PRESSURE PLATE ANALYSIS OF THE MEDIAL COLUMN FOOT INSOLE - A Statistical Study

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Keywords: Pressure Plate Analysis, Surface Area Readings, Media Pressure Readings, Statistical Analysis, Medial Column Foot Insoles, Primus Metatarsus Supinatus, Talar Torsion, Engraming, Homeostasis.

Abstract
Pressure plate analysis is used to collect surface area (sA) and media pressure (mP) readings on 17 Primus Metatarsus Supinatus patients. All 17 patients are fitted with medial column foot insoles. Two sets of surface area (X) and media pressure (Y) readings are recorded on each patient: a baseline set before treatment and a second set after treatment. The observed changes in surface area (ΔX) and media pressure (ΔY) are statistically correlated: (1) are $\Delta X \Delta Y$ patterns randomized events or are they the result of medial column insole therapy, and (2) if the $\Delta X \Delta Y$ patterns are the result of insole therapy, do they have any correlation to postural tonicity?
The results are compelling: (1) the probability that these patterns are randomized events (based on chance alone) is exceeding small ($p < .01$) and, (2) there is a high level of confidence that postural tonicity shifts towards homeostasis *when* insole therapy is effective. From a clinical point of view, $\Delta X \Delta Y$ patterns may prove useful in prognosticating the appropriateness of insole therapy.
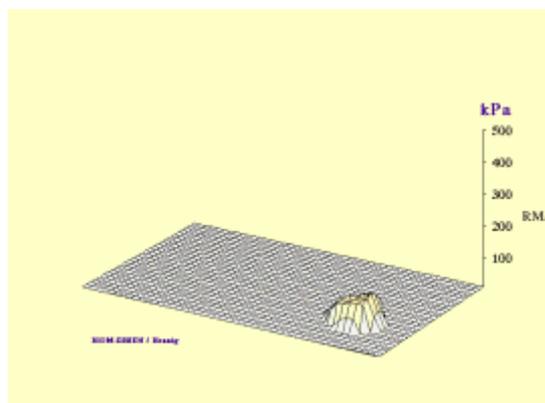
Forefoot osseous abnormalities have been implicated as a common etiology of both static (standing) and dynamic (walking) hyperpronation. Rothbart (2002) described a foot in which the 1st metatarsal is *structurally inverted and elevated* relative to the second metatarsal. Referred to as Primus Metatarsus {Elevatus} Supinatus (PM*s*), this foot type is frequently identified by its deep 1st web space (**See Figure 1**).

Figure 1. **Deep 1st Web Space**. The 1st metatarsal is shorter than the 2nd metatarsal creating the deep 1st web space. This relative shortness of the 1st metatarsal frequently occurs in the Rothbart Foot Structure.

The etiology of PMs has been linked to a lack or deficiency in the embryological development of the talus. Clinically, Primus Metatarsus Supinatus is quantified using microwedges (**See Figure 2**).

Figure 2. **Measuring PMs (Right Foot)**. *Patient Standing, Vision Straight Forward*. Locate the medial talocalcaneal (subtalar) joint. This easily palpable joint is approximately one finger width below and in front of the medial malleolus (21). Keeping your finger on the medial subtalar joint, have your patient slowly rotate their hips, first counterclockwise and then clockwise. This will pronate (evert) and supinate (invert) the right foot respectively. Guide the foot through this range of motion until the upper and lower margins of the subtalar joint feel congruous (parallel) to one another (22). This is the anatomical neutral position of the subtalar joint. If the subtalar joint is pronated or supinated, the joint space will feel collapsed (obliterated) or cavernous respectively. While maintaining this STJ nP, slide the microwedge (30) underneath the 1st metatarsal head until slight resistance is encountered from the bottom of the foot. Record the PMs value (vertical displacement between the 1st metatarsal head and ground). Repeat this protocol for the other foot.

PMs values falling between 10 and 30 mm are referred to as the Rothbart Foot Structure (RFs).

Two distinct *compensatory* patterns have been clinically observed by this author in the RFs patient: bracing and releasing.

