A Comparison of Negative Casting Techniques Used for the Fabrication of Custom Ankle Foot Orthoses

How you cast makes a big difference in correctly capturing an impression of the foot.

By Doug Richie DPM and Jeff Root

Introduction

In the early 1960's, Merton Root D.P.M. developed the theory and practice of functional foot orthotic therapy, which continues to be the mainstay of non-operative interventions used by podiatric physicians today. The unique differentiating feature and cornerstone of this technology was the use of a neutral suspension casting technique to capture an impression of the foot for eventual orthosis fabrication. Compared to other types of foot orthotic devices, the Root Functional Orthosis has strict parameters regarding positioning of the foot during the negative casting process. The orthoses are designed to capture specific alignment of the osseous segments as well as contours of the foot anatomy which are critical to overall efficacy of the device.

Figure 1: Cast A: Suspension casting (SC): Supine technique, subtalar joint neutral, midtarsal joint fully pronated

When the first podiatric ankle foot orthosis, the Richie Brace®, was introduced by Doug Richie D.P.M. in 1996, the differentiating feature of this device was a functional foot orthotic foot plate which was fabricated from a neutral suspension cast. This was a departure from previous tradition in the orthotics industry where standard AFO's were fabricated from impression casts taken of the feet in a partial or full weight-bearing position. This article will compare the differences between a neutral suspension cast technique and a weight-bearing cast technique. We will propose clinical benefits of a neutral suspension cast for the fabrication of foot orthoses as well as functional ankle foot orthoses.

Figure 2: Cast B: Semi-weight-bearing casting (SWC): Patient seated, subtalar joint neutral, plantar surface of foot placed on a two inch thick foam rubber block with very slight downward force applied to the knee to seat in the foot in the foam rubber, no manual positioning of the midtarsal joint or forefoot, tibia aligned to maintain neutral position of the subtalar joint

Background of the Neutral Suspension Cast Technique

The plantar, non-weight-bearing contour of the foot changes with motion of the osseous segments of the foot. Due to their significant range of motion and axial relationship, the relative position of the subtalar and midtarsal joints has a profound influence on the contour of the foot. Root realized that in order to compare the relative structure of feet, it was necessary to develop a standardized position for comparing feet. In searching for a method to compare feet, Root concluded that since the foot can become

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supinated or pronated at the subtalar joint, there must be a transitional point at which the foot is neither supinated nor pronated. Root utilized the neutral position of the subtalar joint as a standard position for comparing the relative structure of feet.

Root developed a technique for bisecting the heel utilizing digital palpation of the posterior surface of the calcaneus (reference Biomechanical Examination of the Foot: Root, Orien, Weed, Hughes). The calcaneal bisection could then be used as a reference to determine the frontal plane position and range of motion of the calcaneus. Although the plantar contour of the heel is rounded, a line which is perpendicular to the sagittal plane bisection of the posterior surface of the calcaneus is used to represent the plantar plane of the rearfoot.

Figure 3: Cast C: Full-weight-bearing casting (FWC): Casted in the patient's angle and base of gait on a two inch thick foam rubber block, fully weight-bearing, subtalar joint placed in the neutral calcaneal stance position, no manual positioning of the midtarsal joint or forefoot

In an effort to further compare structure, Root used the bisection of the calcaneus to compare the angular relationship between the rearfoot and the plantar plane of the forefoot. For standardization purposes, Root fully pronated the midtarsal joint when comparing the forefoot to the rearfoot. Without standardizing the position of the midtarsal joint, positional variability at the midtarsal joint would create inconsistency when comparing the plantar plane of the forefoot to the rearfoot. Using this technique, Root determined that the plantar plane of the forefoot could be inverted, perpendicular, or everted to the rearfoot when the subtalar joint was in the neutral position and when the midtarsal joint was simultaneously, fully pronated.

After establishing a standardized position for comparing feet, Root began to classify structural conditions of the foot. Examples of such conditions include forefoot varus, forefoot supinatus, forefoot valgus, rearfoot varus, and rearfoot valgus. While these terms have become common nomenclature in modern day biomechanics, they would not have been possible without the establishment of a standardized system of classification, which helped revolutionize biomechanics of the lower extremity.

