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PREVENTION & REHABILITATION: EDITORIAL

Chains, trains and contractile fields

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In the film, *Planes, Trains and Automobiles*, the underlying theme is that two men are trying to get home in time for a major social celebration. The story is focused around the challenges these men face as the route from *a* to *b* became increasingly convoluted and indirect.

In animal locomotion, this same theme of getting from *a* to *b* in the most efficient way is often a key aspect of organismal evolutionary fitness.

However, there may be some cases in which a more convoluted, indirect route may be of survival benefit; for example, if you were to track a course of musculature around the body in a spiral fashion (Beach, 2007; Wallden, 2008; Myers, 2001), the longer your route from *a* to *b*, the more muscle fibres can be utilised, and therefore the more power can be generated. This is why when power generation occurs in sports, such as when hitting, throwing, kicking or punching, it typically involves a rotary twist of the body; to access this fast twitch spiral musculature coursing from the lower limb through and around the trunk, and back out via a different limb to its extremity.

Of course, the more powerful a movement, the less efficient it generally is; this applies as much to the human body as it does to planes trains and automobiles. If a Ferrari competes with smart car, the Ferrari may win, but in the long run, the Smart car will go further on the same amount of fuel. Equally, there is little sense in a creature retaining fuel if it is to be some other creatures dinner as a result. Organismal biological design still seems to have the edge on synthetic counterparts; especially in terms of versatility.

Going even further back, prior to human evolution, may provide even deeper insight; for this, it is necessary to look back into deep time.

Deep time

Early life on Earth exhibited poor or limited motility; nevertheless, such motility was sufficient to satisfy survival

within the presenting ecological niche that single-celled, photosynthesising organisms found themselves in.

Early animal forms, such as sponges, anemones and jellyfish all showed very primitive circumferential movement patterns. These movement patterns have been described as the “radial chain” musculature (Beach, 1989, Personal Communication) or “radial contractile field” (Beach, 2008; Wallden, 2008).

Later animal forms, such as flat worms and round worms also exhibit this circumferential movement pattern, but do so sequentially across body segments.

It was not until the evolution of vertebrates in the form of fish that effective longitudinal contraction down the body wall could take place (Kardong, 2002; Wallden, 2008).

Subsequent development merely elaborated on the established fish-based body plan (Erwin et al., 1997); this was the premise of Gracovetsky’s (1988) Spinal Engine theory, the concept that the spine is what drives the legs forward; the limbs simply amplifying spinal motion in steady-state gait.

Recent times

Various thinkers from the exercise and rehabilitation fields have made attempts to understand these developments in the musculoskeletal function of organisms; among them early pioneers including Raymond A. Dart’s *Double Helix Mechanism of the Spine*, Phillip Beach’s *Muscle Chains* (1989), which evolved into a concept now called *Contractile Fields* (2007/2008), Andry Vleeming’s and Diane Lee’s *Slings* (Vleeming et al., 1997) and Thomas Myer’s *Anatomy Trains* (2001).

In short, these people – and many others alongside – were all doing “joined-up-thinking” in the field of human locomotor anatomy.

In the last issue of this Journal, the co-editor of this section of JBMT, Warrick McNeill PT, included a paper on the importance of the deep longitudinal sling in hamstring strain (Panayi, 2010). This sling, described by van Wingerden et al. (1996), Vleeming et al. (1997) and Gracovetsky

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(1997) is key in both stabilization of the lumbopelvic complex and, Gracovetsky argues, in utilising ground reaction force to de-rotate the spine in gait.

Further research, such as Hungerford et al.'s (2003) paper suggest that this sling may also become facilitated as a result of sacroiliac joint (SIJ) pain; the deeper, intrinsic or "inner unit" musculature being somewhat inhibited or delayed in response in SIJ pain patients – when compared with controls – and the biceps femoris firing ahead of these muscles in a feed-forward mechanism.

This may have a logical cross-over to the issues discussed in the paper in this section, by Hashemirad et al. (2010), on the flexor-relaxation phenomenon. They describe how a lumbar spine which has undergone creep due to prolonged flexion (for just 7 min or more) will create a statistically significant delayed flexor-relaxation phenomenon.

