The Unified Theory of Foot Function

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Podiatric Biomechanics

With the development of podiatric biomechanics and orthotic management, diverse theories of its application have evolved. This can lead to perplexity in both clinical and educational settings as to the most efficacious method of patient assessment and treatment.

Harradine, Bevan and Carter 2003
Podiatric Biomechanics

- May be *broadly* defined as:

  “The application of mechanical laws to the foot and its related structures”
Podiatric Biomechanics

- “The *application* of mechanical laws to the foot and its related structures”

- Is there only one method of *application*?
Our methods of application appear to be based upon more than one theory.

These variances can be individual/personal, or podiatrists can follow more universal methods of application.
Are Root Biomechanics Dying?

- From available research and inclusion in relevant literature, biomechanical theory attributed to Dr Root appears to be the most common method of application.

- The above title was an article by Kevin Kirby, 2009. He concluded:

  “... would I say that Root biomechanics are dying? The answer is a definite yes.”
Are Root Biomechanics Dying?

- But if that’s the case, why are so many of us still applying biomechanics to the foot in the methods attributed to Dr Root?

- We have to assume that practitioners are aware of the criticism of this theory in terms of reliability and validity

- Is it because it actually seems to work?
Are Root Biomechanics Dying?

- If it does seem to work, what of the other main podiatric biomechanics theories?
Historical Perspective: Podiatric Biomechanics

- Foot Morphology Theory (1970s)
- Tissue Stress Theory (1980s)
- Sagittal plane facilitation theory (1980s)

All of these theories disagree with each other in the context of:

1. Normal
2. Abnormal
3. Treatment methodology
## Generally Excepted Individual Theory Perspectives

<table>
<thead>
<tr>
<th>Theoretical Perspective</th>
<th>Foot Morphology Theory</th>
<th>Sagittal Plane Facilitation Theory</th>
<th>Tissue Stress Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria for Normalcy</td>
<td>The STJ passes through neutral at key stages of the gait cycle</td>
<td>The foot functions as a pivot allowing adequate hip extension and correct posture</td>
<td>The foot functions in a way that does not result in abnormal tissue stress and injury</td>
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<tr>
<td>Casting Methodology</td>
<td>The foot is cast in STJN, unless large deformity contraindicates this.</td>
<td>Casting methods are not documented, although recent non-custom orthoses from this theory may mean casting is not required</td>
<td>The positive cast is modified when taken to supply the shell shape required to apply the correct forces to the foot</td>
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<tr>
<td>Orthoses aim</td>
<td>To prevent abnormal joint compensation and place the foot into its normal position for key stages of the gait cycle</td>
<td>To allow the foot to work successfully as a pivot and facilitate Sagittal plane motion</td>
<td>To reduce abnormal stress upon symptomatic structures</td>
</tr>
</tbody>
</table>

Harradine and Bevan, JAPMA, 2009.
So, how can they all work?

- If these theories disagree in principle and treatment, why does it appear (from both research and clinical experience) that they can all help the same conditions?
Historical Perspective: Podiatric Biomechanics

- Foot Morphology Theory (1970s)
- Tissue Stress Theory (1980s)
- Sagittal plane facilitation theory (1980s)

Can we find an underpinning theory of *normal*, *abnormal* and *treatment options* that will let us explain the beneficial trends obtained / reported from all three theories....
Agreed Basics of normal foot function....

1. The foot must coordinate the effect of lower extremity internal rotation with the impact at heel strike.
2. It must then reverse the direction of rotation by midstep and accommodate lower extremity external rotation.
3. While simultaneously stabilizing itself to forces that can reach multiples of body weight prior to toe off.
4. And permitting the entire body to pivot over it.
1.&2. The foot must coordinate the effect of lower extremity internal and then external rotation.

- **1)CONTACT** - The Hip is internally rotating (*in relation to the floor/foot*) and the Foot pronating

- **2)MIDSTANCE & PROPULSIVE** – The Hip is externally rotating (*in relation to the floor/foot*) and the foot supinating
3. While simultaneously stabilising itself to forces that can reach multiples of body weight prior to toe off

- **Stability**
  Stability refers to a condition where an object tends to be less likely to undergo translational or rotational motion when subjected to the effects of externally applied forces

- How does this relate to heel lift?
3. While simultaneously stabilising itself to forces that can reach multiples of body weight prior to toe off

- Stability at loading phase is accomplished via the reverse windlass mechanism

- Simple model demonstrating the reverse windlass mechanism

• As the arch lowers it becomes longer and the plantar structures (in this example the plantar fascia) become more taut. This in turn applies a compressive force longitudinally
Additional stabilising factors

- The Long and short plantar ligaments (Calcaneocuboid ligaments)

- The Spring ligament (Calcaneonavicular ligament)
3. While simultaneously stabilising itself to forces that can reach multiples of body weight prior to toe off

- Stability at propulsive phase is accomplished via the windlass mechanism
- Simple model demonstrating the dynamic windlass

As the foot supinates and the arch raises, tension is maintained in the plantar fascia via the ‘winding’ of the windlass around the 1st MTPJ.
4. And permitting the entire body to pivot over it.

