The Advantages of Pressure Analysis and Its Use in Orthotic Evaluation

Are you utilizing this useful tool?

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Pressure analysis via force plates had been used to evaluate gait for decades in academic lab settings. It was the advent of Langer's EDG system in 1982 which made it possible to use this technology in clinical practices. This permitted real time evaluation of patients and the assessment of their foot-related treatments with, for instance, foot orthotics. But what were the useful parameters of this evaluation and what benefits were attainable?

To be able to answer this question, understanding what pressure analysis actually "sees" and how this can be useful must be made clear. As an early adapter of the EDG, and later of the F-scan system by Tekscan, the search for these significant factors became the holy grail of pressure analysis. The focus in these early days was trying to see pronation as a heel contact-related phenomena. Visualizing the subtalar joint over-pronating and what it would take to alter this process was the goal.

During these investigative years, it did not take too long to realize that this was not an effective approach. No matter what changes were made with rear foot posting, there was little to no change in the initial aspect of heel contact force curves visible. The segment from heel strike to peak heel load seemed inalterable. What eventually was observed was that changing with various orthotic design components was the duration of heel contact, specifically from the point just AFTER peak load until the heel lifted off the ground. It was a rather frustrating observation considering all the biomechanics learned in podiatry school had continually pointed to rear foot mechanics of impact. But since the 7th grade, a math teacher had instilled in me a very important concept....always ask why!

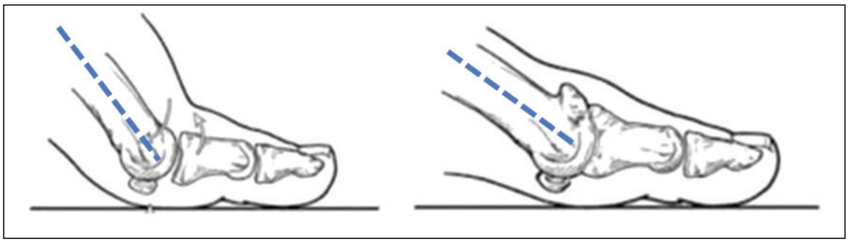

Figure 1: In hallux limitus (functional or structural), limits of range of motion are visible in the metatarsal, but not the hallux.

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A Breakthrough

The first breakthrough came when a female patient with 40 years of left-sided anterior lower leg pain presented for in-shoe pressure evaluation. She had countless examinations, with nothing being effective in finding the etiology of her symptoms. These would always occur at the end of the day, during periods of rest. It would often keep her awake at night. Medications, osteopathic manipulations, and physical therapy failed to resolve her complaints.

Her physical exam was not particularly telling. Foot joint ranges of motion were quite normal. She had a very mild flexible valgus foot type. There was some tightness in the anterior tibial muscle on the anterior lower leg, as this was the sight of her chief complaint.

The EDG evaluation at that time used 7 sensors adhered to the bottom of the foot. These included the sub IPJ of the hallux, the 1st, 2nd and 5th metatarsal heads, and two under the tuberosities of the calcaneus, medial

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and lateral. A final sensor, the "X", could be used on variable plantar locations. Multiple steps could be seen as force/time increases and decreases of the sensor sites on the printout in left/right sequence.

Her first test showed what appeared to be a gross inaccuracy. On one left footstep, she exhibited four times body weight under her hallux. On the next step, the hallux failed to bear weight, with the entire load on the 5th metatarsal head instead. This sequence continued for the entire six steps of this test. When she was subsequently observed, she inverted her left foot on alternative steps. Her anterior tibial tendon could be seen being active while her foot was being inverted. Since anterior tibial is a swing, not stance phase, muscle, the fact that it was symptomatic suddenly became very obvious. What was not obvious was why.

Re-examination of her foot joint ranges of motion did reveal a rather interesting finding, but a certain amount of luck was involved. Her 1st MTP joint showed normal range, until the 1st metatarsal head was gently loaded, which caused a complete absence of dorsiflexion. Once released, motion returned to normal. In other words, during loading, she exhibited a hallux limitus. Otherwise, there were no signs of it. I was familiar with the lateralization of weight in the presence of hallux limitus/rigidus known as the Locke maneuver, originally described by Raymond Locke, a podiatrist from California. The issue here was very different.

