ORIGINAL RESEARCH

Comparison of 3D Digital Contact Casting versus Manual Foam Casting of the Feet for the Design and Fabrication of Custom Foot Orthoses

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ABSTRACT

Objective: To describe a clinical study of 22 patients who underwent an examination and adjustment of the feet. They then had their feet held in a neutral position for manual casting in foam as well as automated 3D contact casting. The purpose was to determine whether patients responded better to custom orthotics designed by either method.

Methods: One week after the initial examination and foot casting, the patients received their first pair of orthotics, at which time their feet were adjusted again before wearing. They wore the first pair for one month, then the second pair with the same protocol. A questionnaire was then given to each patient to evaluate their experience with both sets of orthotics.

Results: Eleven questions of the fifteen required quantitative answers were statistically analyzed. Three questions indicated statistically significant differences in favor of the 3D contact casting technique at a p-value of less than 0.05 with an additional two questions showing significance at a p-value of 0.10. Six questions showed no statistical difference between the foot casting techniques.

Conclusion: A statistical analysis demonstrated greater foot comfort and patient satisfaction from custom orthotics designed with the 3D digital casting technique over those designed using manual foam casting.

Key Words: *Chiropractic, Vertebral Subluxation, Orthotics, Feet, Kinetic Chain*

Introduction

Various methods of foot casting are currently being used to design custom foot orthotics. Current methods used to capture the contours of the plantar surface of the feet include foam impression boxes, pressure transducers, light scanners and contact digitizers (figure 1,2). While various investigators tout the technologies they use, the bottom line is—will the patient wear the orthotic produced from the cast? In addition, are there any true therapeutic and/or practical advantages of one casting method over another? High tech or low tech, is there really a difference in the orthotic made from identical material? The goal of this study was to find answers to these questions by comparing patient satisfaction levels to orthotics made from foam casting and digital contact casting, when orthotics are made by the same laboratory.[1]

Figure 1

Figure 2

1. Private Practice-Boise, Idaho

Materials and Methods

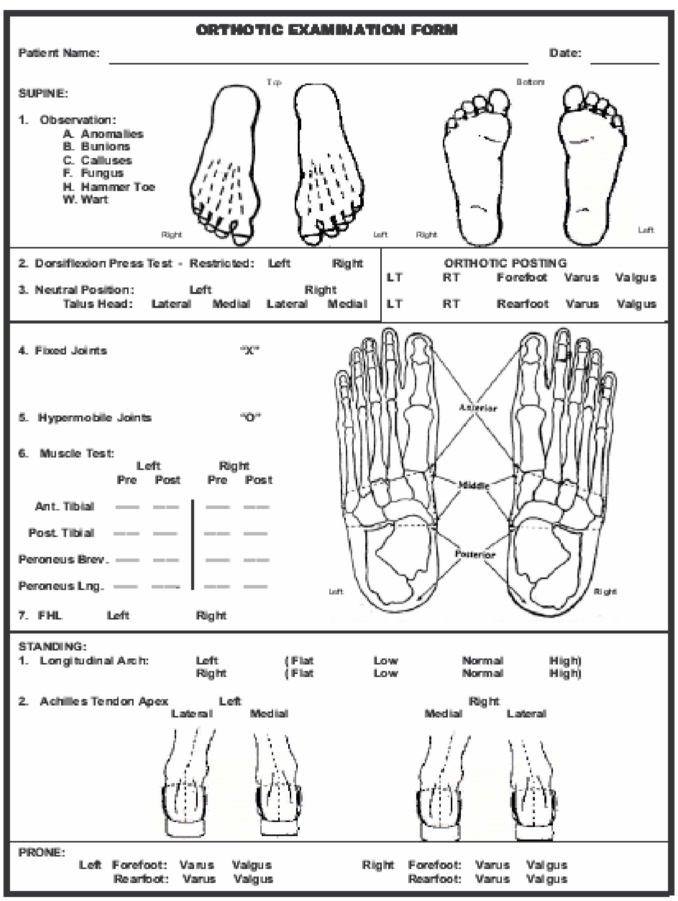
Subject Selection

Twenty-two patients ages 18-70 years old, nine women and thirteen men, with a variety of foot or kinetic chain problems were entered into the study. After their initial examination, each patient that qualified for orthotics was offered a second pair of orthotics at no extra charge for participating in the study. There was no guarantee that they would like either type of orthotic. If however, neither was satisfactory, another pair would be made to attempt to satisfy their needs. A third pair was not required for any of the patients. It was explained that they would wear each pair of orthotics for one month and compare them via a questionnaire at the end of the two month period.

