cadaver specimens to measure the subtalar joint axis and determined that the subtalar joint

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axis was deviated 41.4° from the transverse plane with a range of 27.5° to 54.9°.

The movement of the subtalar joint on living subjects has also been examined. Close et al[13] measured the subtalar joint axis by placing percutaneous pins through the neck of the talus and the body of the calcaneus. The average subtalar joint axis was determined to be 42° from the transverse plane. Phillips et al[14, 15] developed a clinical method of measuring the frontal, transverse, and sagittal plane components of subtalar joint movement with subjects in a nonweightbearing position. A mathematical model was used to define the direction of the subtalar joint axis. Kirby[16] also developed a clinical method of locating the subtalar joint axis in relationship to the plantar surface of the foot.[17]

The average subtalar joint axis deviates 41° to 42° from the transverse plane, which would produce a slightly greater amount of frontal plane component than transverse plane component of subtalar joint motion. During closed-chain subtalar joint motion, the frontal plane component occurs through inversion and eversion of the calcaneus. The transverse plane component of closed-chain subtalar joint motion occurs through abduction and adduction of the talus, which causes external rotation and internal rotation of the leg. The deviation of the subtalar joint axis from the transverse plane has a high amount of variability.[9-17] Root et al[8] theorized that individuals with a high axis subtalar joint (greater than a 42° deviation from the transverse plane) would have an increase in the transverse plane component of subtalar joint motion, which would cause greater rotation of the leg. The increased rotation of the leg would increase the susceptibility of developing overuse symptoms in the leg and knee. If an individual had a low subtalar joint axis (less than 42° deviation from the transverse plane), there would be an increase in the frontal plane component of subtalar joint motion, causing an increase in inversion and eversion of the calcaneus. The increased calcaneal movement would increase the possibility of overuse symptoms in the foot.

The purpose of this study was to determine if a relationship existed between the subtalar joint ratio (transverse plane component to frontal plane component) and the location of overuse injuries. It was hypothesized that individuals with overuse injuries in the foot would have a greater frontal plane component of subtalar joint motion, and individuals with overuse injuries in the leg and knee would have a greater transverse plane component of subtalar joint motion.

Materials and Methods

The subjects were five males and 15 females (age = 27.2 years ± 6.3) who were referred to physical therapy for biomechanical evaluation and treatment of various overuse injuries. All of the subjects participated in activities that involved repetitive walking or running and each subject showed symptoms that were of a gradual, insidious onset without a history of trauma. Ten subjects had unilateral foot symptoms and ten subjects had overuse symptoms in the leg and knee (Table 1). All subjects were informed of the purpose and procedures of the study and signed a consent form that was approved by the University of Pittsburgh Institutional Review Board for Biomedical Research prior to participation in the study.

The calcaneus and the distal third of the leg were bisected to measure the frontal plane component (calcaneal inversion and eversion) of subtalar joint motion. The subjects were positioned prone, with the foot that was to be measured extended beyond the table and the opposite hip in a position of flexion, abduction, and external rotation. The midpoints of the superior and inferior aspects of the posterior surface of the calcaneus were marked through visual estimation following palpation of the medial and lateral borders of the calcaneus. The distal third of the leg was bisected at two points using a caliper to determine the midpoints.[18] The bisections of the calcaneus and distal third of the leg were performed bilaterally.

A 6-inch dowel rod was taped to the medial tibial crest immediately below the medial tibial plateau to assess the transverse plane component (tibial rotation) of subtalar joint motion. The subjects were seated and each placed a foot on a straight line that bisected the calcaneus posteriorly and the second toe anteriorly (long axis of the foot).[8] The tibial rotation was determined by the relationship

Table 1. Location of Subjects' Symptoms

Location	Number
Foot Symptoms	
Plantar fasciitis	2
Medial longitudinal arch	3
Sesamoiditis	3
Hallux abducto valgus	2
Subtotal	10
Leg and Knee Symptoms	
Leg	5
Patellofemoral	4
Iliotibial band	1
Subtotal	10

of the dowel rod to the long axis of the foot from a superior position (Fig. 1).

