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ROTATIONAL EQUILIBRIUM THEORY

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MODELS OF PODIATRIC BIOMECHANICS III :

This is the final Industry Bulletin focused on the more recent models of podiatric biomechanics. We will be presenting the contributions of Drs. Kevin Kirby, DPM and Eric Fuller, DPM. We will first present the evolution of the Rotational Equilibrium Theory (Kirby Model) and will conclude with how these ideas were the foundations for the Fuller Model. The Fuller Model focuses on how the trajectory of the center of pressure (CoP) affects the kinematics and kinetics of the foot and ankle.

In the mid 1980s, Kevin Kirby was completing a fellowship in podiatric biomechanics. It was during this time, that he began to formulate what would become the Rotational Equilibrium Theory. Like other proposed models of podiatric biomechanics, Kirby suspected that there were limitations in the Root Model. In particular, Kirby questioned whether the standard biomechanical exam at the time provided sufficient information to predict how an individual's lower extremity would move during gait and during other functional movement patterns.

John Weed was a mentor to Kirby and he commonly demonstrated a clinical technique whereby a point pressure was applied to the plantar aspect of the foot invoking either foot pronation or supination. Kirby's observation was that there were points, from proximal to distal along the plantar aspect of the foot, where pressure could be applied resulting in no pronation or supination. These points were eventually termed the *points of no rotation (Figure 1)*. Kirby began to assess individuals this way and established that there was a great deal of variability in the position of these points across individuals. In time, Kirby realized that orientation of the *points of no return* may in fact be an approximate trajectory for the transverse plane orientation of the subtalar joint axis.

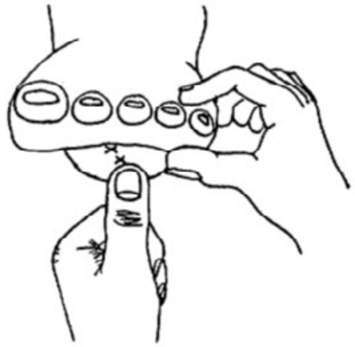

Figure 1: Points of No Rotation (Kirby, 1987)

Over time and following many assessments, Kirby identified that individuals typically exhibited one of three STJ axis orientations:

A. Medially-deviated

B. Within normal limits

C. Laterally-deviated orientations *(Figure 2)*

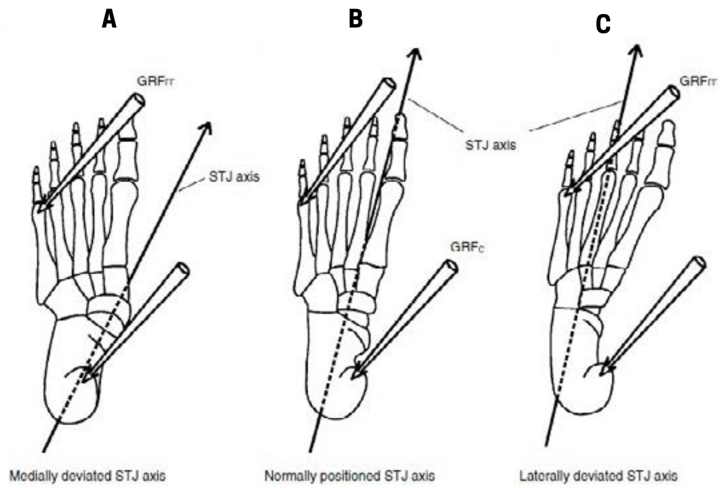

Figure 2: Medially and laterally-deviated STJ axis orientation (Kirby, 2001)

Having pursued graduate work in math and physics, Kirby had a good understanding of angular kinematics and kinetics. He hypothesized that with a medially- deviated subtalar joint axis, there was a decreased moment arm length in the rearfoot to produce an internal supination moment and therefore there would be increased external pronation moments. This type of foot would typically exhibit increased pronation during walking or running. Contrary to this, with a laterally deviated subtalar joint axis, there would be an increased moment arm length producing an increased supination moment across the subtalar joint.

