Resistance of the foot to supination
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Introduction to supination resistance

Foot orthoses are widely used in clinical practice to treat a wide range of lower extremity biomechanical dysfunctions. The most common of these is abnormal pronation of the foot. In these cases ‘abnormal’ may be an excessive magnitude, abnormal timing or prolonged duration of excessive pronation of the foot at the subtalar and midtarsal joints. These dysfunctions are believed to put the foot and proximal structures at increased risk for tissue damage. This belief is based on the traditional theories of what is assumed to be the normal magnitude, timing and amounts of pronation and supination about these joints (1), although recent kinematic work has shown that some of the theories are not sustainable in practice (2). The movements of the subtalar and midtarsal joints have traditionally been suggested to move about simple hinge type axes (1), but the movements about these joints have been shown to be more complicated than this (3-6). However, simplified models of the rearfoot functioning around hinge axes can be considered theoretically coherent and useful fictions (7) that can be used to understand foot function and for pedagogical reasons. If the subtalar joint can be assumed to function around the hinge like axis first described by Manter (8) and Root et al (9) and recently developed into the ‘rotational equilibrium model (10), then the potentially useful clinical assessment of the resistance of the foot to supination can be used. The abnormal pronation of the foot can be assumed to occur about the subtalar joint axis or a rearfoot axis as a rotation with a certain amount of force. If a foot orthoses is to counter this force in order to improve foot function, it must do so by applying a supinatory moment on the medial side of this axis. Theoretically, and perhaps ideally, the amount of supinatory force or moment from the foot orthoses (the orthotic reaction force) should match the amount of force or pronatory moment from the foot. Potentially, if the orthotic reaction force is still too great at the assumed corrected ideal position, the foot could be overcorrected and perhaps lead to additional pathology such as an ankle sprain. If the orthoses reaction force is less than the force from the foot at the assumed ideal corrected position, there could be too little correction to lead to a therapeutic effect. We have recently completed a number of projects investigating the concept of supination resistance (11-16), so the purpose of this paper is to summarise and review this work.

Measurement of supination resistance of the foot
Both mechanical and manual methods can be used to measure the resistance of the foot to supination. A mechanical device has been used in several studies (11-16):
This device consists of a non-stretchable woven fabric (similar to a seat belt material) that was fixed to the base of a platform lateral to the foot in the region of the calcaneocuboid joint. It passes under the foot medial to the talonavicular joint, then proximally to be attached to a pulley system and a Mecmesin® force gauge that measures the force in Newtons. The pulley system is used to apply a force to just overcome the inertia needed to invert the calcaneus, as the investigator observes a bisection that was placed on the posterior aspect of the calcaneus. Subjects have to be instructed not to use any muscular effort and some practice is needed for this. The device has been shown to be repeatable and reliable with an intraclass correlation coefficient for testing on two separate days of 0.95 (11). A wide range of values for the force has been obtained in different individuals, varying from 57 Newtons to 246 Newtons (12). What was noticeable was the high force needed in some people with low body weights and the low forces needed in some people with high body weights. The correlation between body weight and supination resistance is moderate with r=0.34 (p=0.001) in one study 12 and r=0.52 (p=0.001) in another (11). This suggests that bodyweight only explains 11% to 27% of the variability in force needed to supinate the foot.

This mechanical method of measuring supination resistance is not necessarily suitable for routine clinical practice. Kirby (17,18) has described a manual supination resistance test that can be easily used to estimate the force needed to supinate the foot about the subtalar joint.
The test is performed by placing two fingers plantar to the talonavicular joint and applying a force in an upward direction. The amount of force needed to supinate the foot is estimated. Due to the subjective nature of this test, practice is needed on a wide range of foot types to get a feeling for the ranges of resistance to supination. Using a scale of 0/5 (easy supination resistance) to 5/5 (hard supination resistance) it has been shown that this manual test has good inter-tester reliability (ICC=0.89; 95% CI=0.85-0.92) when 4 clinicians of varying levels of experience performed the test on 43 subjects on two days (12). The intra-tester reliability for the two more experienced clinicians was better (ICC’s = 0.82 & 0.78) than that for the two less experienced clinicians (ICC’s = 0.56 & 0.62). This suggests that the test can be used clinically when the clinician is experienced in its use.