The subjects were seated during the measurement process with the thigh stabilized. One camera was posterior to the foot and leg to assess the frontal plane component of subtalar joint motion using the bisection points on the calcaneus and distal third of the leg. A second camera was superior to the knee to assess the amount of tibial rotation using the relationship of the dowel rod and the long axis of the foot.

The subtalar joint was initially supinated, and simultaneous posterior and superior photographs were taken. Simultaneous posterior and superior photographs were then taken with the subtalar joint pronated. This procedure was repeated twice for both the injured and uninjured extremities.

Using the posterior photographs, the bisection points of the posterior aspect of the calcaneus and the bisection points of the distal third of the leg were each connected. The subtalar joint position in both pronation and supination was measured with a goniometer (Fig. 2). The difference between these measurements was calculated to determine the frontal plane component of subtalar joint motion for each trial.

Using the superior photographs, the angle between the dowel rod on the medial tibial crest and the long axis of the foot was measured with a goniometer. The measurement was performed with the subtalar joint in pronation and supination for each trial to determine the transverse plane component of subtalar joint motion (Fig. 3). The amount of the transverse plane component was divided by the frontal plane component to determine the subtalar joint ratio. For example, if the transverse plane movement was 8° and the frontal plane movement was 10°, the subtalar joint ratio would be 0.80.

The intratrial reliability of the subtalar joint ratio using an ICC (2,1) was 0.82. The two trials were averaged and the subtalar joint ratio was calculated for each subject on the injured and uninjured extremities. A two-way ANOVA (injured *versus* uninjured side; foot symptoms *versus* leg and knee symptoms) was calculated.

Results

The subtalar joint ratios for the 20 subjects are listed in Table 2. The mean subtalar joint ratio for subjects with foot symptoms was 0.73 ± 0.27 on the

Figure 1. Superior view of the right foot showing the relationship of the dowel rod to the long axis of the foot.

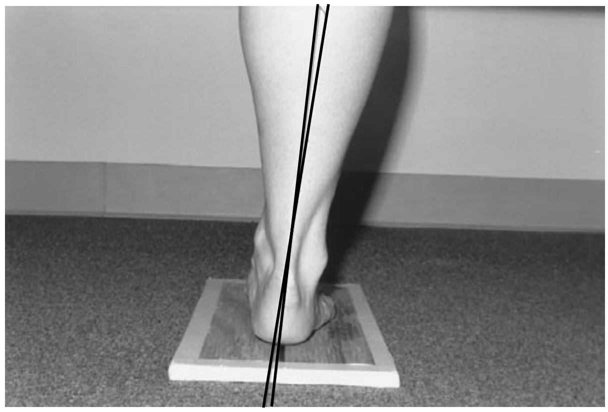

Figure 2A. Posterior view of the frontal plane component of right subtalar joint supination.

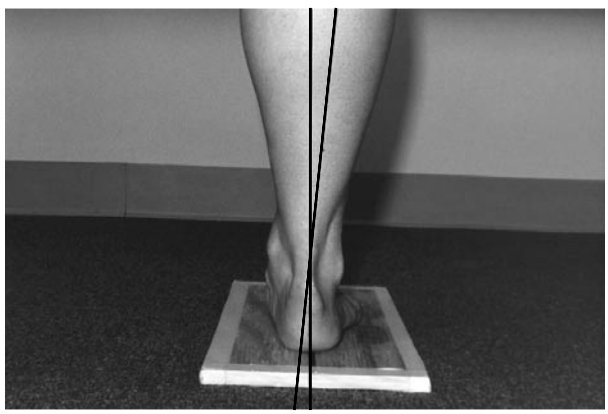

Figure 2B. Posterior view of the frontal plane component of right subtalar joint pronation.

