Sagittal Plane Kinematics of Passive Dorsiflexion of the Foot in Adolescent Athletes

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Background: Although assessment of passive maximum foot dorsiflexion angle is performed routinely, there is a paucity of information regarding adolescents’ foot and foot segment motion during this procedure. There are currently no trials investigating the kinematics of the adolescent foot during passive foot dorsiflexion.

Methods: A six-camera optoelectronic motion capture system was used to collect kinematic data using the Oxford Foot Model. Eight female amateur gymnasts 11 to 16 years old (mean age, 13.2 years; mean height, 1.5 m) participated in the study. A dorsiflexing force was applied to the forefoot until reaching maximum resistance with the foot placed in the neutral, pronated, and supinated positions in random order. The maximum foot dorsiflexion angle and the range of movement of the forefoot to hindfoot, tibia to forefoot, and tibia to hindfoot angles were computed.

Results: Mean ± SD maximum foot dorsiflexion angles were 36.3° ± 7.2° for pronated, 36.9° ± 4.0° for neutral, and 33.0° ± 4.9° for supinated postures. One-way repeated-measures analysis of variance results were nonsignificant among the 3 groups (P = .70), as were the forefoot to tibia angle and hindfoot to tibia angle variations (P = .091 and P = .188, respectively). Forefoot to hindfoot angle increased with the application of force, indicating that in adolescents, the forefoot does not lock at any particular posture as portrayed by the traditional Rootian paradigm.

Conclusions: Participants had very flexible foot dorsiflexion, unlike those in another study assessing adolescent athletes. This finding, together with nonsignificant statistical results, implies that foot dorsiflexion measurement may be performed at any foot posture without notably affecting results. (J Am Podiatr Med Assoc 103(5): 394-399, 2013)

The examination for ankle joint dorsiflexion is an integral part of any orthopedic assessment of the foot because of the ankle joint’s great importance for normal gait. The diagnosis of ankle equinus depends solely on the result of this examination, in which the maximum ankle dorsiflexion angle is measured using one of a variety of instruments, such as a goniometer1–3 or a specifically designed ankle measurement device.4–7

Various authors have proposed different normative angular values for ankle dorsiflexion during gait. It is claimed that during normal locomotion, 10° of ankle dorsiflexion is required for the forward translation of the center of gravity of the body to occur during single-limb support.1 According to Tiberio,8 5° to 15° is necessary for walking. However, Sullivan9 emphasizes that 15° is necessary, with anything less producing compensations and foot adaptations, leading to pain and deformity. Another trial investigating the kinematics of ankle dorsiflexion during gait reported results of 12° to 22°.10 The authors concluded that during gait, ankle joint dorsiflexion in healthy individuals is greater than the value traditionally reported.

Factors Affecting Foot Dorsiflexion

Foot posture and the amount of force (and associated moment) applied to the forefoot to dorsiflex the foot have been reported to influence the maximum foot dorsiflexion angle.11 In adults, three previous
Foot Dorsiflexion in Children

Although this applies to adult foot dorsiflexion, there is certainly a paucity of scientific information regarding passive dorsiflexion in children. Most of the scientific literature seems to concentrate on the effect of neurologic disorders on ankle dorsiflexion, with little attention being given to normative data in healthy children.

Saxena and Kim\textsuperscript{15} studied a group of 40 adolescent athletes (16 girls and 24 boys) with a mean $\pm$ SD age of 14.8 $\pm$ 0.8 years. “0” was defined as a 90$^\circ$ relationship between the lateral border of the foot and the long axis of the leg. Ankle dorsiflexion was measured at the subtalar joint neutral position using a goniometer aligned with the lateral border of the foot and the long axis of the leg. Ankle dorsiflexion was measured in asymptomatic athletes was 0$^\circ$ with the knees extended and 5$^\circ$ with the knees flexed. They also concluded that some degree of equinus is “normal” in adolescent athletes. These results show an influence of the gastrocnemius muscle because the knee position affected the results; perhaps, being athletes, their gastrocnemius muscle was more developed than average. However, the overwhelming evidence of the unreliability of goniometric measurement\textsuperscript{2,16-18} casts doubt as to the validity of these results.

In a study of 82 children with injured ankles, Tabrizi et al\textsuperscript{19} found mean dorsiflexion values of 5.7$^\circ$ with the knee extended and 11.2$^\circ$ with the knee flexed. In 85 controls, mean dorsiflexion was 12.8$^\circ$ and 21.5$^\circ$, respectively. However, to what extent the ankle injuries could have limited the amount of dorsiflexion is unclear.