Bracers tend to display a cavus arch (off weight bearing), contracted toes (on weight bearing). Lateral heel wear patterns are pathognomonic for bracers. Their pressure plate surface area readings are relatively low (less inner arch contact with the base plate). Their media pressure readings are relatively high (increased tonus). Typically their measured PMS values fall below 19 mm.

Releasers tend to have the "Chameleon foot", increasing in length or width (or both) on weight bearing. Medial heel wear patterns are typical. Their

surface area readings are relatively high (more inner arch contact with the base plate). Their media pressure readings are relatively low. Typically their measured PMS values fall above 19 mm.

The terms bracing and releasing are not synonymous with the terms supination and pronation. Many bracers are diagnosed as hyperpronators when evaluated for gait perturbations.

Medial column foot (mcf) insoles are used to stabilize RFs. Their mode of action is very different from conventional supportive-type orthotics. It has been suggested that these types of insoles act as a tactile stimulant to the bottom of the foot, providing a feedback to the cerebellum where the postural corrections are made (Fusco 2000, Gagey and Weber 2000, Bricot 1996, Willem 2003, Scoppa 2002).

This paper investigates the clinical effectiveness of medial column foot insoles using pressure plate analysis. The statistical data resulting from this study are based on independent trails with 3 degrees of freedom.

Review of the Literature
Measuring 1006 Egyptian Feet, Sewell (1905) was the first to publish on the substantial variances in the twist (torsion) of the talar head relative to its body (angle alpha) (**See Figure 3**, **1a and 2a**).
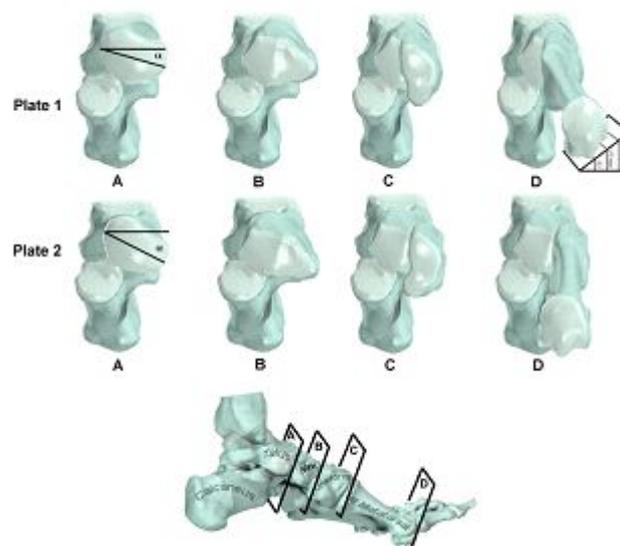

Figure 3. **Medial Column Supinatus**. [Sectional Views, Frontal Plane] Lower alpha angles are linked to Primus Metatarsus Supinatus. Supinatus of the talar head determines the structural position of the medial column. Plate 1A illustrates Talar Supinatus, Plate 1B Navicular Supinatus, Plate 1C Cuneiform (Internal) Supinatus, and Plate 1D Metatarsal Supinatus and Microwedge. Higher alpha angles are linked to the plantargrade position of the 1st Metatarsal. The unwinding of the talar head, 'directs' the unwinding of the entire medial column of the foot, navicular to hallux (See Plates 2A –D).

Subsequently, Straus (1927) reported alpha angles ranging from 26 to 43 degrees, McPoil (1987) from 24 to 51 degrees, Sarrafian (1993) from 30 to 65 degrees. Tax (1980) and Hlavac (1970) proposed that the twist in the talar

head determined the structural position of the forefoot (i.e., forefoot varum or forefoot valgum). Rothbart (2002) suggested that lower alpha angles position the navicular in supinatus (**See Figure 3**, **1b**), the internal cuneiform in supinatus (**See Figure 3**, **1c**), the metatarsal in supinatus (**See Figure 3**, **1d**), and ultimately, the hallux in supinatus. In the adult foot, this supinatus (structural elevation and inversion) of the 1st metatarsal/hallux is termed Primus Metatarsus *S*upinatus (PM*s*). (In a previous published paper this foot structure was termed Primus Metatarsus *Elevatus*. However, a Google search of the internet archives uncovered a paper describing Primus Metatarsus Elevatus as a *positional* deformity. Hence to avoid any further confusion, the osseous deformity was renamed Primus Metatarsus *Supinatus*).