There was no arthritis, spurring, enlargement or pain in or around the 1st MTP joint. It was totally symptom-free, yet she avoided it on alternative steps. She was compensating for something that did not hurt and had what appeared as a totally functional disorder! This single thought became the basis for understanding the significance of pressure analysis and the implications in understanding pathomechanics of gait, and the term functional hallux limitus was used to describe it.

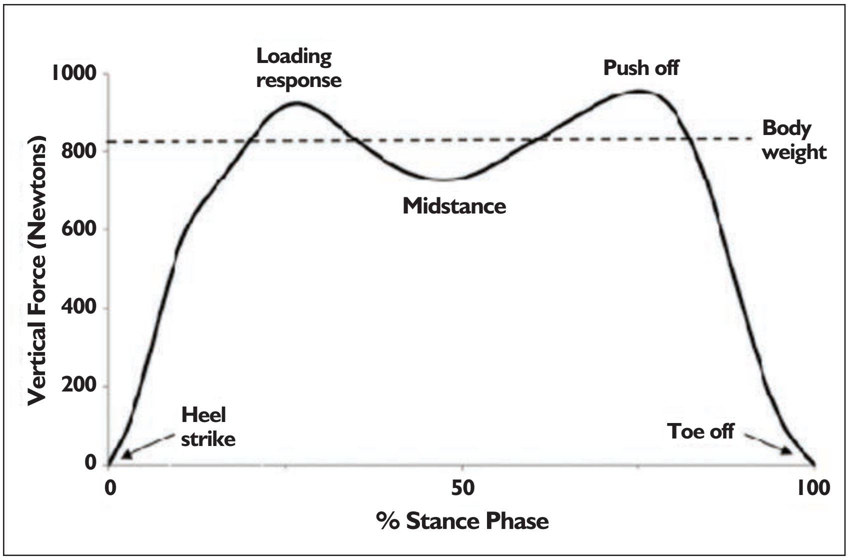

Figure 2: Understanding the meaning of force/time curve shape.

When hallux limitus/rigidus (functional or structural) is present, it is the metatarsals and more proximal foot structures which are restricted in their motion, not the hallux itself.

In Chapter 2 of Root, et al., *Abnormal and Normal Function of the Foot,* the physics of weight-bearing is described in detail. Force parallelograms were used to describe how weight transfer occurs and how motion and positional change affect this loading mechanism. The essence is that weight does not flow through the foot like water through a hose. Weight flow is positionally contingent. The more horizontal the metatarsals are to the support surface, the less the loads are expressed under the metatarsal heads.

Conversely, the more vertically oriented the metatarsals are to the support surface, the greater the loads under the same metatarsal heads. Therefore, in any given step, as the heel lifts from the ground, the metatarsal bases should pivot about the metatarsal heads, yielding a progressively increasing load application to the support surface. Since metatarsal head loading characteristics can be displayed as curves on force/time graphs, the actual motion of any or all the metatarsals can be visualized related to the slopes of these curves. The flatter these curves, the less motion evident. The steeper the slopes of these curves, the greater the motion.

Returning to the case described above, there was a very important secondary finding. On the steps with high sub-hallux loading, heel contact duration was longer than on the steps when the foot was inverted. In other words, functional hallux limitus delayed the timing of heel-off. While the difference was under 100ms, over the highly repetitive nature of steps/day, this does become an issue, particularly if unilateral. Heel lift requires motion at the metatarsal heads. Temporary absence of available MTP joint motion could therefore temporarily impede heel lift.

To understand this distinction, once the hallux is on the ground, it does not move until toe-off. When hallux limitus/rigidus (functional or structural) is present, it is the metatarsals and more proximal foot structures which are restricted in their motion, not the hallux itself. (Figure 1) Failure of the MTP joint to dor-

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siflex has little to no effect on the position of the hallux. It is the alteration of the motion patterns of the proximal structures which shows the greatest impact.