- Our foot is shaped like this:
4. And permitting the entire body to pivot over it.

- *Not* like this!

But, we need it to work like this....
4. And permitting the entire body to pivot over it. – 3 rockers

1) Heel
2) Ankle
3) Digits
Recap of normal foot function (although presented ‘in order’, there is an overlap of these segments)

1. The 1<sup>st</sup> (Heel) Rocker
2. Internal hip rotation with foot pronation
3. The reverse windlass
4. The 2<sup>nd</sup> (Ankle) Rocker
5. External hip rotation with foot supination
6. The 3<sup>rd</sup> (Digits) Rocker
7. The Windlass mechanism with medial column propulsion
8. Adequate hip and knee extension for normal posture and swing phase
Principles of Abnormal Foot Function – ‘Over Pronation’

What goes wrong....?
Normal STJ and Foot Function
Normal STJ and Foot Function
Normal STJ and Foot Function
Normal STJ and Foot Function
Principles of Abnormal Foot Function

The see-saw STJ axis analogy

- Force Lateral to the axis
- Force medial to the axis

Normal STJA
The inverted see-saw STJ axis analogy

Cross section through heel

Normal STJA

Force Lateral to the axis

Force medial to the axis
Moments across the STJ axis

If the fulcrum, in this case a normal STJA, is in the middle of the see-saw and forces applied to the see-saw are equal and equidistant, **no motion will result**
Moments across the STJ axis

If the axis moves closer to one end of the lever, the lever will be longer on one aspect on the axis and the applied force increased. In this example, a motion occurs around the axis (in this example, pronation).
Normal STJ and Foot Function
But what if the axis was NOT in the ‘middle’.....

- But had instead moved medially......
What can increase pronation?

- Relative increase of forces lateral to the STJ axis
Dorsal estimation of STJ Axis
Defining “OVER-PRONATION”

1. Pronating too hard, meaning the foot cannot resupinate.
2. Pronating too far, meaning there is lower limb functional malalignment.
3. Pronating too far, placing too much stress in the plantar fascia

Reduced ability to pivot over the 1st MTPJ (functional hallux limitus)
1. Pronating too hard, meaning the foot cannot resupinate.

- The foot should supinate in midstance, allowing external rotation of the hip at this stage (in relation to the floor). If this does not occur, compensatory gait mechanisms may be employed.

- Examples include:
  1) Abductory twist
  2) Reduced external hip rotation
2. Pronating too far, meaning there is lower limb functional malalignment.

- A commonly used example here is excessive internal hip rotation with excessive pronation. This often presents as a ‘squinting patella’. 
3. Too much pronation limits hallux dorsiflexion via the reverse windlass

- Simple model demonstrating the reverse windlass mechanism

- As the arch lowers it becomes longer and the plantar structures (in this example the plantar fascia) become more taut pulling the digits DOWN
3. Too much pronation limits hallux dorsiflexion via the reverse windlass and ALSO... dorsiflexing the first ray

Normal Hallux dorsiflexion with first ray plantarflexion

Functional limitation of hallux dorsiflexion due to limited first ray plantarflexion with pronation

Ground reaction force
What can ‘increase’ pronatory moments across the STJ?

- Intrinsic and Extrinsic

- Examples Include:
  1. muscle activity
  2. foot morphology
  3. specific activity
To improve abnormal foot function, we would therefore aim to:

1. Reduce pronatory moments across the STJA optimally
2. Reduce dorsiflexory moments on the first ray

Did any of the old theories achieve this?
1) Shells are cut narrow or positive casts are modified so as not to impinge on first ray function:

Normal Hallux dorsiflexion with first ray plantarflexion

1st ray complex

Sagittal view

Functional Limitation of Hallux dorsiflexion due to an increase of dorsiflexory moments on the first ray from an ‘incorrect’ / high medial contour (arch) orthosis
1) Shells are cut narrow or positive casts are modified so as not to impinge on first ray function

2. Posting applied to the medial side of the STJA
To improve abnormal foot function we would therefore aim to:

It appears that although the theoretical reason for doing this varied greatly, all three theories do:

1. Reduce pronatory moments across the STJA
2. Reduce dorsiflexory moments on the first ray
Pick a paradigm, any paradigm.