Foot Assessment

Examination of each patient was performed following the form recommended by the Council on Extremity Adjusting (CEA) (figure 3). Adjustments were performed to the feet where fixations were located, to restore normal joint-glide and facilitation of nerves to the muscles of the feet.[2,3] Another benefit of foot/ankle adjustment is that neutral postural position becomes normal instead of pathological due to the changed angle of the ankle mortise upon restoring a malpositioned talus.[2] It is believed that this protocol maximizes the ability of the feet to adapt to the control of the orthotic due to the restoration of functional glide of the arches of the feet (figure 4, 5).

Figure 3



ORTHOTIC EXAMINATION FORM

Patient Name: Date:

SUPINE:

1. Observation:
   A. Anomalies
   B. Bunions
   C. Calluses
   F. Fungus
   H. Hammer Toe
   W. Wart

Top Right Left

Bottom Right Left

2. Dorsiflexion Press Test - Restricted: Left Right

3. Neutral Position: Left Right
   Talus Head: Lateral Medial Lateral Medial

ORTHOTIC POSTING
LT RT Forefoot Varus Valgus
LT RT Rearfoot Varus Valgus

4. Fixed Joints "X"

5. Hypermobile Joints "O"

6. Muscle Test:

	Left Pre	Left Post	Right Pre	Right Post
Ant. Tibial				
Post. Tibial				
Peroneus Brev.				
Peroneus Lng.				

7. FHL Left Right

Anterior Middle Posterior Left Right

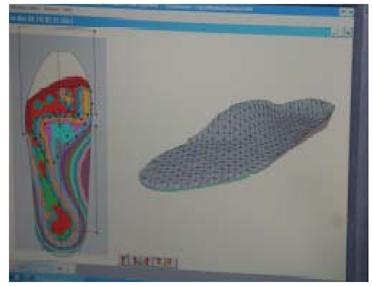
STANDING:
1. Longitudinal Arch: Left (Flat Low Normal High)
   Right (Flat Low Normal High)

2. Achilles Tendon Apex Left Lateral Medial Right Medial Lateral

PRONE:
Left Forefoot: Varus Valgus Right Forefoot: Varus Valgus
Rearfoot: Varus Valgus Rearfoot: Varus Valgus

Figure 4

Figure 5



Foot Casting

<u>Automated/Digital Casting</u>

After foot adjustment, each patient was asked to stand on their tiptoes to lock the tarsals while in a weight-bearing position. The patient then sat in a chair for 3D digital casting of the plantar surface of the feet using a computerized contact digitizer (Footfax-SL, Amfit Inc., Vancouver, WA). Casting was done in a sitting position with the same side forearm leaning on top of the vertical knee in the coronal plane, equivalent to a semi-weight bearing position. The foot was held in neutral position[3,4] to preserve congruency of the talo-navicular joint (figure 6) and placed on the digitizer platform where an array of over 500 sensors were raised under controlled pneumatic pressure to accurately measure the contours of the plantar surface of the foot.[5] (figure 1) The electronic casting process takes approximately 10 seconds per foot. This procedure was then repeated for the other foot. After evaluation of the 2D and 3D digital foot images displayed on the computer monitor (figure 7), the medial longitudinal tarsal arch was lowered by 10% using the interactive medical software. (figure 8) This modification was done to allow for the lowering of the arch when a patient was in a full weight bearing position and to ease their comfort in the new custom orthotic. Each orthotic was also modified to incorporate a broad metatarsal pad to ease rolling onto the metatarsal heads under load.[4] The modified digital foot file data was saved for subsequent transfer to a precision CAD/CAM carving mill.