Motion Characteristics

There is a great deal of literature which describes findings in pressure analysis. One of the most classic waveforms is the double hump curve (Figure 2). This is a classic double hump curve depicting the changes in plantar foot loads during walking. There are two peaks with a central depression between them.

As the body steps over the planted foot during single support phase, several foot-related motions are required for this transition to be smooth. Heel lift must be timely. Metatarsal rotation of the bases about the heads permits efficient heel-off. This allows raising and lowering of the center of mass of the body concurrent with forward advancement. Timely heel lift is also relevant in permitting normal extension of the hip joint during walking. The more the heel lift is delayed, the less hip extension can occur.

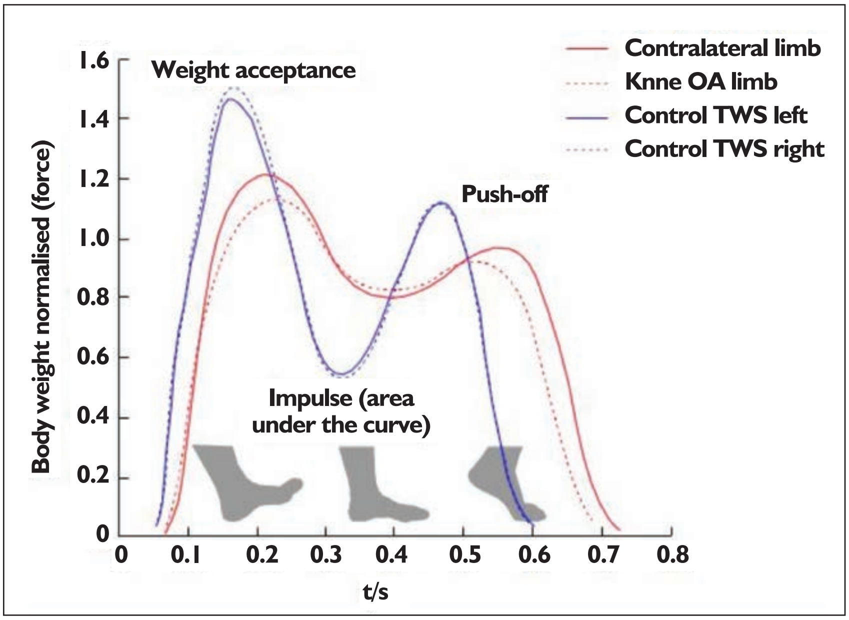

Figure 3: The graph above compares normal (blue) to subjects with OA of the knee (red). Note the flattening of the central area of the red hashed curve vs. the depth of the central area in the blue curve. Also note how much longer the total step length is in the red curve, but shorter in the blue. Speed and timely motion are integrally related.

Figure 3 depicts all these motion characteristics. The first peak shows the loads at heel strike. This is followed by a central depression, the lowest point of which represents the highest point for the center of mass. The rate that the heel unweights and ultimately lifts off the ground is depicted by the slope of this section of the graph. The flatter the slope, the slower the heel lifts at this stage of the step. The steeper the slope, the faster the heel lifts.

From this lowest point on the central depression to the final peak on the second hump, the actual pivotal rotation about the metatarsal heads is demonstrated. As with the heel curve section, the flatter this curve, the slower the motion. The steeper the slope of this curve, the greater the amount and speed of metatarsal rotation. Therefore, the heel strike curve peaks when the body aligns directly over the plantar calcaneal tuberosities, and the forefoot loading peaks when the metatarsals have maximally dorsiflexed at the MTP joints, peaking the orientation vertically. It is what happens in between these two peaks which details the significant foot motions (or lack thereof).

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Associated Pathology

There is a substantial body of information regarding pathology associated with these graphic displays. For instance, when osteoarthritis of the knee is evaluated using force plate technology, there has been a common finding. The area of the central depression is far flatter than in normal conditions. Since the loading is based on the percent of verticality achieved, limits in slope of these curves coincides with limits in the motion of the forefoot. It is this single factor which represents the most important finding with regard to the clinical value of pressure analysis. Does motion occur in a timely fashion, and what affect does treatment (i.e., foot orthotics, surgery, therapy) have on this loading process? This ability to measure whether motion has or has not improved can be used to determine potential treatment success or failure.