While Merton Root, D.P.M. is known for his pioneering work in theoretical biomechanics, he was very much a practical clinician. His quest to improve treatment options inspired him to develop the functional foot orthotic. Utilizing his knowledge of the complex interaction between the subtalar and midtarsal joints, he experimented with different casting techniques for the manufacture of foot orthoses. Through trial and error, Root found that the neutral position of the subtalar joint was an optimal position for casting the foot when making foot orthoses. (reference Development of the Functional Orthosis-Clinics in Podiatric Medicine and Surgery April 1994)

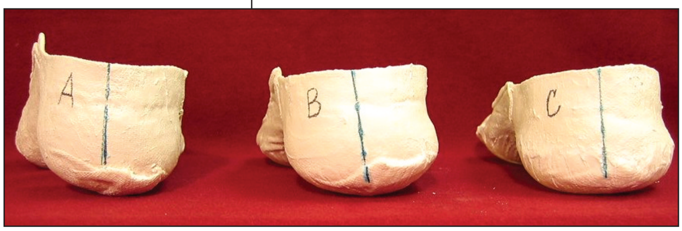

Figure 4: Heel bisections drawn on negative casts

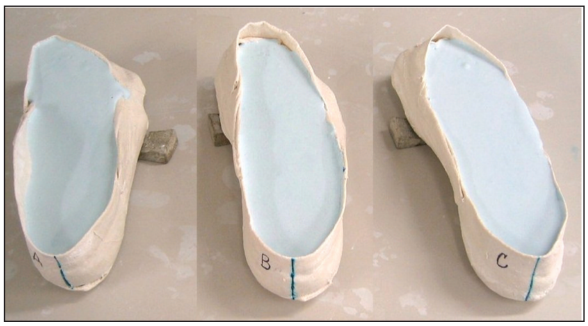

Figure 5: Wedges placed under forefoot areas of casts to align the heel vertical. Plaster of Paris is poured into negative casts

Using the two-axis model of midtarsal joint function developed by J. H. Hicks, Root began to cast the foot with the midtarsal joint in a fully pronated position. While the rationale behind Root's theory of casting the foot is not fully understood, Root believed that a cast of the foot taken with the subtalar joint in the neutral position and the midtarsal joint in a fully pronated position had the following benefits:

1) It was logical to manufacture an orthosis from a neutral position cast in order to encourage the subtalar joint to pronate at heel strike and then re-supinate during midstance and propulsion.

2) It was important to capture the plantar, non-weight-bearing contour of the heel, so that the orthosis would conform to the anatomical shape of the heel and capture it in all three planes (triplane heel cup).

3) Fully pronating the forefoot on the rearfoot would capture the midtarsal joint in a position of osseous stability so the orthosis will support this relationship and resist compensatory motion (forces) at the midtarsal and/or subtalar joint.

4) Casting the foot with the midtarsal joint pronated and the subtalar joint in neutral was clinically reproducible among similarly trained prac-

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Figure 6: Forefoot eversion or inversion position differs significantly between the three cast techniques

Negative Casting...

Figure 7: After completing all measurements, the casts were progressively sectioned in the frontal plane with a bandsaw at two centimeter increments starting at the most posterior aspect of the heel

titioners utilizing the same technique.

The primary goal of neutral position, suspension casting, is to accurately replicate the plantar, non-weight-bearing contour of the foot so that the orthosis can act to support the underlying osseous relationship. Using the cardinal planes as a reference, one can evaluate the contour of a cast of the foot.

The foot should have a sagittal plane angle of inclination along the medial and lateral aspects of the heel. In the frontal plane, the heel should have a convex contour. The slope or inclination angle of the medial heel is typically greater than that of the lateral heel due to the increased height of the medial arch. As the foot pronates, this inclination angle decreases due to plantar-flexion and adduction of the talus, which also lowers the height of the navicular. A functional orthosis must provide reaction force in this area to resist excessive plantar-flexion and adduction of the talus (and talonavicular unit) that would otherwise occur when there is excessive pronation. In the frontal plane, the concave heel cup resists transverse plane motion (adduction) of the talus or the talonavicular unit. Because calcaneal eversion occurs during closed chain pronation of the subtalar joint, resisting talar adduction and plantarflexion can reduce the range of calcaneal eversion. Conversely, resisting calcaneal eversion helps resist talar adduction and plantar-flexion.