**Rearfoot axis position and supination resistance**

Kirby (19) first described a non-weightbearing clinical method for locating the transverse plane position of what he described as the subtalar joint axis. While the dynamic function of the rearfoot complex is much more complicated than this simplified non-weightbearing hinge model (3,5,6), it is more appropriate to refer to it as a rearfoot axis (11). However, it appears to be clinically useful in the determination of the amount of force needed from a foot orthoses and conceptualising rearfoot function (10). This is illustrated in below.

**Hypothetical positions of the transverse plane position of a rearfoot axis – refer to text for details (reprinted with permission from ref 18)**
Foot A is assumed to have a relatively normal position of the rearfoot axis in the transverse plane relative to the plantar surface of the foot. There is a large area of the foot medial to the rearfoot axis for a foot orthoses to apply a force. Foot B is assumed to be a more medially located rearfoot axis. The amount of the foot that is medial to the axis is smaller than the normally located axis, so it is assumed that if the foot orthoses is needed, more force will be needed from the orthoses in this smaller area (10). As the axis passes through the medial midfoot area, any foot orthotic device that applies its force in this area is assumed to have a shorter lever arm to the axis to counter any pronatory force, so it is assumed that a more rearfoot controlling device, such as a medial heel skive (20), DC wedge (21) or inverted device (22) are indicated. Foot C is assumed to have a more laterally located rearfoot joint axis. In feet like this, foot orthoses are assumed to be very effective (or too effective) as the lever arm that the orthoses will have relative to the axis is longer than in the feet in A & B, increasing the moment associated with a given magnitude of force.

To further investigate this concept, the supination resistance device described above was used to measure the force required to supinate the foot, relative to the position of the assumed subtalar joint axis (11). An inked footprint was obtained from each subject and the position of their subtalar joint axis in the transverse plane was determined and marked on the footprint. A positive correlation was found between the force needed to supinate the foot and the perpendicular distance from the joint axis to the fifth metatarsal head (r=0.59; p=0.02). This supported the theoretical approach of Kirby (10), but the position of this subtalar joint or rearfoot axis still only explained 35% of the variation of the force needed.

Posture of the foot and supination resistance
It is possible that the more excessively pronated foot requires more force to resupinate it. Clinically, a decision to use a foot orthoses that provides a greater supinatory force may be based on the foot’s appearance or posture. A potentially useful tool, The Foot Posture Index (FPI), has been developed by Redmond (23-25) as a measure of the posture of the foot has been compared to the force to supinate the foot (13). The FPI gives each foot a composite score based on 8 weightbearing observations to represent the posture of the foot. These are talar head palpation, supra and infra lateral malleolar curvature, Helbing’s sign, calcaneal position, prominence of talonavicular region, congruence of medial longitudinal arch, congruence of the lateral border of the foot and position of forefoot on the rearfoot. Each observation is given a score from −2 (supinated) to +2 (pronated) depending on its posture. A composite negative score is considered to represent a supinated foot while a positive score represents a pronated foot with a score of −1 to 4 assumed to be a relatively normal foot. A score of 5 to 9 is considered mildly pronated with a score of 10 above is considered highly pronated (maximum score is 16).

The correlation between the FPI and resistance of the foot to supination was 0.35 (p<0.0001) (13). This can be interpreted as the posture of the foot only explaining 12.2% of the variation in the force needed to supinate the foot. Of the individual measures that make up the FPI, those in the transverse plane (adduction/abduction of the forefoot on the rearfoot and congruence of the lateral border of the foot) were not correlated to supination resistance. The height or congruence of the medial longitudinal arch was only weakly correlated (r=0.27; p=0.01), explaining only 7.3% of the supination resistance. The highest correlations were with Helbing’s sign (r=0.41; p=0.001) and calcaneal position (r=0.39; p<0.0001) with these measures explaining 16.8% and 15.2% of variability in the supination resistance. Both of these components of the FPI are in the frontal plane and in the rearfoot.