For those unfamiliar with this response, the typical clinical response being observed is a switch from a "muscular" trunk strategy (erector spinae) to a "ligamentous" trunk strategy (transversus abdominis pulls on the thoracolumbar fascia and whole posterior ligamentous system of the spine tightens) at around 45 degrees of trunk flexion or around 90% of lumbar flexion. This reflex is stimulated by mechanoreceptors in the posterior ligamentous system of the spine inhibiting the lumbar erectors.

An implication of Hashemirad et al.'s findings, is that the normal stretch does not activate the flexor-relaxation of the lumbar erectors at the usual time; this means that the hamstrings, the transversus abdominis (and it's tensioning of the deep layer of the thoracolumbar fascia) which normally become dominant at this point in the movement, are delayed in their action.

The upshot is decreased intra-abdominal pressure (due to delayed TrA contraction), decreased force closure at the sacroiliac joints (due to TrA not activating the nut-cracker phenomenon of force closure at the SIJ), decreased extensor moment action of the diamond-shaped middle layer of the thoracolumbar fascia, extended lumbar erector contraction in a position of increased flexion and therefore greater risk of posterior annular loading and potential injury.

In short, from one simple act of flexing the lumbar spine for a little too long, the ability of the body to effectively transfer loads during lifting or squatting, via a posterior myofascial chain incorporating the hamstrings, sacrotuberous ligaments, thoracolumbar fascia, posterior ligamentous system, lumbar erectors and transversus abdominis, is compromised. This means that the SIJ's and the discs become more vulnerable to injury; and the ramifications may be greater than that.

The later that the hamstrings become dominant in this movement pattern, for example, the greater the leverage on their proximal insertion due to the angle of trunk inclination. Might this influence their risk for becoming strained? If the loading on the hamstring changes its real-time orientation based on the body's long-established reflex mechanisms, could this have ramifications further down the deep longitudinal sling – as far as the arch of the foot and its role in absorption, storage and recoil of ground reaction forces?

At this point the answers are unclear, but what is known is that a change in the spatiotemporal relationships of the

body; especially if this occurs under load or velocity, such as in a sporting event, creates significant computational stress onto the nervous system, to adapt to a situation that it isn't reflexively equipped for.

Perhaps a clinical realisation arising from this is that not only are ergonomics key, but also paying attention to other causes of creep on the ligamentous system, such as the hypnotic effect of computer and TV screens, the sedative effects of alcohol consumption or of chronic sleep deprivation; potentially switching the body off from its own mechanoreceptive feedback, may offer greater understanding in preventing low back injury.

Muscle, fascia and force transmission

A second paper appearing in this edition's *Rehabilitation and Prevention* section is titled "Muscle fascia and force transmission" by Peter Purslow, (2010a) PhD. This paper explains in great detail how the inner fascial components of the muscle; the endomysium, which surrounds the myofibril, and the perimysium, which surrounds the muscle fibre bundles, form a network to create fascial continuity between different contractile units; even if one unit is fatigued, damaged, being repaired or, indeed, is simply growing.

A muscle can be imagined to behave a little like a bridge, connecting one piece of land (bone) to another piece of land (bone) while traversing some kind of ditch or gap (joint). In this way the bridge (muscle) would be built of hundreds of units – perhaps bricks – (sarcomeres) placed both end to end (in series) and alongside each other (in parallel). These bricks (sarcomeres) are designed to both withhold and to generate great forces. In the structure of the bridge, this is a relatively static role, but in the structure of the muscle, this is a far more complex dynamic interplay between resting tone, and various contractile states (concentric, eccentric, isometric and so on).

If one or more bricks were to become damaged, or be knocked out of the structure of the bridge, its integrity and ability to both withstand and to generate force would be significantly impaired. However, in both muscles and in bridges this happens regularly, and reconstruction and maintenance is an ongoing feature of such a functional load-bearing structure.

In order to be able to safely repair the bridge while it can still allow loads to be taken, some kind of extrinsic scaffolding needs to be in place; probably across the whole bridge (the epimysium), and it is likely that a more focused brace (perimysium) will need to be placed under the section of bridge that is to be repaired; while, specifically, the bricks (sarcomeres) in contact with the actual brick to be repaired (damaged sarcomere) may need a very specific, localised brace to hold them, while the stone mason is doing his work. This allows replacement of the damaged brick (sarcomere) and effective force transmission between the adjacent bricks (sarcomeres) so that the bridge (muscle) doesn't lose much, if any functional capacity. This is critical to maintain motility of the system of which the muscle (bridge) is a part (Fig. 1).