Studying a population with an average age of 25 years in which ankle dorsiflexion was measured with a supinated foot, Grady and Saxena\textsuperscript{20} found values of 3$^\circ$ with the knee extended and 9$^\circ$ with the knee flexed. This differs from other later studies\textsuperscript{15} where the foot was not kept in any specific position, so other joints could have dorsiflexed as well,\textsuperscript{21} making comparison difficult. Notwithstanding this, the values of 3$^\circ$ and 9$^\circ$ compare quite well with 0$^\circ$ and 5$^\circ$ with knees extended and then flexed, respectively. The authors themselves admit that one of the limitations of the study was the goniometric assessment, which is subject to evaluator variability and, thus, raises questions as to the validity of the measurement.\textsuperscript{15}

The study of intrinsic foot movement is nowadays possible with the use of kinematic foot models, such as the Oxford Foot Model. This model, which has been shown to be reliable in adults and children,\textsuperscript{22-24} divides the foot into tibia, hindfoot, forefoot, and hallux segments. It has been used in a similar trial investigating foot segment analysis of passive foot dorsiflexion in adults.\textsuperscript{14}

Need for this Study

Because children’s feet are inherently more flexible than adult feet, it has been postulated that these will function differently during passive ankle dorsiflexion. Hence, it was hypothesized that foot posture would affect the maximum ankle dorsiflexion angle and the range of movement of the tibia to hindfoot and tibia to forefoot angles.

Methods

Ethical permission was provided by the University of Malta Research Ethics Committee. Because all of
the participants were minors, informed consent was obtained from parents and participants. A convenience sample of eight girls with a mean ± SD age of 13.2 ± 1.7 years and a mean ± SD height of 1.53 ± 0.09 m was recruited from a local gymnastics club. Participants trained in this sport on an amateur basis, attending an average of two to three 3-hour sessions per week. The exclusion criteria included any recent foot injury, pain, and the presence of neurologic or systemic conditions or musculoskeletal deformities.

Markers, as required by the Oxford Foot Model protocol (Fig. 1), were applied to each participant’s lower extremities, with the full marker set on the right foot. A six-camera optoelectronic system (Vicon, OMG, Oxford, England), sampling at 100 Hz, was used to capture motion. Each participant was seated on a flat examination couch, with the arms gripping the sides of the couch for support, to ensure that all of the markers, especially the right and left posterior superior iliac spine markers, were visible to at least two cameras.

The principal investigator (A.G.), who has more than 20 years of clinical experience in finding the subtalar joint neutral position, was responsible for maintaining the foot in the three required postures, ie, pronated, neutral, and supinated. Each posture was determined randomly by the biomedical engineer (O.F.), who was also responsible for data capture. Foot posture was determined by the talonavicular congruency method: the neutral position was determined by equally palpating the head of the talus on the medial and lateral aspects, the pronated position was determined when the head of the talus was palpable only on the medial aspect, and the supinated position was determined when the head of the talus was palpable only on the lateral aspect. Although finding subtalar joint neutral has been shown to be notoriously difficult for less-experienced raters, an intraclass correlation coefficient of 0.88 has been demonstrated in experienced clinicians who are claimed to be within ±3° of subtalar neutral position 90% of the time.

The foot was dorsiflexed maximally to the end of motion by the application of a force to the metatarsophalangeal joint area and was maintained at the determined posture, where it was held for 3 seconds before being released. Ten trials were captured and recorded for each posture to ensure that enough data were collected.

Each participant’s data were normalized and then averaged for each posture before further statistical analysis with a software program (SPSS version 19; SPSS Inc, Chicago, Illinois). Reference for the minimum foot dorsiflexion angle was the “0” mark, ie, dorsiflexion range was considered to be from 0° up to the maximum foot dorsiflexion angle. The level of significance was set at P ≤ .005 throughout all of the statistical analyses.

Results

Maximum Foot Dorsiflexion Angle

The mean ± SD maximum foot dorsiflexion angles for all of the participants were 36.3° ± 7.2° for pronated, 36.9° ± 4.0° for neutral, and 33.0° ± 4.9° for supinated postures (Fig. 2).