From this data it appears that the posture of the foot forms only a part of the information that could be used when making decisions about how much force may be needed from a foot orthoses. This data may also have potential applicability to the prescription of running or athletic footwear. This type of foot wear is generally made in different forms for the, so called, mild, moderate and severe pronator, when it may be more appropriate to prescribe the footwear based on mild, moderate and severe resistance to supination and not the physical appearance based on the amount the foot has pronated.

Correlation between mechanical and manual supination resistance
While both the manual supination test and the mechanical supination device have been shown to be repeatable, the correlation between the two is only moderate (r=0.57; p<0.0001) (12). The correlation between the FPI and the manual supination resistance test was 0.60 (p<0.0001), which was higher than the correlation between the FPI and the supination resistance device (r=0.35; p<0.0001). Based on this later finding it is speculated that clinicians were rating the manual supination resistance higher in those with a more pronated foot, hence the higher correlation with the manual supination resistance test and the FPI. For example, if the clinician was attempting to decide if the manual supination resistance test should be rated 3/5 or 4/5, they may have given it 4/5 if the foot was more pronated. It could be assumed that this was a subconscious or intuitive
response as the more severely pronated foot could have been assumed as being the foot that needs more force to supinate it, which has now been shown to not be the case.

**Subtalar joint tip-over sign and supination resistance**

During the above experiments, consideration was given to a particular pattern of movement of the subtalar joint. If the foot is held in the defined subtalar joint neutral position with one hand grasping the posterior aspect of the calcaneus and the lateral aspect of the forefoot is loaded with a force directly the sagittal plane with the other hand (below), one of three responses is noted at the subtalar joint when the hand holding the calcaneus is released. The foot will remain in place, or there will be a slight tendency to pronate, or the foot will literally fall over into pronation as the leg internally rotates. This later response has been likened to balancing the subtalar joint on a ‘knife edge’. This phenomenon appears to has been widely noticed clinically, but has not previously been explicitly documented in the literature or investigated. We have called it the ‘subtalar joint tip-over sign’ (14).

The reason for this sign are not clear, but it may be due to the position of the subtalar joint axis, as the more medial the axis is, the greater the lever arm there will be from the lateral aspect of the forefoot to the axis and hence a greater pronatory moment created at the joint, as in foot B above. Another possible explanation for the sign is the position of the sustentaculum tali (and maybe the spring ligament) which support the head to the talus when the subtalar joint pronates. It has been shown that in children with ‘pes valgus’ that the sustentaculum tali is more everted in comparison to controls (28), which could account for the ‘falling off a knife edge’ when the subtalar joint is pronated. The
arc of motion of the joint may be much steeper due to the everted position of the sustentaculum tali.

Using the supination resistance device, those who were considered to have the subtalar joint tip-over sign required more force to supinate the foot that those who did not (1.92 (±0.44) N/kg vs 1.49 (±0.36) N/kg; p<0.001) (14), which could lend support to the medially located subtalar joint axis hypothesis. Also those who were positive for the sign had a more pronated foot, as indicated by the FPI (7.03 (±2.53) vs 4.97 (±4.97); p=0.016). The presence or absence of the sign may have some clinically utility in that the foot orthoses used for those who are positive for the sign may need an orthoses with a greater supination force. Determination of the sign is reliable enough for clinical use. Of the 66 feet in the study (14), the two clinicians (one experienced and one inexperienced) assessing the subjects agreed that the sign was present in 20, absent in 40 and disagreed or were not sure in only 6.

The presence of the tip-over sign may also have implications for the neutral position negative impression casting. The postion in which the foot is held for the test for the sign is the same as the postion that the foot is held in for the neutral position cast. In order to maintain the foot in its defined subtalar joint neutral position an adductory force will be needed to be applied to the forefoot. The effect of this would be to invert the forefoot about the traditionally assumed oblique axis of the midtarsal joint (5,7,26) with the effect being to create a negative impression cast with a false forefoot varus. This may result in a foot orthoses with inappropriate medial posting that has the potential to interfere with what is assumed to be normal first ray function and establishment of the windlass.