Anterior to the heel area, the cast should capture the medial and lateral longitudinal arches of the foot and any inverted or everted angle of the forefoot (i.e., forefoot varus or valgus). A functional orthosis should support the medial and lateral longitudinal arch of the foot to reduce the extent of lowering of these structures that occurs when there is closed chain subtalar joint pronation. It is also important to provide support for any inverted or everted forefoot deformity. It may be advantageous to reduce any forefoot supinatus (acquired or false forefoot varus) in the foot during the casting process (Figure 14). Allowing this acquired, inverted deformity to be captured in the negative cast will produce an orthosis which will supinate the midtarsal joint when worn by the patient. This orthosis will not only be uncomfortable, it will also allow greater range of rearfoot eversion, which is undesirable in many of the pathologies treated with AFO therapy.

While much speculation has occurred over the past 40 years regarding how foot orthoses work, recent research conducted at the University of Calgary has re-affirmed the importance of accurate contouring of the foot orthosis made possible by the neutral suspension casting technique. Mundermann and co-workers measured 15 kinetic and kinematic variables in 15 human subjects running in three different types of foot orthotic devices: a flat insole, and "molded" foot orthosis fabricated from a neutral suspension cast, and a "molded and posted" device also made from a neutral suspension cast. The authors concluded that molding or contouring of the device to the foot in a neutral position was the most important variable in determining a positive treatment effect.

Figure 8: Cutting cast with band saw

Neutral Suspension Casting for Ankle Foot Orthoses

In 1996, Doug Richie, D.P.M. introduced the concept of a functional ankle foot orthosis which combined the Root Functional Foot Orthosis technology with a leg brace. It had been recognized that most traditional AFO's were fabricated from impression casts taken of the foot and leg in a semi-weight-bearing position which failed to align the osseous segments in the relationships which were critical to the Root theory. By performing a neutral suspension technique for impression casting of the foot and ankle, and correcting the positive cast according to Root principle, the "functional podiatric ankle foot orthosis" was born.

As the podiatric profession has implemented ankle foot orthotic therapy into everyday practice, there has emerged a misconception about the value of the incorporation of the functional foot orthosis into the overall AFO device. Specifically, the importance of proper neutral suspension casting technique cannot be overlooked in the final production of a functional AFO. It is proposed that clear differences in overall shape, comfort and functioning of the orthosis exist when impression casting techniques are compared.

Outside of the podiatric profession, casting techniques for ankle foot orthoses usually employ a semi-weight-bearing or full weight-bearing positioning of the foot on a supportive surface. This practice is based upon a philosophy that the orthosis is best manufactured from a model of the foot and leg in a "real life" form, as it truly functions on the ground. The Root Theory would propose that a model made of the foot and leg in a semi-, or full weight-bearing position would capture the foot in a compensated position. This compensated position is thought to be the underlying cause of the pathology being treated, and a brace fabricated to such a model would only preserve the undesirable

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position of the skeletal segments. Functional AFO therapy is intended to specifically resist this adverse, compensatory motion of the foot.

We have attempted to provide a comparison of the neutral suspension casting technique to the semi- and full weight-bearing techniques in terms of differences in shapes and relationships of skeletal segments. The differences are important not only for the proposed efficacy of foot orthoses, but also functional ankle foot orthoses.