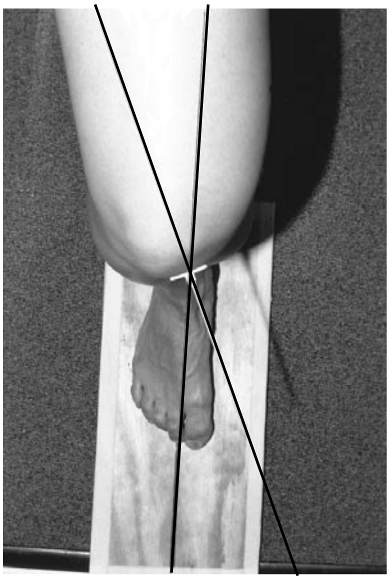

Figure 3A. Superior view of the transverse plane component of right subtalar joint supination.

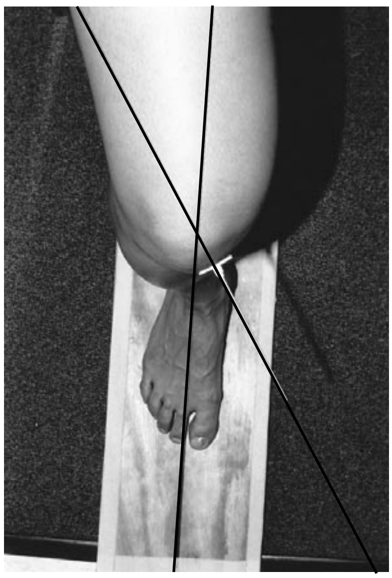

Figure 3B. Superior view of the transverse plane component of right subtalar joint pronation.

Table 2. Subtalar Joint Ratio (Transverse to Frontal) of Subjects with Foot Symptoms and Subjects with Leg and Knee Symptoms

Subject	Foot Symptoms		Subject	Leg and Knee Symptoms	
	Uninjured side ratio	Injured side ratio		Uninjured side ratio	Injured side ratio
1	0.44	0.34	1	1.15	0.98
2	1.00	0.74	2	1.42	0.82
3	0.79	1.05	3	0.88	0.87
4	0.43	0.46	4	0.75	1.38
5	0.84	0.90	5	0.56	1.34
6	0.68	0.80	6	1.0	1.29
7	0.32	0.31	7	1.06	1.06
8	0.76	1.00	8	0.47	0.88
9	0.90	0.82	9	1.14	1.10
10	0.88	0.91	10	0.59	0.70

involved extremity and 0.70 ± 0.23 on the uninvolved extremity. The mean subtalar joint ratio for subjects with leg and knee symptoms was 1.04 ± 0.23 on the involved extremity and 0.90 ± 0.31 on the uninvolved extremity (Table 3). The two-way ANOVA showed that a significant ($p < 0.05$) difference in subtalar joint ratios existed when comparing subjects with foot symptoms to subjects with leg and knee symptoms. There was no significant difference between the subtalar joint ratios when comparing involved with uninvolved extremities, suggesting that the subtalar joint ratios were symmetrical when comparing bilaterally (Table 4). Based on the symmetry of measurements, the subtalar joint ratios were recalculated for each group of subjects combining the involved and uninvolved extremities. The mean subtalar joint ratio for subjects with foot symptoms was 0.72 ± 0.24 and 0.97 ± 0.28 for subjects with leg and knee symptoms. The mean subtalar joint ratio for all subjects was 0.85 ± 0.30 (Table 5).

Discussion

A subtalar joint ratio of 1 would provide equal amounts of transverse and frontal plane components. The subtalar axis deviation from the transverse plane is the angle whose tangent is the subtalar joint ratio. The average subtalar joint ratio (transverse plane component to frontal plane com-

Table 3. Subtalar Joint Ratio (Transverse Plane Component to Frontal Plane Component) Comparing Subjects with Foot Symptoms with Subjects with Leg and Knee Symptoms

	Injured			Uninjured		
Symptom Location	Mean	Standard deviation	Standard error of measurement	Mean	Standard deviation	Standard error of measurement
Foot symptoms	0.73	0.27	0.08	0.70	0.23	0.07
Leg and knee symptoms	1.04	0.23	0.07	0.90	0.31	0.09

Table 4. Two-way Analysis of Variance Comparing Site of Symptoms (Foot, Leg, and Knee) to Side of Involvement

	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio	Significance
Symptoms	1	0.64	0.64	7.11	0.02[a]
Error	18	1.63	0.09		
Side	1	0.07	0.07	1.53	0.23
Error	18	0.08	0.05		
Interaction	1	0.03	0.03	0.66	

[a] Indicates significant for $p < 0.05$.

