The Role of Forces on the Foot
(theoretical background)

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Why my hair fell out

Craig Payne
Department of Podiatry &
Musculoskeletal Research Centre

Monday, 8 March 2010
Aim:

• Review my current understanding of the how and why of foot orthoses

• If we know the ‘how and why’ we can do it better

• Where has the evidence taken me

• How that is guiding where we are heading with our research and understanding (and our teaching and clinical practice)
This is the ‘stereotype’ of what we live for

‘pronatory pathology’
Clinical Practice:
Evidence based or commonly accepted wisdom?

- “Make foot orthoses to try and stop rearfoot pronating → patient gets better”
- “Therefore…. excessive pronation must have been the cause”
- Correlation vs causal relationship?
No doubt, this is what we have been trying to do.
“Standard” Protocol

- The calcaneal angle of the rearfoot is determined when the patient is standing with the subtalar in its neutral position.

- A cast is taken of the foot with the subtalar joint is in neutral (neither pronated or supinated).

- An orthoses is made from the cast to hold the calcaneus in the position so that the subtalar joint is in its neutral position (or a prefabricated device is used to move the foot towards this position).
This is the position we wanted
Can we test if that actually happens: changes in calcaneal angle with foot orthoses

- 12 subjects with casts taken of the foot in STJ neutral and the calcaneal angle determined by two clinicians
- Casts sent to lab with a prescription for the orthoses to hold the foot at the calcaneal angle when the STJ neutral
- Calcaneus bisected and angle of calcaneus measured on and off foot orthoses in STJ neutral and relaxed positions
- All subjects got better
Results

- RCSP = 1.3° (+2.5) everted
- NCSP = 3.4° (+2.8) inverted \( (p=0.02) \)
- Cast on orthoses, CSP = 3.2 (+2.1)
- Foot on orthoses = 0.7° (+3.3) everted \( (p=0.42) \)
Correct Eversion With A Post

10° Wedge

Works Well On Plastic Foot

Monday, 8 March 2010
Static stance response to foot orthoses

<table>
<thead>
<tr>
<th>Orthosis</th>
<th>Change in Frontal Plane Calcaneal Angle (°)</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wedge</td>
<td></td>
<td>2.82 ± 2.05</td>
<td>-2.50–8.00</td>
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<tr>
<td>Arch cookie</td>
<td></td>
<td>0.44 ± 2.19</td>
<td>-6.00–5.50</td>
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<tr>
<td>Prothotic</td>
<td></td>
<td>2.66 ± 1.78</td>
<td>-0.75–6.75</td>
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<tr>
<td>Formthotic</td>
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<td>0.47 ± 1.79</td>
<td>-2.50–5.00</td>
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<tr>
<td>Orthopro</td>
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<td>1.87 ± 2.18</td>
<td>-2.25–8.50</td>
</tr>
<tr>
<td>Vasyli</td>
<td></td>
<td>0.54 ± 1.57</td>
<td>-3.00–4.00</td>
</tr>
</tbody>
</table>

Static vs dynamic (more later)
## Static stance response to foot orthoses

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In some subjects, the rearfoot pronated/everted more when standing on an inverted foot orthotic
Why did some pronate more?
Calcaneal Geometry is Round
Why did some pronate more?
Calcaneal Geometry is Round
Soft Tissue Interposition

- Calcaneus
- Bursa
- Fat

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Soft Tissue Interposition
Effect of Adding a 10° Medial Wedge Under The Rearfoot
The problem:

- We clinically use foot orthoses to alter the pattern of rearfoot motion (ie treat excessive foot pronation)

- What is the evidence that “pronation” is even a problem?
What is the evidence that foot pronation is even a problem?

- **Cross sectional studies:**
  - Bunions and ‘flat feet’ (Kalen & Brechner; 1988; Inman, 1976; Goldner & Gaines, 1976)
  - MTSS (‘shin splints’) and pronated feet (Vittasalo and Kvist, 1983; Messier and Pittala, 1988)
  - No correlation (Rome et al, 2001; Hogan et al 2002)
  - Pronated foot protective (Cain et al, 2006)

- Only possible to infer cautions and generate hypotheses from cross-sectional studies
- Need prospective studies to determine causation
What is the evidence that foot pronation is even a problem?

• Prospective studies:
  • Weak relationship between foot pronation and overuse injuries (White & Yates, 2002; Reinking 2006, Willems et al, 2007)
The problem:

• We clinically use foot orthoses to alter the pattern of rearfoot motion (ie treat excessive foot pronation)

• The prospective studies either show no or weak relationship of injury to excessive foot pronation

• What is the evidence that foot orthoses even change rearfoot motion?
Do foot orthoses change even change rearfoot motion?