As Purslow goes on to discuss, there is more to these systems than just biomechanics. He illustrates, for example

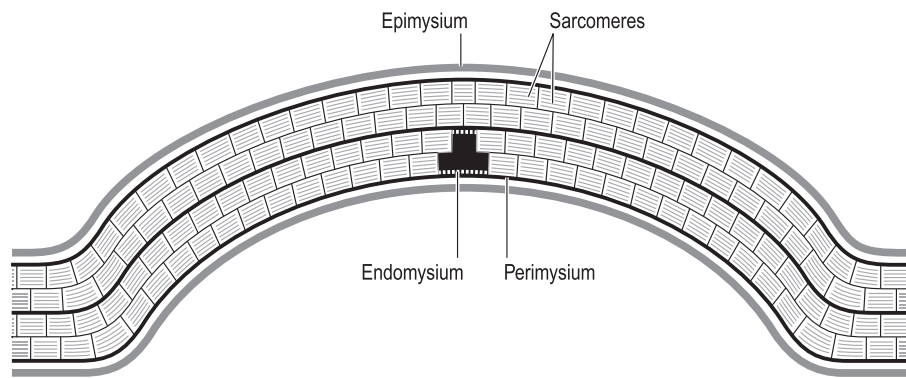


Figure 1 Muscle, fascia and force transmission. The 3 key components of the fascia which envelops a muscle; the endomysium, perimysium and epimysium, can be seen a little like the struts that may support a brick bridge that is under repair. Since muscle tissue is constantly under conditions of growth, damage and repair, there must be mechanisms in place to allow continued function of the muscle when required. The endomysium and perimysium appear to allow for this, and for intra-muscular force transmission, while the epimysium may be more involved in intermuscular force transmission.

that additional crosslinks may form through advanced glycation end products (AGEs); typical of the changes in connective tissues in those with blood sugar dysregulation, from smoking and from aging. Connective tissue function is not just, then, about how the body is used biomechanically, but what it is exposed to biochemically.

Purslow's work is also relevant to the concept of slings discussed by Panayi (2010) in JBMT issue 14(1), by Myers (1997a, b) many times in this Journal and in his book *Anatomy Trains*, as well as by Beach (2007, 2008).

These slings are, important in providing a whole-body appreciation of dysfunctional states, helping us to track back to where a problem may have arisen from and, indeed, as McNeill (2010) and Chaitow (2010) have discussed, to predict where a future problem may arise.

What Purslow's work seems to indicate is that contractile forces passing through the sarcomeres and direct into the myotendinous junction are route-1 for force generation, but that if a given line of sarcomeres has a damaged unit in series (or "brick" in the line), then this doesn't stop every other sarcomere in that series from working; but simply allows contractile forces to be transmitted laterally across to a parallel series of sarcomeres (line of bricks) allowing continued function of the muscle,

without significant compromise to performance or to repair.

Interestingly, Hunter (2005) presented prospective research on English Premiership soccer players which demonstrated that those players with greater measurable stiffness in their hamstrings at the beginning of the season were the least likely to suffer a hamstring strain during that season. Muscle stiffness is known to be generated by the series elastic components, which act like springs in between each sarcomere (Sarhmann, 2002). Therefore, the more sarcomeres (bricks) in parallel, the more series elastic components, the greater the stiffness, and the more possible pathways for force transmission – as well as for running repairs during play and across the season in general.

As to whether these forces can pass out of the contracting muscle and into the surrounding fascia (epimysium), Purslow is uncertain, but explains that it would seem entirely feasible and that there is certainly evidence of a hydraulic amplifier mechanism occurring between agonist muscles within a compartment.