Cuernavaca Study

The Midicapteur's Podolab 2000™ pressure plate analysis system was used to capture changes in surface area (sA) and media pressure (mP) readings after insole therapy. These readings were hard copied in both numerical and graphical format (**See Figure 4**) and then statistically evaluated to determine if the observed changes were the result of insole therapy or chance occurrence alone.
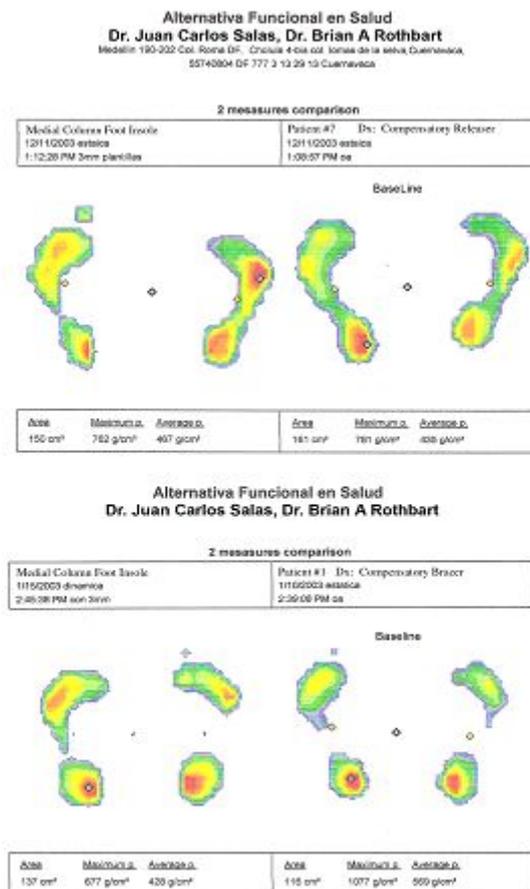

Figure 4. **Hard Copy of Data** Generated by Force Plate Analysis.

Protocol

17 patients diagnosed as RFs were selected to participate in this study. Patients were excluded from this study if they were (1) diagnosed as having an upper or motor neuron lesion or any foot pathology that altered gait patterns, (2) amputees, or (3) if they required the use of a crutch or cane to walk. The selection of patients was not randomized relative to age, weight, height, sex, social or ethnic backgrounds. Each patient was fitted with a medial column foot insole dimensioned at approximately 30% of the measured PMs. The insoles, manufactured by Postural Dynamics Inc., incorporated a medial bar into a 1mm thick, flexible, flat base plate (**See Figure 5**).
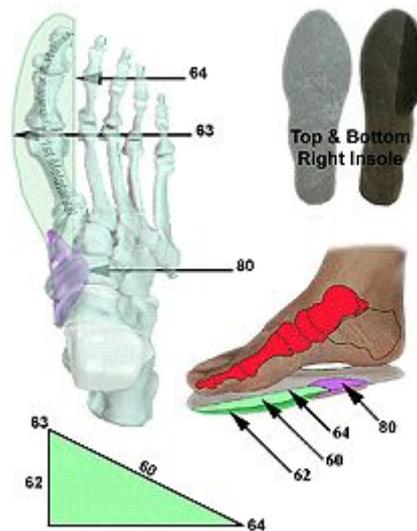

Figure 5. **Medial Column Foot Insole**. Manufactured by Posture Dynamics Inc., a subsidiary of GRD BioTech Inc. (top right photograph) (http//www.PostureDyn.com). The dimensions of the medial bar are demonstrated (middle right drawing): 60 represents the slope, 63 the vertex (maximal tactile input) and 64 the nadir (minimal tactile input) of the medial bar. Arch supports (80) are used in functional flatfeet where the structural integrity of the talonavicular joint is severely compromised.