**Response to different foot orthoses and supination resistance**
The greatest potential of supination resistance testing is the potential to explain some of the variable response seen in some subjects to different types of foot orthoses. The results of kinematic studies on foot orthoses are variable, and it is possible that one of the reasons for the variable response is a mismatch between the force needed to supinate the foot to a corrected position and the force from the foot orthoses (27). Theoretically, the greater the supination resistance force of the foot, the more controlling or more aggressive type of foot orthoses that may be needed. If these concepts can be validated, supination resistance testing can be used to assist orthoses prescription decision making.

Hypothetically, it could be speculated that all feet would change posture with a device that exerts a high supination force, but only those feet with a low supination resistance force would respond to those devices that provide a low supination force. It could be assumed that feet with a high supination resistance force would simply pronate ‘through’ a device with that exerts low supination force. While all feet could be assumed as changing posture with a device with a high supination resistance force, these devices may not be an appropriate prescription for feet with a low supination resistance force, perhaps predisposing these feet to ankle sprains if these devices are used. The concept of matching supination resistance of the foot to the supination force from a foot orthoses is potentially one explanation for the subject specific responses seen in kinematic studies to foot orthoses.
As a preliminary test of this concept the static stance response to 6 different prefabricated foot orthotic devices was determined by measuring the change in the position of the posterior aspect of the calcaneus (15). Of the six devices used, only three resulted in a statistically different change in the position of the calcaneus. The mean change for all the subjects in the calcaneal position for the heel wedge was 2.82 degrees (p<0.0001), for the Prothotic™ it was 2.66 (p<0.0001) and for the Orthopro™ it was 1.87 degrees (p<0.0001). There was no significant change in the position of the calcaneus for the Formthotics™ (0.47 degrees; p=0.98), the Vasyli™ (0.54 degrees; p=0.96) or an arch cookie (0.44 degrees; p=0.98). The three devices (heel wedge, Orthopro™, Prothotic™) that are assumed to provide a higher supination force due to the construction of the device placing a greater force medial to the subtalar joint axis did result in a significant mean change in the position of the foot. However, the correlation between the supination resistance force of the foot and the response to the different orthoses was not significant, so the hypothesis that was tested could not be accepted. The hypothesis assumed that the feet with a low supination resistance force would respond to all the devices, especially those that provide an assumed lower supination resistance force. The reason for the hypothesis not being accepted is that there was no mean change of any the feet to those devices (Vasyli™, Formthotics™ and arch cookie), including those feet that needed a low force to supinate.

In a subsequent study, using the Interpod™ range of prefabricated foot orthoses, that come in the same profile but with different arch heights, it was shown that during static stance, the amount of force needed to supinate the foot was negatively correlated to the change in the frontal plane angle of the calcaneus. Those feet that had a higher resistance to supination, had a smaller changes in the frontal plane position of the calcaneus. Further investigation of this hypothesis is needed with custom made devices and dynamic rather than static testing.

**Conclusion about supination resistance**

Resisting an excessive pronatory moment from the foot by a foot orthoses may be only one of the mechanisms by which foot orthoses exert their effect. Other effects may include the establishment of the windlass mechanism and other autosupports, reduction of tissue stresses, the alteration of sensory input or altering kinetic rather than kinematic variables. Determining the resistance of the foot to supination potentially has significant use as a clinical decision making tool to assist in prescribing foot orthoses. Further work remains to be done to determine the validity of the clinical use of supination resistance testing, especially dynamic responses of the foot to orthoses in pathological populations.

**References**


8. Manter JT: Movements of the subtalar and transverse tarsal joints. Anatomical Record 1941; 80:397-403
13. Payne CB & Noakes H: Foot posture and the force needed to supinate the foot (submitted)
14. Payne CB, Kirby KA, Oates M, Noakes H: The clinical significance of the subtalar joint tip-over sign (submitted)
16. Payne CB, Oates M, Mitchel A: The response of the foot to prefabricated orthoses of different arch heights (submitted)

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