Purslow (2010b, Personal Communication) states: "Whether epimysium in some muscles at least can also act in the same way to hydraulically stiffen the muscle so that

Text box 1. Evidence for hydraulic amplification between agonists in muscle compartments

"...compartmentalisation increases the efficiency of muscle contraction. The contraction of one muscle within the group pressurises the compartment (from 15 mmHg in normal contractions up to approx. 80 mmHg in tetanic conditions), and even a small elevation in pressure raises the contractile efficiency of all members in the muscle group. Cutting the fascia releases 50% of this normal pressure generation and decreases contractile force for a given extension by 16% (Garfin et al., 1981).

The interactions of the contractile proteins actin and myosin in muscle are known to be sensitive to high pressures, but very large pressures (10 MPa, or 100 atm) are required, and the effect of these are to reduce the active tension generated (Knight et al., 1993). Perhaps the more useful explanation of the effect observed at such low pressures is the lateral constraint effect proposed by Aspden (1990), which argues that the reduction in lateral expansion that pressurisation of neighbouring muscles may cause increases the effective muscle stiffness in active contraction, thus leading to increased force production for a given length of contraction."

it produces more force for a given length change is, as far as I know, not known, but in some muscles with heavy sheets of tendon-like epimysium it certainly looks a possibility.”

Load transfer

Research conducted by [Vleeming et al. \(1997\)](#) supports this notion of the capacity of the epimysium to transfer load across compartments into adjoining muscle groups.

Research conducted both on the transfer of load between the gluteus maximus and the contralateral latissimus dorsi via the thoracolumbar fascia, and on the peroneus longus through to the tendon of biceps femoris, showed that a percentage (approximately 18%) of forces applied to the cadaveric myofascial system were, indeed, transferred across muscle groups. The most likely explanation for this (as had been hypothesized by authors such as Myers, Beach and others) is the direct fascial attachments; but specifically of the epimysium (as opposed to contributions from the endomysium or perimysium).

The limitations of these studies are clear, inasmuch as the subjects were not living, had been prepared as cadavers (factors which will both significantly alter tissue properties) and were assessed on a dissection table (ie not in a functional load-bearing or sports-specific position), and using extrinsic application of force rather than intrinsic myogenic contractile forces.

Nevertheless, such research allows the bodyworker and movement therapist the possibility of making associations between the apparent “functional anatomy” and what they see clinically.

Time to rewrite the biomechanics books?

One such example is the biomechanics of gait.

For the last 10 years or so, the running community has been in debate about whether running with a heel strike is functional or not. Many running coaches have suspected that the natural state is to strike the ground with the forefoot since a higher proportion of elite distance runners forefoot strike, than those in the lower echelons of the sport. Yet, despite this, heel striking runners still outnumber the forefoot strikers by some significant margin ([Downey, 2009](#)).

This is why the research from [Lieberman et al. \(2010\)](#) published earlier this year met with so much interest from the world’s media and, in particular with the biomechanics and podiatry communities.

What [Lieberman et al. \(2010\)](#) did, for the first time, was to assess groups of habitually unshod runners, versus habitually shod runners, from different cultures, comparing their running style both barefoot and in running shoes.

Adults were sampled from three groups of individuals who run a minimum of 20 km per week: (1) habitually shod athletes from the USA; (2) athletes from the Rift Valley Province of Kenya (famed for endurance running), most of whom grew up barefoot but now wear cushioned shoes when running; and (3) US runners who grew up shod but now habitually run barefoot or in minimal footwear.

Adolescents from two schools in the Rift Valley Province were also compared: one group (4) who have never worn shoes; and another group (5) who have been habitually shod most of their lives.

Subject	Condition	RFS	MFS	FFS
Habitually shod adults, USA	Barefoot	83	17	0
	Shod	100	0	0
Recently shod adults, Kenya	Barefoot	9	0	91
	Shod	29	18	54
Habitually barefoot adults, USA	Barefoot	25	0	75
	Shod	50	13	37
Barefoot adolescents, Kenya (never)	Barefoot	12	22	66
	Shod	–	–	–
Shod adolescents, Kenya	Barefoot	62	19	19
	Shod	97	3	0

RFS = Rearfoot strike.

MFS = Midfoot strike.

FFS = Forefoot strike.

What these results seem to clearly demonstrate is that, while humans are able to rearfoot, midfoot or forefoot strike, it would appear that the primary discriminating factor in this behaviour, is more to do with whether they are shod, rather than their genetic or biomechanical heritage ([Figure 2](#)).