• **They don’t change rearfoot kinematics** (eg Rodgers & Leveau, 1982; Blake & Ferguson, 1993; Brown et al, 1995; Nawoczenski et al, 1995; Nigg et al, 1997; Butler et al, 2003; Stackhouse et al, 2003; Williams et al 2003…)  


• and when they do change rearfoot kinematics, its small → biological significance?
The problem:

- We clinically use foot orthoses to alter the pattern of rearfoot motion (i.e., treat excessive foot pronation).
- The prospective studies either show no or weak relationship of injury to excessive foot pronation.
- The kinematic studies show that the foot orthoses are not really altering the pattern of rearfoot motion much, if at all.

What is the evidence that foot orthoses improve clinical outcomes?
RCT’s; outcomes studies; patient satisfaction studies; eg

- **Blake & Denton (1985);** Survey; Orthoses definitely helped 70%; 78% felt that their devices improved their posture

- **Donatelli et al (1988);** 81 subjects; retrospective survey; 91% satisfied with their foot orthoses; 94% still wearing the foot orthoses; 52% would “not leave home without them”

- **Mororas & Hodge (1993);** prospective survey of 523; 83% satisfied with their orthoses; at 14 weeks post issue 63% had their symptoms completely resolved and 95% completely or partially resolved.

- Etc; etc; etc; etc; etc; etc; etc; etc; etc; etc; etc
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- The prospective studies either show no or weak relationship of injury to excessive foot pronation.
- The kinematic studies show that the foot orthoses are not really altering the pattern of rearfoot motion much, if at all.
- The RCT’s, outcome studies, and patient satisfaction studies show patients get better when we use foot orthoses that try to alter the pattern of rearfoot motion to treat excessive pronation.

What do orthotics do to different people?
eg Foot orthoses and knee pain

3 RCT’s on foot orthoses for PFPS
• Comparison of foot pronation and lower extremity rotation in persons with and without patellofemoral pain.
  Foot Ankle Int. 2002 Jul;23(7):634-40; Powers CM et al

• Abnormal foot pronation and subsequent rotation of the lower extremity has been hypothesized as being contributory to patellofemoral pain (PFP). The purpose of this study was to test the hypothesis that subjects with PFP would exhibit larger degrees of foot pronation, tibia internal rotation, and femoral internal rotation compared to individuals without PFP. Twenty-four female subjects with a diagnosis of PFP and 17 female subjects without PFP participated. Three-dimensional kinematics of the foot, tibia, and femur segments were recorded during self-selected free-walking trials using a six-camera motion analysis system (VICON). No group differences were found with respect to the magnitude and timing of peak foot pronation and tibia rotation. However, the PFP group demonstrated significantly less femur internal rotation compared the comparison group. These results do not support the hypothesis that individuals with PFP demonstrate excessive foot pronation or tibial internal rotation compared to nonpainful individuals. The finding of decreased internal rotation in the PFP group suggests that this motion may be a compensatory strategy to reduce the quadriceps angle.
Comparison of foot pronation and lower extremity rotation in persons with and without patellofemoral pain.
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Cross sectional design
A prospective biomechanical study of the association between foot pronation and the incidence of anterior knee pain among military recruits.


Excessive foot pronation has been considered to be related to anterior knee pain. We undertook a prospective study to test the hypothesis that exertional anterior knee pain is related to the static and dynamic parameters of foot pronation. Two weeks before beginning basic training lasting for 14 weeks, 473 infantry recruits were enrolled into the study and underwent two-dimensional measurement of their subtalar joint displacement angle during walking on a treadmill. Of the 405 soldiers who finished the training 61 (15%) developed exertional anterior knee pain. No consistent association was found between the incidence of anterior knee pain and any of the parameters of foot pronation. While a statistically significant association was found between anterior knee pain and pronation velocity (left foot, p = 0.05; right foot, p = 0.007), the relationship was contradictory for the right and left foot. **Our study does not support the hypothesis that anterior knee pain is related to excessive foot pronation.**
Effect of inverted foot orthoses on EMG of vastus muscle timing

- Inverted foot orthoses
- Earlier onset of VMO considered good in PFPS

Change in VMO-VL timing difference (ms)