Figure 6

Figure 7

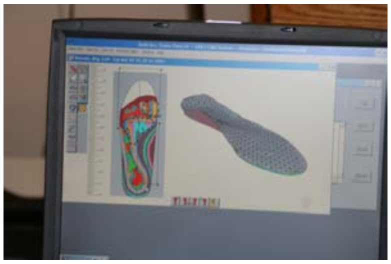
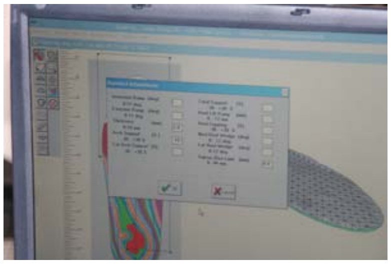


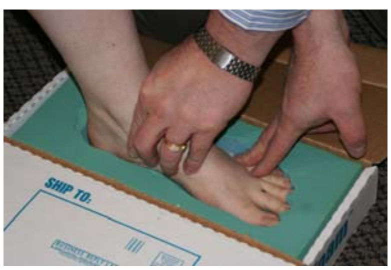
Figure 8



<u>Manual/Foam Casting</u>

The foam cast was made using a similar adjustment and positioning protocol, except no modifications were made to the arch height or the addition of a metatarsal pad.[5] The foam impression technique was done in 2” thick memory foam. (figure 2) After the foot was pushed into the foam, the 4^{th} and 5^{th} metatarsal heads were manually pressed down until tissue resistance stopped them and the angle in the foam approximated the angles seen and documented in the examination. (figure 9) These foam foot casts were then sent to the same fabrication laboratory as the digital foot casts.

Figure 9



Orthotic Fabrication

At the Amfit Fabrication Facility (Vancouver, WA), custom foot orthotics were made from foot profiles derived from each of the casting methods. Using the automated technique, the modified digital foot files were transferred to a CAD/CAM carving mill. Custom orthotics were carved from ethylene vinyl acetate (EVA) blanks of specific densities to best fit the patients’ weight and activity levels.

Using the manual technique, the foam casts were filled with a proprietary casting medium (similar to plaster) and the medium was allowed to set up. The foam was then stripped away and the positive models of the patient’s feet were scanned on the Footfax digitizer.[1] The digitizer accurately captures the geometry of the plantar surface of the molded models of the feet. These patient-specific digital files were then transferred to Amfit’s precision CAD/CAM mills where custom orthotics were carved from EVA blanks. The personalized custom orthotics were finished with a top cover material and returned for dispensing to the patient.

Application

The first pair of custom orthotics designed with the 3D digital casting method were usually available to the patient 1-2 weeks after the initial examination. The patient’s feet were again checked for subluxations and adjusted if necessary before fitting them into the shoes. The patient was instructed to wear the orthotics all the time, unless they were intolerable. If they were out of them for any length of time they needed to walk on their tip toes to lock the tarsals in place. This was important to prevent repetitive subluxations of the feet that would affect comfort level.

After a month of wearing the digitally cast orthotics, the patients came in for their second pair of orthotics, designed using memory foam. Once again the feet were checked for subluxations and corrected if necessary; and the orthotics were fit to their shoes. Care was taken to remove any existing insoles that were supplied by the shoe manufacturer.

Questionnaire

The following set of 15 questions were given or sent by mail to each patient following the total two month period of wearing the orthotics:

Have you worn both pairs of orthotics? Yes/No
Do you like one pair better than the other? Yes/No – 1^{st}/ 2nd
Do you like the right or left better? Yes/No – Rt/Lt

On a scale of 1 to 10 (10 being best) rate the orthotics:
Is the heel area comfortable? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.
Is the arch area comfortable? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.
Is the toe area comfortable? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.
Can you wear them all day? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.
Do your ankles feel better? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.
Do your knees feel better? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.
Do your hips feel better? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.
Does your back feel better? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.
Can you walk farther? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.
Do you have more energy? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.
Do you sleep better? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.
Do you want another pair? 1^{st} pair Lt./Rt., 2^{nd} pair Lt./Rt.