At this early stage in the research, it would seem that the working conclusion is that the natural state for running appears to be a forefoot strike, while adorning the foot with a running shoe seems to be the primary causative factor in rearfoot strike behaviour.

Clinical implications

Assuming further ongoing research seems to support this notion, what may be the clinical implications for such an understanding?

Firstly, of course, the biomechanics books may have to be re-written with respect to running gait. Interestingly, of course, most such texts have been written since people started wearing running shoes in 1970s and beyond; and therefore have used data from shod groups.

Secondly, other findings, both within this research from [Lieberman](#) and from other groups suggest that barefoot running and shod running differ with respect to lower limb joint angles, muscle activation firing patterns, leg stiffness, joint torques, and so on ([DeWit et al., 2000](#); [Divert et al., 2005](#); [Kerrigan et al., 2010](#)).

Weaker epidemiological studies suggest the possibility that these factors may reduce injury profiles ([Warburton, 2001](#)).

While research from the strength and conditioning field suggests that increasing leg stiffness; something that happens naturally when running barefoot, is a key way to increase top flight running speed ([Peak Performance, 2009](#)).

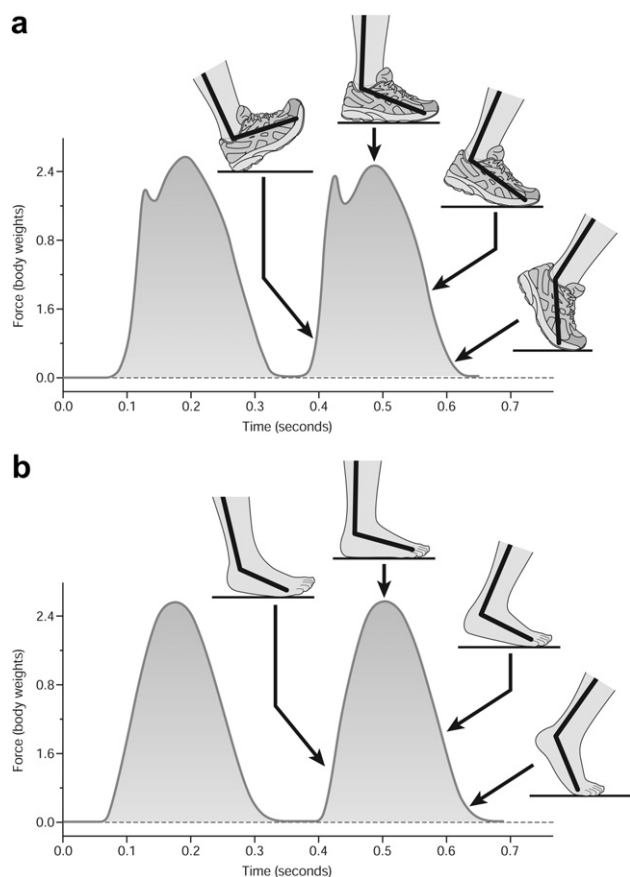


Figure 2 Rearfoot Strike and Forefoot Strike (adapted from Lieberman et al., 2010). When running in supportive trainers, the majority of runners will strike the ground with their heel. This changes the gait cycle, the cadence, the biomechanics and the loading profile. When running barefoot, the majority of runners will strike the ground with their forefoot. Since cushioned shoes are a recent phenomenon, it is likely that the barefoot condition is more akin to the “natural condition” and to the way human biomechanics have evolved to function.

Back to the fusion

If we are to place this research regarding the natural biomechanical state into the context of “joined-up-anatomy”, or the fusion of musculature hitherto regarded as “separate” entities, it may be possible to identify a dual speed system: one for low-speed gait (walking) and one for supra-walking pace gait (running, to include jogging, and sprinting).

The reason for this is that there is a potential problem with the deep longitudinal system, as described by van Wingerden (2006), Vleeming (1997), Panayi (2010), in the context of this new research on the forefoot strike; it can only really work if you heel strike.