Subject 1  | Subject 2  | Subject 3  | Subject 4  | Subject 5

Delayed Vastus Medialis Obliquus to Vastus Lateralis Onset Timing Contributes to the Development of Patellofemoral Pain in Previously Healthy Men

A Prospective Study

Damien Van Tiggelen, Sallie Cowan, Pascal Coorevits, Nathalie Duvigneaud, and Erik Witvrouw
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Changes in knee joint moments are the main risk factor for knee OA
The problem:

- We clinically use foot orthoses to alter the pattern of rearfoot motion (ie treat excessive foot pronation)
- The prospective studies either show no or weak relationship of injury to excessive foot pronation
- The kinematic studies show that the foot orthoses are not really altering the pattern of rearfoot motion much, if at all
- The RCT’s, outcome studies and patient satisfaction studies show patients get better when we use foot orthoses that try to alter pattern of rearfoot motion to treat excessive pronation
- Subject specific responses to the same type of foot orthoses are in “different directions”
- What about different types of orthotics?
Effectiveness of Foot Orthoses to Treat Plantar Fasciitis

A Randomized Trial

Karl B. Landorf, PhD; Anne-Maree Keenan, MA; Robert D. Herbert, PhD

Background: Plantar fasciitis is one of the most common foot complaints. It is often treated with foot orthoses; however, studies of the effects of orthoses are generally of poor quality, and to our knowledge, no trials have investigated long-term effectiveness. The aim of this trial was to evaluate the short- and long-term effectiveness of foot orthoses in the treatment of plantar fasciitis.

Methods: A pragmatic, participant-blinded, randomized trial was conducted from April 1999 to July 2001. The duration of follow-up for each participant was 12 months. One hundred and thirty-five participants with plantar fasciitis from the local community were recruited to a university-based clinic and were randomly allocated to receive a sham orthosis (soft, thin foam), a prefabricated orthosis (firm foam), or a customized orthosis (semirigid plastic).

Results: After 3 months of treatment, estimates of effects on pain and function favored the prefabricated and customized orthoses over the sham orthoses, although only the effects on function were statistically significant. Compared with sham orthoses, the mean pain score (scale, 0-100) was 8.7 points better for the prefabricated orthoses (95% confidence interval, −0.1 to 17.6; \(P = .05\)) and 7.4 points better for the customized orthoses (95% confidence interval, −1.4 to 16.2; \(P = .10\)). Compared with sham orthoses, the mean function score (scale, 0-100) was 8.4 points better for the prefabricated orthoses (95% confidence interval, 1.0-15.8; \(P = .03\)) and 7.5 points better for the customized orthoses (95% confidence interval, 0.3-14.7; \(P = .04\)). There were no significant effects on primary outcomes at the 12-month review.

Conclusions: Foot orthoses produce small short-term benefits in function and may also produce small reductions in pain for people with plantar fasciitis, but they do not have long-term beneficial effects compared with a sham device. The customized and prefabricated orthoses used in this trial have similar effectiveness in the treatment of plantar fasciitis.

Arch Intern Med. 2006;166:1305-1310

- 12 month randomised controlled trial of custom made foot orthoses (modified Root), Formthotics and a placebo for insertional plantar fasciitis

- At 3, 6 & 9 months no difference between the custom made and the prefabricated groups, but both better than the placebo groups

- At 12 months, no difference between the 3 groups

- Improvements of about 30 points in the FHSQ pain subscale and 15 points in the function subscale
Foot Orthoses in Lower Limb Overuse Conditions: A Systematic Review and Meta-Analysis

Natalie Collins, B.Phys. (Hons 1); Leanne Bisset, B.Phys., M.Phys (Sports and Musculoskeletal)¹; Thomas McPoil, P.T., A.T.C., Ph.D²; Bill Vicenzino, B.Phys., Grad. Dip. Sports Physio., M.Sc., Ph.D¹

There is evidence from pooled data that there is no difference between the use of custom and prefabricated foot orthoses, inferring that practitioners may use either in the prevention and treatment of lower-limb overuse injuries.
• **Systematic reviews of foot orthoses:**
  • Shouldn’t an inclusion criteria for the study also include something like “the orthotics used in the study are of the type and protocol actually used in clinical practice”?
  • How many of the included studies actually meet that criteria?