Over time, Kirby refined this clinical technique and it was coded. One of the refinements was to standardize the positioning of the patient during the assessment. Eventually, he established that the assessment should be done in the supine position with the individual either sitting or lying.

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He established the Plantar Parallel Position and this was the anatomical point of reference for which the assessment technique was done *(Figure 3)*.

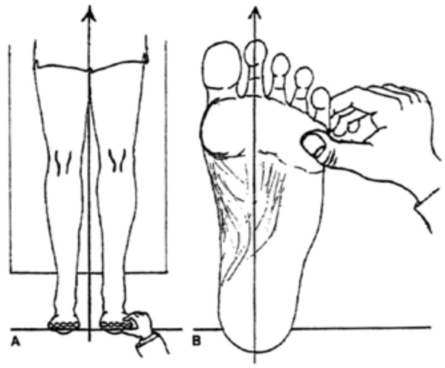

Figure 3: Plantar parallel position (Kirby 1987)

This involved having the individual in a supine position and there were three criteria:

1. The sagittal bisection of the plantar aspect of the foot was positioned in a vertical position;
2. The plantar plane of the forefoot was parallel to the patient's transverse plane; and
3. The lower extremity of the patient was positioned as it would be in or during the typical base of gait. For example, the feet would be positioned apart like how they would be observed in quiet stance.

Following this innovation, Kirby proposed the medial heel skive as an orthotic modification that would intuitively decrease the external pronation moment particularly in individuals who had a medial-deviated, subtalar joint axis *(Figure 4)*. This is an orthotic modification that is commonplace today.

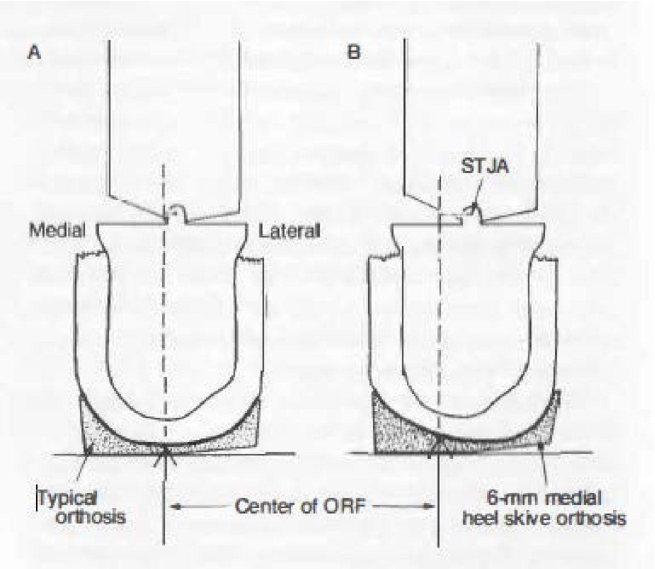

Figure 4: Medial heel skive orthosis (right) (Kirby, 1992)

Furthermore, Eric Fuller expanded on the Rotational Equilibrium Theory proposed by Kirby. Fuller (1999) suggested that the location of the Center of Pressure (CoP) of the ground reaction force relative to the subtalar joint axis (STJA) would presumably influence the degree of pronation and supination of the foot. The CoP on the plantar aspect of the foot is defined as the centroid/center point of external ground reaction forces *(Figure 5)*.

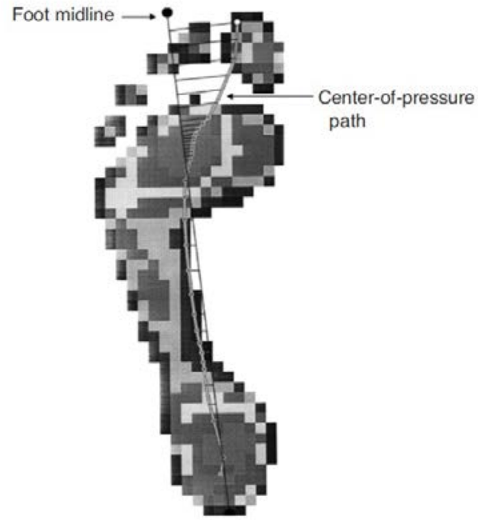

Figure 5: Typical CoP trajectory during gait (Wong et al., 2008)

Within the foot and ankle, internal moments are produced by bones, ligaments and muscles to resist the external ground reaction forces (GRFs) applied to the foot. For example, GRFs applied to the foot may lead to an external pronation moment. Internally, muscles/ligaments/bones produce an equal and opposite supination moment to stabilize the foot. When the external pronation or supination moments are increased, intuitively we can predict that the internal tissues resisting may be susceptible to injury.