Table 5. Subtalar Joint Ratio (Transverse Plane Component to Frontal Plane Component) of the Injured and Uninjured Extremities Combined

	Mean	Standard Deviation
Foot symptoms	0.72	0.24
Leg and knee symptoms	0.97	0.28
All subjects	0.85	0.30

ponent) for all subjects in this study was 0.85, which is an axis of 40.4° from the transverse plane. A ratio of 1 would equal amounts of the transverse and frontal components. The average subtalar joint axis was 44.1° from the transverse plane in subjects with leg and knee symptoms and 35.8° from the transverse plane for subjects with foot symptoms. The average subtalar joint axis has been found to be located between 41° and 42° from the transverse plane in cadaver and clinical studies.[9-13]

The average subtalar joint axis for this study was lower than those cited in other studies. The lower subtalar joint axis could be caused by a low calculation of the transverse plane component or a high calculation of the frontal plane component. The technique used during the frontal plane measurement of subtalar joint motion has been described previously and uses the calcaneus directly during the measurement. The transverse plane component of subtalar joint motion occurs when the talus abducts and adducts, which causes concomitant external rotation and internal rotation of the leg. The motion of the talus was not measured directly in this study. Instead, rotation of the leg was measured, which may have underestimated the amount of transverse plane subtalar joint movement leading to a lower average subtalar joint axis as compared with other studies.

The range of the subtalar joint ratio in this study was from 0.31 to 1.42. This range would describe subtalar joint axis deviations from the transverse plane of 17.2° to 54.8°. The range of the subtalar joint axis deviation from the transverse plane was 29° to 47° by Manter et al[9]; 22° to 55° by Root et al[10]; 20° to 68° by Isman and Inman[11]; and 27.5° to 54.9° in the study by Van Langelaan[12]. The highest subtalar joint axis deviation from the transverse plane in this study was similar to other studies with the exception of Manter who found a 47° deviation from the transverse plane in one specimen. The lowest subtalar joint axis deviation from the transverse plane in this study was less than all other studies. The further the subtalar joint axis deviates from the 45° position from the transverse plane, the greater the imbalance between the transverse plane and frontal plane components. A significant increase or decrease in the position of the subtalar joint axis may increase the potential for injury caused by the imbalance of movement into the foot or up the kinetic chain.

The results of this study show a relationship between the subtalar joint ratio and the location of overuse injuries. The average subtalar joint ratio (transverse plane component to frontal plane component) for all subjects was 0.85. Six subjects with foot symptoms had a subtalar joint ratio less than 0.85 and seven subjects with leg and knee symptoms had ratios greater than 0.85. It is important to realize that the subtalar joint biomechanics are only one potential factor that may cause overuse injuries of the lower extremity. Other factors such as training errors, strength and flexibility deficits, and shoe selection must also be evaluated.[3, 4]

The determination of the subtalar joint ratio in this study was calculated using static measurements. It is important to consider that the subtalar joint ratio may vary between static and dynamic measurements. Further study is needed to determine the ratio of the transverse plane to frontal plane components of subtalar motion during gait and if a relationship exists between the subtalar joint ratio and overuse injury patterns.

Conclusion

The position of the subtalar joint axis from the transverse plane will influence the amount of the frontal and transverse plane components of subtalar joint motion. This study showed that static measurement of the ratio of frontal plane movement to transverse plane movement of the subtalar joint was related to the location of overuse symptoms in the lower extremity. Further research is needed to determine if this relationship exists during dynamic activities.

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