• **Is it really:**
  • Custom **molded** vs prefab
  • And not custom **prescribed** vs prefab?
Effects of three retail foot inserts on plantar fasciitis

(Payne & Dawes, 2004)
Results

• All subjects, except 3 had improvement in symptoms at 1 month (varied from 0% to 80%; mean 39.8%)

• Change in Foot Health Status:

<table>
<thead>
<tr>
<th></th>
<th>Orthaheel</th>
<th>Boots</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>FHSQ Pain</td>
<td>22.5 (+18.7)</td>
<td>31.2 (+16.7)</td>
<td>31.1 (+15.5)</td>
</tr>
<tr>
<td>FHSQ Function</td>
<td>12.5 (+16.8)</td>
<td>20.8 (+16.4)</td>
<td>34.4 (+19.5)</td>
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- Subject specific responses to the same type of foot orthoses are in “different directions”
- All studies comparing types of orthotics are showing no differences in outcome (but are showing differences in lab based parameters)

What about the relationship between clinical outcomes and the changes in rearfoot motion?
Rearfoot motion changes and clinical outcomes

Changes in rearfoot motion pattern and foot orthoses outcomes

- Subjects with foot symptoms considered related to “excessive foot pronation”

- FHSQ (Bennett et al, 2001) at baseline and 4 weeks

- Frontal plane rearfoot motion determined with and without foot orthoses
Normal foot position

Foot position with excessive pronation
With orthoses       No orthoses

Distance between malleoli and shoe centre

Monday, 8 March 2010
Horizontal distance between MM and shoe centre

Horizontal distance between LM and shoe centre
**Correlation between outcome and rearfoot motion changes**

<table>
<thead>
<tr>
<th>Malleolus:</th>
<th>Pain:</th>
<th>Function:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial Malleolus:</td>
<td>0.25 (p=0.5)</td>
<td>-0.38 (p=0.3)</td>
</tr>
<tr>
<td>Lateral Malleolus:</td>
<td>0.60 (p=0.8)</td>
<td>0.28 (p=0.5)</td>
</tr>
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</table>

- There was no correlation between the...
The problem:

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- The kinematic studies show that the foot orthoses are not really altering the pattern of rearfoot motion much, if at all

- Even when they do alter kinematics, those changes are not correlated to changes in symptoms
Effect of Inverted Orthotic on Rearfoot Mechanics (Williams et al, 2003)

- 11 subjects; no clinical response to standard neutral position style device; clinical response to Blake inverted style device

<table>
<thead>
<tr>
<th>Kinematics</th>
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<th>Invert</th>
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<tr>
<td>Pk EV</td>
<td>7.5</td>
<td>9.1</td>
<td>8.7</td>
</tr>
<tr>
<td>Ev Exc</td>
<td>15.8</td>
<td>15.0</td>
<td>15.8</td>
</tr>
<tr>
<td>Ev Vel</td>
<td>242.5</td>
<td>215.7</td>
<td>225.6</td>
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Orientate to graph:
• 0-100% of stance phase
• Below 0 line: inverted/supinated position
• Above 0 line: everted/pronated position
Subject Five

*pronated (everted) more with the inverted orthotic and the standard
*pronated less without foot orthoses
Subject Twelve

* pronated (everted) more with no orthoses
* no difference between the
Subject 13

* pronated (everted) more the standard orthoses
* pronated less with no orthoses

Consistent with the static data presented earlier
A paradox is a statement or group of statements that leads to a contradiction or a situation which defies intuition.

Do we have a paradox?
The paradox:

- We clinically use foot orthoses to alter the pattern of rearfoot motion (ie treat excessive foot pronation)
- The prospective studies either show no or weak relationship of injury to excessive foot pronation
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- Even when they do alter kinematics, those changes are not correlated to changes in symptoms
- Subject specific responses to the same type of foot orthoses are in “different directions”
- All studies comparing types of orthotics are showing no differences in outcome (but are showing differences in lab based parameters)
What about running shoes?

- What are motion control shoes for?
- If pronation has been shown to not be a problem, then what are running shoes doing?
- Do they impact on outcomes?
Can we solve this apparent paradox?

• How to solve a paradox
  • Step One:
    – Digest the paradox. The first step in solving a paradox is to understand it.
  • Step Two:
    – Makes sure that what you are calling a paradox is actually a paradox
  • Step Three:
    – Translate the paradox into other systems or languages
  • Step Four:
    – Challenge the premises
Effect of Inverted Orthotics on Rearfoot Mechanics (Williams et al, 2003)

• 11 subjects; no clinical response to standard neutral position style device; clinical response to Blake inverted style device