Though it wasn’t explicitly discussed by Panayi (2010), the lower portion of the deep longitudinal sling, namely the tibialis anterior and the peroneus longus, which form a connective tissue stirrup around the arch of the foot, to control pronation of the medial longitudinal arch, will work very well if the foot is dorsiflexed before heel strike, as it means that the leverage of the ground

reaction force against the heel, in tandem with the descending load of the bodyweight through the talocrural joint, will result in a very strong eccentric load through this lower portion of the sling (which is when a muscle is strongest); effectively controlling both plantar flexion of the ankle and pronation of the medial longitudinal arch. But, if the natural state of running is to plantarflex the foot and to forefoot strike, then this system suddenly becomes very inefficient; not serving to control pronation, nor to translate forces up the sling to provide force closure to the load-bearing sacroiliac joint. In forefoot strike, the deep longitudinal sling’s appears to be practically nullified.

Since this forefoot strike appears to be the natural state; and this in tandem with the prevailing theory of human evolutionary nutrition, for the last 2 million years, it seems relied heavily on the persistence hunt where the prey is literally run to exhaustion (Lieberman et al., 2010; Liebenberg, 2006), it would seem that effective load transfer through the myofascial net would be key in allowing our ancestors to optimally exploit their ecological niche.

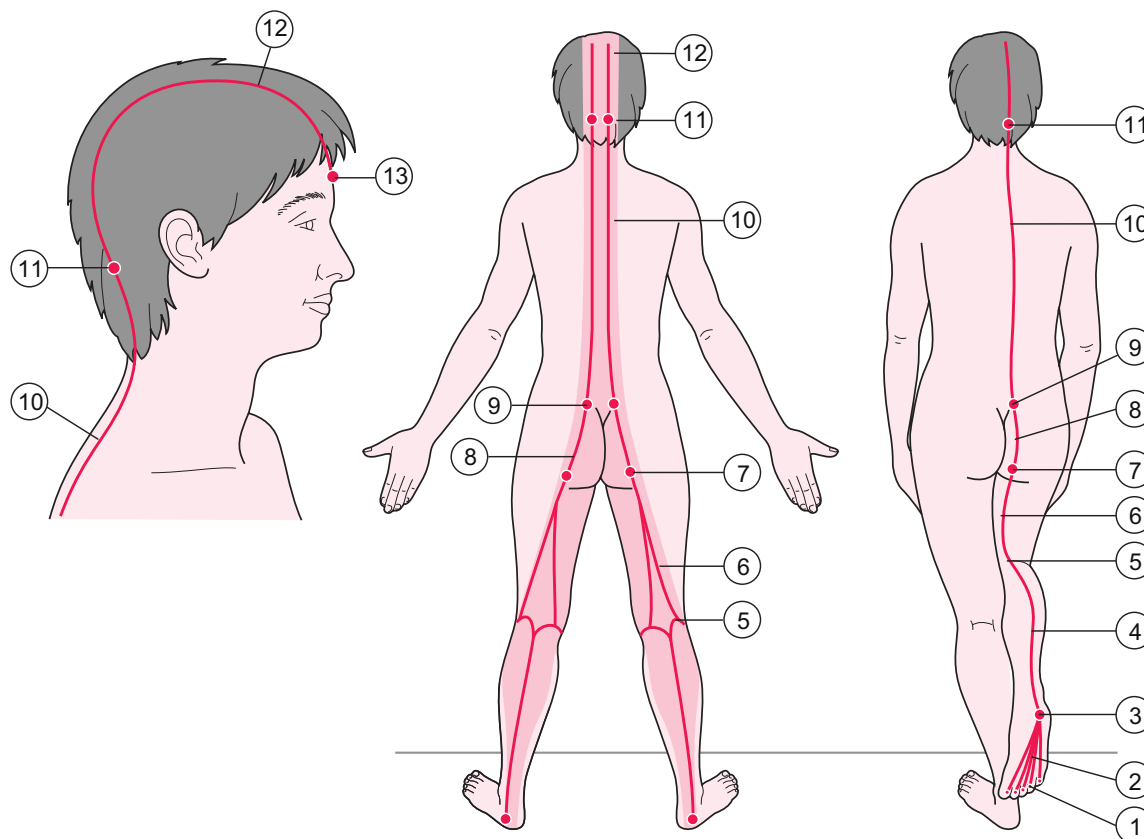
So what is the answer? Perhaps there is another means of explaining the efficiency of natural state human running gait. The stability of a moving object increases as its velocity increases. Similar to a cyclist moving at a very slow speed, versus at high speeds, gait may also be recognized for the fact that there is greater transverse plane motion; translated into greater pronation stresses during walking, than there is during sprinting. Indeed, the efficacy with which the human body can create sagittal plane or forward momentum is key in its ability to get from *a* to *b* quickly and without energy “leakage” into the frontal or transverse planes.