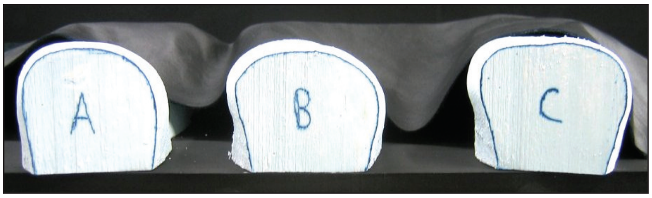

Figure 9: Cross section of casts at heel area. Note progressive flattening with weight-bearing casts

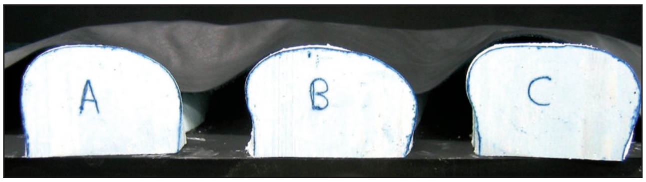

Figure 10: Cross section at anterior heel cup

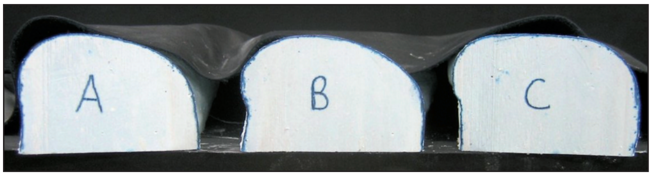

Figure 11: Cross section at proximal arch

The right foot of a 34 year old female subject was cast using three different techniques. After the application of the plaster-of-Paris splints, slipper casts were taken using the following casting protocols:

Cast A: Suspension casting (SC): Supine technique, subtalar joint neutral, midtarsal joint fully pronated (Figure 1).

Cast B: Semi-weight bearing casting (SWC): Patient seated, subtalar joint neutral, plantar surface of foot placed on a two inch thick foam rubber block with very slight downward force applied to the knee to seat in the foot in the foam rubber, no manual positioning of the midtarsal joint or forefoot, tibia aligned to maintain neutral position of the subtalar joint (Figure 2).

Cast C: Full-weight bearing casting (FWC): Casted in the patient's angle and base of gait on a two inch thick foam rubber block, fully weight-bearing, subtalar joint placed in the neutral calcaneal stance position, no manual positioning of the midtarsal joint or forefoot (Figure 3).

The resulting negative casts were then placed on a table and the forefoot was wedged with the heel bisection vertical. Due to differences in the position of the forefoot related to the different casting techniques, it should be noted that the wedge was placed under the 1st metatarsal head for the SWC and FWC casts and under the 5th metatarsal head for the SC cast (See Figures 4, 5 & 6). Prior to the initial casting, the subject's heel was bisected using an indelible ink pencil so that the bisection line would transfer to the negative cast.

This line remained visible on the subject's skin and was retraced prior to each casting to eliminate any variability in heel bisection. The heel bisection was transferred to the exterior surface of the negative casts by puncturing the inside of cast with a pin along the length of the heel bisection. This produced a linear series of puncture marks which enabled the heel bisection to be transferred to the exterior surface of each negative cast. The casts were then poured with plaster-of-Paris and the top surfaces were then leveled.

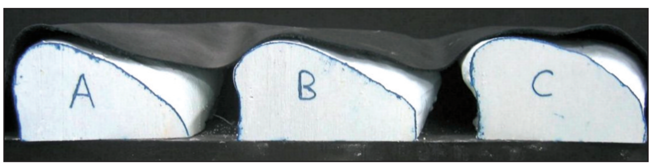

Figure 12: Cross section at mid-arch. Note steepness of slope in suspension cast A

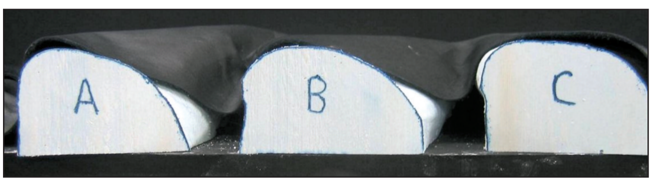

Figure 13: Cross section at distal arch

After curing, the negative casts were separated from the positive models and the following measurements were taken to quantify their differences. The results of these measurements were:

Total length of foot:

Suspension cast: 23.5 centimeters

Semi-weight-bearing cast: 24.1 centimeters

Full-weight-bearing cast: 24.4 centimeters

Maximum width of heel:

Suspension cast: 67 millimeters

Semi-weight-bearing cast: 72 millimeters

Full-weight-bearing cast: 74 millimeters

Maximum width of forefoot:

Suspension cast: 100 millimeters

Semi-weight-bearing cast: 102 millimeters

Full-weight-bearing cast: 102 millimeters

Forefoot to rearfoot relationship:

Suspension cast: 4 degree everted forefoot

Semi-weight-bearing cast: 7 degree inverted forefoot

Full-weight-bearing cast: 3 degree inverted forefoot

In analyzing these measurements, the influence of ground-reaction force on the plantar surface of the foot can easily be appreciated. The total length of the foot increased incrementally in the semi-weight-bearing and full weight-bearing casts by as much as nine millimeters. The maximum width of the heel also increased incrementally by as much as seven millimeters due to displacement of the plantar fat pad. Associated flattening of the heel is visible in Figure 9, which is sectioned two centimeters anterior to the posterior aspect of the heel (note loaf of bread appearance). Ground-reaction force had less of an influence on the width of the forefoot, with only a two millimeter increase seen in both of the weight-bearing conditions.

The forefoot to rearfoot relationship demonstrated

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some interesting findings. Both the semi-weight-bearing and full weight-bearing casting conditions resulted in inversion (supination) of the forefoot. Conversely, the non-weight-bearing suspension cast demonstrated a four degree everted forefoot position, which was an eleven degree difference from the semi-weight-bearing cast. It is interesting to note that the semi-weight-bearing condition actually resulted in more forefoot supination than did the full-weight bearing condition (Figure 6). The authors speculate that the semi-weight-bearing condition resulted in less compression of the foam, which therefore supinated (inverted) the forefoot more than it did in the full weight-bearing condition. This problem is also commonly seen in casting foam impressions. It is possible that had the subtalar joint not been maintained in neutral, the full weight-bearing condition might have resulted in more forefoot supination than was present with the joint in neutral.

Figure 14: Acquired forefoot supinatus deformity can be reduced in the suspension cast by pushing down on first ray.

After completing all measurements, the casts were progressively sectioned in the frontal plane with a band saw at two centimeter increments starting at the most posterior aspect of the heel (Figures 7 & 8). After each section was cut, the cast was photographed to record the contour of the foot in the frontal plane at equal distances from the posterior aspect of the heel.

The photographs reveal graphic differences in the frontal plane contour of the casts at corresponding sections. (Figures 9–13) As evident in the heel section of the casts (Figure 9), there is a loss of heel contour as the foot is progressively placed into a weight-bearing position. The rounded heel shape in the neutral suspension cast progressively flattens with weight-bearing, producing an orthosis with a flat, rather than rounded heel cup. A round, contoured heel cup is considered essential for rearfoot control in an orthosis.

Further sectioning of the casts in the arch area reveals a reduction in the height (slope) of the medial arch in both weight-bearing casting techniques as compared to the suspension technique.(Figures 10–11). The lack of arch height and contouring of the weight-bearing casts are clearly evident in the cross sections taken at the level of midtarsal joint (Figures 12 & 13).

Summary

1) With weight-bearing, impression casting captures an elongated foot shape, which is attributed to a lower arch configuration, compared to a shorter foot and higher arch in the suspension cast.

2) The heel portion of a neutral suspension cast (SC) is narrower and more rounded than the shape captured in a semi-weight-bearing (SWC) and full weight-bearing cast (FWC).

3) In the frontal and sagittal planes, the height and slope of the medial arch is significantly greater in the SC cast and is progressively lower and flatter in the SWC and FWC.

4) The forefoot to rearfoot measurement is everted (valgus) in the SC cast, but is inverted (varus) in both the SWC and FWC. An impression cast, which captures an inverted forefoot position when a true forefoot varus does not exist, will produce an orthosis which will supinate the midtarsal joint in this particular patient. Not only would this orthosis be uncomfortable, it will allow greater range of rearfoot eversion when worn by the patient.

5) In most pathologies treated with functional ankle foot orthoses, maximal rearfoot control and accurate medial arch contour are critical to a successful outcome. ■

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