Podiatry has understood pathologic pronation as a factor in a wide variety of conditions from sports injuries to chronic foot/lower extremity pain. The motion of pronation, in and of itself, however, does not appear to be the issue. It is the timing that renders it pathologic. Pronation which occurs at heel strike is NORMAL. It is only abnormal when it occurs during the late mid-stance phase of the step, and in the period after heel-off would have normally taken place. But the mechanics, locations, and motions of the foot are considerably different in the later rather than the earlier phases.

In later phases, the heel has been lifted off the ground (or is about to

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be lifted) and the forces which act on the entire foot have now switched directions. Rather than proximal to distal (STJ through the mid-foot to the forefoot), the progression of the step has now resulted in the force being applied distal to proximal. The previous rules with which we think about pronation become null and void. Considering the leveling force curve findings in osteoarthritis and other musculoskeletal issues, pathologic pronation would seem to coordinate with a lack of forefoot pivotal motion. Why?

In 1954, JH Hicks, in the *Journal of Anatomy*, published a series of four articles collectively known as the "Mechanics of the Foot". In one of these, he describes the Windlass Effect. The plantar fascia originates at the plantar calcaneus and inserts into the inferior surfaces of the bases of the proximal phalanx of each toe. The largest fascia slip is to the great toe, and progressively reduces in sizes to the lesser toes. Using the plantar fascia as the "cable", dorsiflexion of the MTP joints pulls the base of the calcaneus towards the fixed toes. This acts as a winch-type mechanism, re-supinating the entire foot and externally rotating the entire lower limb to the hip. Hicks is very specific in noting that once the Windlass starts its winding process, the motion it creates cannot be resisted. This effect times perfectly with the requirement that rotations be simultaneous so as to match from the hip down with the foot's bottom up. And finally, Hicks specifically describes the windlass as non-muscular. In other words, it is a purely mechanical process independent but synergistic with phasic muscular activity.

Controlling impact pronation with rear foot posted orthotics may not be the best approach in managing pathology.

Considering the association of metatarsal rotation restriction in the late mid-stance phase with pathologic pronation, is it really the negative impact of prolonged contact pronation which is the source of pathology? The answer in most cases is no. Rather, it appears to be a failure to re-supinate in a timely fashion. The loss of timely motion at the MTP joints means there is no windlass effect. Pronation is the accommodation to internal rotation of the limb at heel strike coupled with impact force storage for return later in the step. Therefore, controlling impact pronation with rear foot posted orthotics may not be the best approach in managing pathology. Re-establishing MTP joint motion to occur in a timely way may be the better approach.

What is required to achieve MTP joint motion is not always a straightforward process. In some cases, but less commonly than believed, inverting the foot with rearfoot posts may be the best option. In other situations, particularly if the patient is already inverted (as indicated by lateral foot complaints, excessive lateral shoe wear, etc.), increasing the inversion would appear contraindicated. Instead, using a variety of 1st ray cutout shapes, which ideally permit the necessary plantarflexion/eversion of the 1st metatarsal, may be the appropriate approach. And while trial and error has been used in podiatry for decades, in-shoe pressure testing removes the guesswork as one can visualize outcomes immediately and make necessary changes to orthotic design.

The availability of pressure analysis has its place in the podiatric management of foot and related pathology.

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Understanding that the latter half of the step is actually more important than the contact portion is highly significant. Using the appropriate forefoot orthotic adjustments to better permit rather than control motion may be the most suitable for the majority of pathologies seen in clinical practice. **PM**

References

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Dr. Dananberg became well known in podiatry for his work on functional hallux limitus and its relationship to chronic lower back pain. He has published extensively and has lectured worldwide. He is the recipient of the MIT-Lemmelson Inventor of the Week Award and has also won the Scholl's Award for Outstanding Clinical Paper of the Year published in JAPMA. He serves as a consultant to Vasyli Medical and Tekscan, and is a principal in Insolia.