- So, which one do we use.....

- Do we really use the one we think we are?

- Are we all getting people better? With Plantar fasciitis for example, this appears to be the conclusion.
Benefits of a unified theory...

- If so, is there a ‘wrong or a right’, or is there a ‘best or a better’

- We can utilise the unified theory to simplify our undergraduate and postgraduate education and allow us a more valid approach to research and patient care

- We can improve our orthotic manufacture by not being restricted by previous theory guidelines........
In-shoe appliances....Introducing the Medial Oblique Shell Inclination (the MOSI)

- By reducing pronatory moments via applying force \textit{optimally}

- By facilitating medial column propulsion
Orthoses and normalising foot function

The larger yellow arrow represents additional force from the orthosis, the ‘orthosis reaction force’. In this case the moment applied to the axis via the orthoses reaction force is great enough to ‘level the see-saw’ (in this example, reduce the pronation).
Orthoses and normalising foot function

The larger yellow arrow represents additional force from the orthosis, the ‘orthosis reaction force’. In this case the moment applied to the axis via the orthoses reaction force is not great enough to ‘level the see-saw’. However, pronatory moments would still have been decreased. This means the force applied at ‘A’ would still be decreased. Moment vrs Movement
Orthoses and normalising foot function

- By reducing pronatory moments via applying orthoses reaction force optimally

This is why podiatrists emphasise the importance of rearfoot ‘posting’ / wedging.
Applying Force optimally

The Medial heel skive applies a force, that may be described as an ‘orthosis reaction force’, to the medial aspect of a medially deviated STJA. However, it does not apply this force perpendicular to it. A medially deviated STJA runs at an oblique angle from lateral posterior to anterior medial but the classic medial heel skive places a force onto the STJA at an angle approximately parallel to the edge of the shell.
Applying Force **optimally**

This means that although the medial heel skive applies the moment in the desired place of the foot, the moment applied is reduced via the direction of its application.
Forces and Axis
Forces and Axis
The MOSI — Applying ORF optimally

- $F_x = P \cos \alpha$
- $F_y = P \sin \alpha$
- Where
  - $F_x =$ Horizontal force
  - $F_y =$ Vertical force
  - $P =$ Applied force

Example of vertical force lost
- $F_y = 45N \cdot \sin 60$
- $F_y = 38.97N$
- **Force Lost 6N, or approximately 13%**

Cross section through calcaneus
Orthosis Reaction Force Applied by a Heel Post or Skive

This means some of the applied orthoses force to reduce the pronatory moment via the vertical force is lost to a horizontal force component being placed upon the heel. This component in turn places a force to move the foot laterally on the shell, rather than directly reduce pronatory moments.
The MOSI — Applying ORF optimally

- \( F_x = P \cos \alpha \)
- \( F_y = P \sin \alpha \)
- Where
  - \( F_x \) = Horizontal force, not present
  - \( F_y \) = Vertical force
  - \( P \) = Applied force

- Example of vertical force lost
  - \( F_y = P \sin \alpha \)
  - \( F_y = 45 \text{N} \cdot \sin 90\)
  - \( F_y = 45 \text{N} \)
  - **Force Lost 0N, or 0%**
The MOSI (medial oblique shell inclination) was first published in 2008 by Harradine et al as a modification to aid in controlling the difficult pronator with a medial deviated subtalar joint axis.

It can therefore be seen that by aligning the orthoses reaction force more perpendicular to the STJ axis by running the shell inclination parallel to it, a greater supinatory force may be applied to STJ. This can be achieved through custom OR new prefab orthoses.
A unified theory also allows greater interdisciplinary understanding and communication


Specific finding: The range of rearfoot eversion was significantly decreased

We can’t just hide away and pretend this did not happen.....!
And these are only the foot based theories...the unified theory must also explain.....

- Weak lateral rotators theoretically increase pronation. Strengthening will reduce pronatory moments and therefore all the possible consequences that can arise from this ‘over pronation’ (e.g. FnHL) can subside....
A Unified Theory?....

Excepting that:

‘Our present satisfaction with our state of understanding may reflect the paucity of the data rather than the excellence of the theory.’

The Unified Theory

"entities must not be multiplied beyond necessity".

"plurality should not be posited without necessity".

Occam's razor