Media pressure and surface area readings were obtained via the following protocol: (1) wearing shoes, the patient walked for several minutes, (2) shoes and socks removed, standing *barefooted* on the pressure plate, baseline mP and sA readings were recorded, (3) mcf insoles were fitted and placed in the shoes, the patient again walked (shod) for several minutes, (4) standing *barefooted* on the pressure plate, a second set of mP and sA readings were recorded. In all, 34 sets of measurements were obtained. Of salient importance was that all measurements were recorded while the patient was standing barefooted on the pressure plate.

Results

Baseline surface area (X_i) and media pressure (Y_i) readings for each of the 17 patients are presented in **Table 1**.

**Table 1. Means and Standard Deviations
of Initial (Baseline) Set of Readings**

Patient	x_i (sA)	y_i (mP)
1	171	345
2	163	429
3	161	435
4	162	367
5	113	239
6	160	545
7	177	418
8	208	368
9	162	390
10	181	370
11	155	387
Mean =	164.82	390.27
Std Deviation =	22.70	73.89
12	116	569
13	169	479
14	199	664
15	144	412
16	129	473
17	168	436
Mean =	154.17	505.50
Std Deviation =	30.38	94.32

Table 1. Means and Standard Deviations of Initial (Baseline) Set
of Readings.

Patients 1-11 (clinically diagnosed as releasers) recorded higher surface area readings (mean = 164.82 cm^2) and lower media pressure readings (mean = 390.27 gms/cm^2) compared to patients 12-17 (clinically diagnosed as bracers). The second set of surface area (X_i+1) and media pressure (Y_i+1) readings are listed in **Table 2**.

**Table 2. Means and Standard Deviations
of Second Set of Readings**

Patient	x_i+1 (sA)	y_i+1 (mP)
1	161	383
2	144	486
3	150	467
4	152	403
5	104	260
6	156	590
7	171	433
8	196	383
9	156	394
10	174	385
11	160	398
Mean =	156.91	416.55
Std Deviation =	22.90	81.56
12	137	428
13	174	466
14	203	652
15	157	357
16	164	372
17	164	433
Mean =	166.50	451.33
Std Deviation =	21.73	106.35

Table 2. Means and Standard Deviations of Second Set of
Readings.

The vector changes in surface area (ΔX) and media pressure (ΔY) were computed and listed in **Table 3**.

Table 3. Computed Changes in mP and sA Readings

Patient	$\Delta x = (x_{i+1}) - x_i$	$\Delta y = (y_{i+1}) - y_i$
1	-10	38
2	-19	57
3	-11	32
4	-10	36
5	-9	21
6	-4	46
7	-6	15
8	-10	15
9	-6	4
10	-7	15
11	5	11
Mean =	-7.91	26.27
Std Deviation =	5.80	16.43
12	21	-141
13	5	-13
14	4	-12
15	13	-56
16	35	-101
17	-4	-3
Mean =	12.33	-54.17
Std Deviation =	14.00	56.26

Table 3. Computed Changes in mP and sA Readings

Bracers (patients 12-17) demonstrated a greater absolute mean change in surface area (12.33 cm^2) and media pressure (54.17 gms/cm^2) compared to releasers (patients 1-11). (The negative and positive numbers indicate direction of change along the x and y axis).

Four distinct ΔXΔY patterns emerged from the Cuernavaca study: (1) +ΔX,-ΔY; (2) -ΔX,+ΔY; (3) -ΔX, -ΔY; (4) +ΔX,+ΔY. Using these ΔXΔY patterns the following null hypothesis was proposed: **ΔXΔY patterns occur randomly** (H_a = ΔXΔY patterns are due to insole therapy).

This null hypothesis was tested for level of confidence using the Chi-Square (X^2) test:

$$\chi^2 = \sum_i \frac{(N_i - n_i)^2}{n_i}$$

Where N_i are the *observed* frequencies in each pattern and n_i are the *expected* frequencies in each pattern *if* based on **chance** occurrence alone.

The results of the Chi-Square (X^2) test (**See Table 4**) *rejects* the null hypothesis.