Results

All 22 patients enrolled in the study completed the two-month evaluation comparing the orthotics designed by either foam or digital casting. Patient preferences for questions 1, 2, 3 and 15 (non-quantitative answers) are presented in Table 1.

Question	Yes	No	No resp
Q1. Wear Both Pairs	20	-	02
Q2. Like One Pair Better	15	05	02
Q3. Like Left/Rt. Better	03	17	02
Q15. Want Another Pair	13	06	03

Table 1-Patient Responses to Subjective Questions

Based on each patient's experience and evaluation with the foot orthotics, answers to questions 4-14 (quantitative answers) were statistically analyzed using the Paired t-Test and the Wilcoxon Signed Rank Test (Table 2).

Table 2- Paired t-Test and Wilcoxon Signed Rank Test Result for Comparing Orthotics Designed with 3D Digital Casting versus Foam Casting

	Left Foot			Right Foot		
	Test Method	Test Statistic	P-value	Test Method	Test Statistic	P-value
Q04	Paired-t	0.830	0.207	Paired-t	0.663	0.257
	Signed rank	10.000	0.222	Signed rank	6.000	0.287
Q05	Paired-t	2.375	**0.014	Paired-t	1.926	**0.034
	Signed rank	41.500	**0.015	Signed rank	34.500	**0.024
Q06	Paired-t	-0.344	0.633	Paired-t	-0.222	0.587
	Signed rank	0.500	0.488	Signed rank	-1.500	0.544
Q07	Paired-t	1.936	**0.033	Paired-t	1.909	**0.035
	Signed rank	28.500	**0.037	Signed rank	25.000	**0.042
Q08	Paired-t	0.523	0.303	Paired-t	0.413	0.342
	Signed rank	5.000	0.295	Signed rank	2.500	0.412
Q09	Paired-t	1.446	*0.081	Paired-t	1.262	0.110
	Signed rank	8.000	0.102	Signed rank	5.500	0.141
Q10	Paired-t	0.310	0.380	Paired-t	0.557	0.292
	Signed rank	2.000	0.422	Signed rank	4.500	0.324
Q11	Paired-t	-0.070	0.528	Paired-t	0.141	0.445
	Signed rank	0.000	0.500	Signed rank	3.000	0.404
Q12	Paired-t	1.558	*0.067	Paired-t	1.534	*0.070
	Signed rank	21.000	*0.079	Signed rank	21.500	*0.070
Q13	Paired-t	2.028	**0.028	Paired-t	2.072	**0.026
	Signed rank	10.000	*0.055	Signed rank	12.500	**0.043
Q14	Paired-t	0.716	0.241	Paired-t	0.716	0.241
	Signed rank	4.000	0.281	Signed rank	4.000	0.281

** Indicates statistically significant at the α=*O.05* level.
Represents statistical significance at α=*0.10* level.

Of the 11 questions, 5 questions showed a statistical difference favoring the orthotics made using the 3D digital casting method. Three of the five questions were highly significant with p values of less than 0.05. These 3 questions were:

#5 Is the arch area comfortable?

#7 Can you wear them all day?

#13 Do you have more energy?

Two additional questions showed a lower statistical preference for the 3D digital method with a p value of less than or close to 0.10. These two questions were:

#12 Can you walk farther

#9 Do your knees feel better?

Discussion

If five questions were chosen to support the efficacy of a foot orthotic casting method, the questions in this study that showed statistical preference for the 3D digital method would do very well. To achieve the required therapeutic benefit, the patient must find the orthotic comfortable and commit to wear the custom orthotic as much as possible. This goal was achieved in most cases with the digital casting technique.