• **Kinematics:**
  - Pk EV: 7.5, 9.1, 8.7
  - Ev Exc: 15.8, 15.0, 15.8
  - Ev Vel: 242.5, 215.7, 225.6
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<tr>
<td>Ecc Inv Work</td>
<td>-1.80</td>
<td>-1.07</td>
<td>-0.44*</td>
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<td></td>
<td>(J/bw.ht)</td>
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</table>
Maclean, Davis & Hamill (2006)

- rearfoot motion (p=0.02) change of maximum rearfoot eversion of 1 degree (5.20º vs. 6.28º) (ES=0.32) (reduced in 10/15)

- reduction in the ankle inversion moment (10-70%) (p<0.0001) (reduced in 14/15)
Possible Solution to Paradox

• It's all about the forces

• Forces, not motion do the damage to the tissues

• So, have we been measuring and trying to change the wrong parameter and succeeded clinically by accident?

• How do we apply that clinically (and to running shoes)?

• What do we have to change in our clinical assessments to apply the solution to the paradox?
Measuring force needed to supinate the foot

- If alterations in the forces are important clinically, how can that be applied?
- Rather than focus on magnitude of excessive foot pronation, may need to focus on measuring the force needed to supinate the foot (‘supination resistance’)
- ‘Supination resistance’ is an example of one of the forces that can be clinically estimated (windlass forces are another).
Supination Resistance Test

- Supination resistance testing:
- 60-350N range
Unilateral pathology
(Payne et al, 2002)

- Subjects – unilateral lower limb pathology that could be to what is assumed as being due to excessive pronation of the foot
- n=28
- FPI > on symptomatic side 15/24 (= in 4)
- Supination resistance > on symptomatic side 25/28
- p=0.012
- **Conclusion:** Pronatory force more predictive of symptomatic side that pronated position
Force needed to supinate the foot

- Posterior tibial dysfunction group:
  - 328 (±21) Newtons (n=14)

- Reference group:
  - 138 (±46) Newtons (n=142)
Peroneal tendonitis
Peroneal tendonitis

- n=13
- Mean FPI = 5.6 (+2.7)
- Mean supination resistance 91 (+21)N
- (reference population 138 (+46) N)

Conclusion:
- Foot is pronated, but force needed to supinate the foot is low (peroneals may have to work harder)

Implications:
- May need to increase pronatory force on lateral side of rearfoot (despite pronated position)
Peroneal tendonitis
Peroneal tendonitis

Cross sectional designs
Hypothesis?

- The foot orthoses (~running shoe) need design parameters that match the supination resistance force.
- Rigidity and/or inverted position of orthotic supination resistance.
- 'motion control’ features in running shoes supination resistance.
- How test this? How to apply this clinically?
Kinetic changes (conceptual and simplified explanation)

NORMAL FOOT

Medial

Lateral

Calcaneus

Typical orthosis

FOOT WITH MEDIALLY DEVIATED SUBTALAR JOINT AXIS

Talar-tibial unit

Subtalar joint axis

Center of orthosis reaction force

6 mm medial heel skive orthosis
Kinetic changes (width of arrow represent amount of ‘force’)

NORMAL FOOT

FOOT WITH MEDIALLY DEVIATED SUBTALAR JOINT AXIS

Medial  Lateral

Calcaneus

Talar-tibial unit

Center of orthosis reaction force

Subtalar joint axis

Typical orthosis

6 mm medial heel skive orthosis
Kinetic changes

NORMAL FOOT

FOOT WITH MEDIALLY DEVIATED SUBTALAR JOINT AXIS

Medial

Lateral

Calcaneus

Typical orthosis

Center of orthosis reaction force

Talar-tibial unit

Subtalar joint axis

6 mm medial heel skive orthosis
Conclusion

- Forces damage tissues
- Motion does not damage tissues
- Why all the focus on motion?
- It was never about foot motion, foot alignment or foot posture
- This is where the evidence has taken me
All I Need To Know About Life I Learned From

STAR TREK
THE NEXT GENERATION

Nanites and computers don’t mix. The respect of a Klingon is not easily earned. Never make fun of Q. When you’ve talked to one Borg -- you’ve talked to them all. If it needs to be done, “Make it so”. To have loved and lost in the holodeck is better than never having loved at all. “Boldly go where no one’s gone before”. When danger threatens, separate the saucer section. There’s no emotional problem that a hot fudge sundae cannot soothe. If you can’t see it,

Monday, 8 March 2010
• There is an apparent paradox in the understanding of the effects of foot orthoses

• Considering the forces and not the motion, is a possible solution to this paradox

• We have some new parameters to explore with foot orthoses and running shoes use

• What clinical tests give us this information?
Thank You

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