Fuller expanded on Kirby's ideas by relating the position of the STJA to potential injury mechanisms. In the case of the medially-deviated STJA, the external pronation moment would likely be increased because the CoP would be primarily lateral to the STJA and, thus, the external pronation moment would be greater. Given this scenario, internal tissue would have to produce a greater internal moment to resist and, therefore, would be susceptible to injury. Theoretically, the structures that produce the internal supination moment resisting pronation are:

1. The floor of the sinus tarsi
2. The medial slip of the plantar fascia; and muscles including the tibialis posterior, flexor digitorum longus and tibialis anterior.

Alternatively, with a laterally-deviated STJA, the external supination moment would be increased with the CoP located primarily medial to the STJA.

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With this scenario, internal structures would produce an equal and opposite rotational force (moment) to resist the supination of the foot. In terms of injury, this is the likely mechanism of lateral ankle instability where the production of the supination moment may be impaired due to:

1. Peroneal weakness
2. A latency in peroneal muscle activation
3. Ligament laxity

More recent research provides some insight on CoP trajectory that might support the models by Kirby and Fuller. Wong et al. (2008) used the Foot Posture Index to group individuals into supination, neutral and pronation foot types. Each group was analyzed for CoP trajectory during overground walking. These authors presented potential differences in CoP excursion area between groups which are depicted in *Figure 6*.

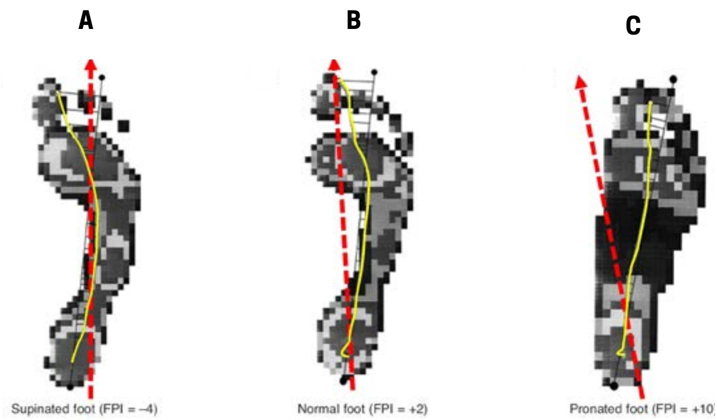

Figure 6: CoP excursion (yellow trace) between differing foot types (Wong et al., 2008). The red trace is an estimation of the orientation (superior view) of the STJ axis proposed by Kirby (A. Supinated/ laterally-deviated; B) Normal; and C) Pronated/medially-deviated)

If you observe the supinated foot (A), the CoP is located medial to the projected STJ axis at heel strike, progresses slightly lateral through midstance and then swings medial again through toe-off. With the medial orientation of the GRF vector/CoP, intuitively one would expect it to be in a supinated/inverted position. Conversely, in the pronated foot (C), the CoP is located medial at heel strike and for a very short duration swinging lateral of the projected STJ axis for the rest of the stance phase through midstance and toe off. Again, if the GRF/CoP is lateral to the STJ axis throughout most of stance, one would expect this foot to be in a pronated position. The challenge in all of this is quantitatively knowing the position of the STJ axis throughout stance. This is not currently possible using measurement techniques.

In the next Industry Bulletin, we will be presenting what we have learned about custom foot orthotic therapy and how it relates to the models of podiatric biomechanics presented here, and in previous issues.

Thank you for reading this edition of the Industry Bulletin.

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