Table 4 - Chi Square Test

Observed[a]

	Bracers	Releasers
Δ+x, Δ-y	5	0
Δ-x, Δ+y	0	10
Δ-x, Δ-y	1	0
Δ+x, Δ+y	0	1

[a] = Interpolated from Table 3

Expected[b]

	Bracers	Releasers
Δ+x, Δ-y	2.13	2.13
Δ-x, Δ+y	2.13	2.13
Δ-x, Δ-y	2.13	2.13
Δ+x, Δ+y	2.13	2.13

[b] = Expected if based on random distribution

$$X^2 = 2.89972E-09$$
$$\text{ChiDist} = 1$$

Table 4. Statistical Analysis

The statistical probability of ΔXΔY patterns being generated randomly is less than 1% (X^2 = 2.90E-09). This gives us a very high level of confidence (> 99%) that the observed ΔXΔY patterns in the Cuernavaca study were the result of insole therapy and not the result of chance occurrence.

A postulate for the observed ΔXΔY patterns is: (1) baseline readings are skewed left in bracers and right in releasers, and (2) effective insole therapy shifts surface area (ΔX) and media pressure (ΔY) toward homeostasis (**See Figure 6**).
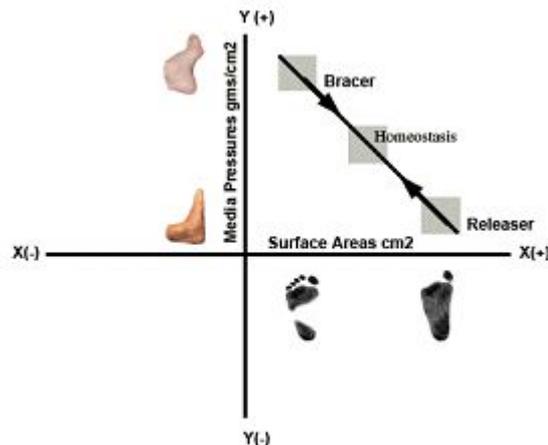

Figure 6. Normalizing mP and sA Readings. Cartesian Graph demonstrating the normalization (towards homeostasis) of medial pressure and surface area readings. The vectors towards normalization have both directional and magnitude properties.

This premise is substantiated in 15 of the 17 patients (**See Table 3**). The probability of this occurring randomly is less than 1 in 847 (based on a binomial distribution where p = 0.5).

Cuernavaca Study – One Year Follow-up
15 patients responded very positively to insole therapy. Their level of musculoskeletal pain was significantly less. However, patients #11 and #17 discontinued wearing their insoles for a sundry of visceral and musculoskeletal complaints. Interesting enough, their ΔXΔY were skewed (away from homeostasis). ΔXΔY may prove to be an invaluable tool in prognosticating the appropriateness of insole therapy (towards homeostasis = appropriate; away from homeostasis = inappropriate). However, more research needs to be done.

Discussion
It appears that media (average) pressure readings actually represent the summation of two separate but concurrent forces: (1) the vertical component of the body's weight and (2) a smaller vertical component which represents the state of tonicity within the foot. This author suggests that the degree of tightness (digital contracture) of the toes against the pressure plate determines this reading and that it can vary when an afferent tactile stimulation is applied to the bottom the foot.

Conclusions
Statistical evaluation (chi square test) of the data obtained in the Cuernavaca study yielded a > 99% level of confidence that the observed ΔXΔY patterns were the result of insole therapy. It was postulated that *effective* insole therapy shifts surface area and media pressure readings toward homeostasis: (1) in releasers, surface areas would decrease (improved arch contouring), media pressures would increase (improved tonus in postural muscles), (2) in bracers, surface areas would increase (severity of arch diminished) media pressures would decrease (improved tonus in postural muscles). This was observed to be true in 15 out of 17 independent trials. The probability of this occurring randomly is < 0.5%.
Since all pressure plate readings were taken weight bearing and barefooted, what we were measuring appears to be the body's ability to maintain improved homeostasis without support or continual tactile input, a process referred to as engraming. This correlated to our clinical experience of patients using their medial column foot insoles less and less, while still maintaining their level of wellness.

Call for Further Research
Medial column foot insoles appear to be very effective in normalizing (towards homeostasis) surface area and media pressure readings in RFS patients. However, further research is needed to elucidate the precise 'modus operandi' of these insoles and whether ΔXΔY patterns can be used to prognosticate the appropriateness of insole therapy.

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