One-way repeated-measures analysis of variance was used for statistical analysis of the maximum foot dorsiflexion angle. There was no significant difference in this angle among the pronated, neutral, and supinated postures (P = .70). Post hoc analysis also revealed similar results comparing one posture with the other: pronated with neutral (P > .99), pronated with supinated (P = .299), and neutral with supinated (P = .039)

Forefoot to Hindfoot Angle

The ranges of variation in the forefoot to hindfoot angle are taken from 0° of foot dorsiflexion to the maximum dorsiflexion angle; the forefoot to hindfoot angle variation was positive in all of the
participants, ie, the forefoot to hindfoot angle increased with the application of force compared with the starting position at 0° dorsiflexion of the foot. However, a one-way repeated-measures analysis of variance indicated a nonsignificant difference for the forefoot to hindfoot angle variation between groups \((P = .346)\). Pairwise comparisons demonstrated a nonsignificant difference between pronated and neutral \((P = .46)\) and both neutral and supinated and pronated and supinated postures \((P = 1.0)\).

Hindfoot and Forefoot Movement

The mean forefoot to tibia and hindfoot to tibia angles are presented in Figure 3. Both angles returned non–statistically significant results. Repeated-measures analysis of variance shows no significant differences among the three groups \((P = .0910\) for the forefoot to tibia angle and \(P = .188\) for the hindfoot to tibia angle).

Discussion

Notwithstanding the fact that assessment of ankle dorsiflexion is performed frequently, little is known as to what actually occurs to the foot as a whole and how foot segments behave during this passive procedure. What little information is presented has been acquired using traditional goniometric measurements, which are known for their unreliability.\(^{2,16-18}\) Measurement of foot dorsiflexion is notoriously difficult to perform as the foot has to be held in the subtalar joint neutral position and the goniometer has to be aligned with the lateral aspect of the lower leg and the lateral aspect of the foot while the foot is dorsiflexed to its end of range of motion.

To overcome this limitation, this trial used an optoelectronic motion capture system with a well tried and tested foot model that can measure foot and foot segment movement much more accurately than a simple goniometer.

Unlike in the adult foot, there is no trend for the maximum foot dorsiflexion angle produced in the pronated posture to be greater than in the supinated posture. In fact, all of the statistical results returned nonsignificant differences, implying that there is little variation among the maximum foot dorsiflexion angles obtained in any of the three postures. This may be due to the increased flexibility in adolescents’ feet. In fact, angles obtained in this trial were significantly higher than those reported by Saxena and Kim,\(^{15}\) who studied adolescent athletes and concluded that 0° of dorsiflexion (ie, no dorsiflexion) was quite normal for these athletes.

The only comparable result to the similar adult trial\(^{11}\) is the behavior of the forefoot to hindfoot angle. This angle clearly increases as a moment is applied to the forefoot, indicating that forefoot movement is greater than hindfoot movement, as also confirmed by the difference between the forefoot to tibia and hindfoot to tibia angles in all three postures in Figure 3. This implies that putting the subtalar joint in the neutral position and
“locking the midtarsal joint” does not eliminate forefoot movement as Rootian theory has been suggesting for the past 30 years and that any measurement of foot dorsiflexion will be different from ankle dorsiflexion due to sagittal plane movement of the midtarsal joint, which can be quite considerable. Thus, any measurement of ankle dorsiflexion, as differentiated from foot dorsiflexion, must not involve the forefoot, otherwise larger angles may result, possibly giving false results that could give rise to a wrong diagnosis and treatment.

It could also be hypothesized that this high flexibility may be due to the nature of the sport itself; this clearly demonstrates that the amount of foot dorsiflexion will have to be investigated in different athletic populations because results cannot be generalized over the whole adolescent population. An obvious limitation of this trial is the small number of participants. However, trends are clear from the several trials of data, although another trial with a much larger participant population could confirm these clinically important results.

Conclusions

Results indicate high flexibility in female adolescent gymnasts’ feet, unlike results obtained in another study using alternative, less accurate methods. The measurement of maximum foot dorsiflexion angle in this population may be performed at any posture as the range of this angle will not be affected, contrary to what occurs in adults. This is possibly due to the high flexibility reported.

During passive foot dorsiflexion, the forefoot to hindfoot angle increases gradually with the application of a moment, disputing earlier Rootian theory of the midtarsal joint locking mechanism. Measurement of ankle dorsiflexion should not involve the forefoot if unrealistically large angles are to be avoided.

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References


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