It is generally agreed that the foot cast is the most essential element in the design of an effective orthotic device. Thus, a method that puts total control in the hands of the chiropractor is preferable. The open design of the contact digitizer allows the clinician to position the foot in the adjusted and corrected position during the casting process. The 2D and 3D contour displays can be immediately evaluated to assure a perfect cast was taken while the patient is still in the office.

In addition, the clinician can make precise modifications to the digital cast using medical software and evaluate the modifications on the display monitor before sending the foot files to the fabrication laboratory. Thus, giving the chiropractor total control of the design and modifications required for effective therapy. After the foot files are transferred to the fabrication laboratory, via modem, first generation custom orthotics are carved directly from the digital files using CAD/CAM carving mills. This digital process provides precise control and accuracy for fabricating the custom foot orthotics.

Unlike the foam technique, where the unmodified foot impressions are sent away to the orthotic laboratory for secondary plaster casting, to make positive molds of the feet, followed by subsequent clinician prescribed modifications by technicians.[3] Thus, numerous technician-dependent variables can affect the final quality of the custom orthotic and physical fit to the patient's foot.

The digital casting technique has several other inherent advantages over the foam method. Digital storage of the foot files is highly efficient, cost effective and the files remain in the digitizer's memory with the chiropractor.

Thus, the foot files can be reviewed at any time, and duplication of additional pairs of custom orthotics for the patient can be ordered over the internet. With subsequent patient visits, digital foot files can be compared over time, on the monitor display in the office, to assess the therapeutic progress and if necessary make additional modifications as required for effective therapy. And lastly, digital foot files can be easily printed for documentation of pathologic conditions and therapeutic progress for the patient's medical records.

The Kinetic Chain & Subluxation

The importance of effective orthotic therapy goes beyond simply affecting the biomechanics of the feet. A brief overview of the kinetic chain and its relation to vertebral subluxation follows.

Normal pronation and supination are dependent upon normal glide of the mid foot bones to allow the raising and lowering of the arches. If these arches are fixated then this motion is compromised and full pronation and supination cannot perform their full shock absorbing functions.

The Primary Shock Absorber of the Body is foot pronation when operating correctly. The foot is a great example of utilizing the two laws of physics that reduce shock.[4]

1. Pronation increases the time it takes to bottom out by lowering the longitudinal tarsal arch slower through eccentric contraction of the posterior tibia muscle.
2. Pronation increases surface area of the mass that is striking by widening the foot and elongating the foot.[4]

What if the arch of one foot is dropped, flattened and fixated already and there is no increased time before bottoming out, would this change the amount of shock up the leg? Yes. Many people are trying to function this way. The leg stays in internal rotation and the Ilium stays in forward flexion and pulls the lumbar spine to the contact side.[4]

The Secondary Shock Absorber of the Body is knee flexion. This is a result of internal rotation of the tibia on the femur which activates the popliteus muscle and flexes the knee its first 15 degrees off of full extension. If the leg is already in internal rotation knee flexion may not happen increasing shock onto the pelvis and lumbar spine.

Both of these functions would then fail to allow supination of the foot which would normally externally rotate the femur, leaving the ilium in forward flexion and the lumbar spine pulled to the contact leg side by the psoas muscle.[4] The imbalance of leg rotation on one side would then reproduce a lumbar and sacroiliac subluxation upon weight bearing. The shear stress on the lumbar disc would tend to weaken it and potentially breakdown the annulus fibrosis.

The combination of foot adjustments to restore glide to the arches and foot orthotics made to a normal foot instead of a pathological foot is the mechanism for correction of not only the feet but the knees, hips, SI joints and low back for stability and longer lasting adjustments of the spine.

Conclusion

Custom foot orthotics designed with 3-dimensional digital contact casting are preferred over manual foam casting under the conditions described in this study.

The combination of manipulation of the foot and ankle, for optimum alignment and angulation, is advantageous for accurate digital mapping of the corrected foot contours provided by the contact digitizer. Patient compliance and acceptance is critical to orthotic therapy when controlling the kinetic chain of motion. Use of 3D digital contact casting appears to be a good step in the right direction in providing our patient's with effective foot orthotic therapy.

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