Hence it would be reasonable to assume that the laterally placed (and therefore counter-pronation) musculature of the deep longitudinal system (peroneus longus, tibialis anterior and biceps femoris into sacrotuberous ligament), may be more important at slower, walking velocities, but that it may become usurped in a higher velocity activities such as running, but another sling mechanism.

Myers’ *superficial back line* or “train” has been described in earlier editions of JBMT (Myers, 1997a, b) and in his book “The Anatomy Trains”, Myers depicts this myofascial sling as running from the deep toe flexors (active eccentrically in forefoot strike) and plantar fascia and, direct through the connective tissues into the Achilles tendon and into the triceps surae.

The ankle being plantarflexed before heel strike means that as the forefoot strikes the ground, the triceps surae will be eccentrically loaded (where they are at their strongest) and, interestingly, it is eccentric loading that is missing from the gait cycle if someone rearfoot strikes. Could there be a correlation between a lack of forefoot striking and Achilles tendinopathy, after all, since the work of Alfredson (1998), one of the primary methodologies for treating tendinopathic injury has been to prescribe an eccentric loading protocol.

Following the anatomy up, the two heads of the gastrocnemius run medially to their super-incumbent hamstrings, the semimembranosus/tendinosus and the two heads of biceps femoris; sweeping around laterally to insert on the condyles of the femur.



Myers Superficial Back Line. Myer's description of the superficial back line runs from 1) the deep toe flexors into, 2) the plantar fascia to, 3) the junctional fascia between the plantar fascia and Achilles tendon. 4) is the triceps surae and 5) is where the two head of the gastrocnemius wrap around the tendons of 6) the medial and lateral hamstring groups. The hamstrings course up and are continuous both with each other and with 7) the sacrotuberous ligament, which spans from 8) the ischial tuberosity up to 9) the sacroiliac joint, where it blends with 10) the deep fibres of the multifidus and the erector group – finally running all the way up to 11) epicraneus and 12) the frontalis muscle.

The functional relevance of this is that if there is a strong contraction of the triceps surae complex, as would be expected during landing with a forefoot strike, this will create a sudden sharp pull on the hamstring tendons; akin to a tendon-jerk reflex. This will stimulate a strong and bilateral contraction of both hamstring groups (in contrast to just the laterally placed biceps femoris of the deep longitudinal sling), which will transfer loads into the sacrotuberous ligament and across the load-bearing sacroiliac joint.

It has been reported by [Vleeming et al. \(1997\)](#), as though it is only the tendon of the biceps femoris which blends with (and therefore transfers load into) the sacrotuberous ligament, yet to quote Gray's Anatomy 37th edition (1989), *the biceps femoris has two proximal attachments: a long head, attached to ... the ischial tuberosity by a tendon common to it and the semitendinosus, which blends with the lower part of the sacrotuberous ligament.*

This edition of Gray's goes on to say of the proximal semimembranosus that its *fibres are partly interwoven with the biceps femoris and semitendinosus*, so it would seem quite logical to deduce that all three muscles may contribute something to the force closure described by

[Vleeming et al. \(1997\)](#) in their description of the deep longitudinal sling.

A possible parallel field of investigation

In the field of podiatry, there is an emerging concept around a similar dual mechanism focused around the foot mechanics; termed *biaxial propulsion*- see Textbox 2 below ([Curran, 2010a](#)).

In summary, the high and low gear axis really only works during the propulsive phase, so it may be that during a forefoot strike, the autosupport of the foot may gain high gear (a functionally pronated forefoot) and appropriate calcaneocuboid stability as a result. If this were correct, then with the toe-heel-toe loading of forefoot strike runners, it would seem to imply that the high gear mechanism may be engaged to provide stability "in both directions" both receiving load and expressing load. The same may be said of the windlass mechanism; that it may both store up energy on toe strike and recoil energy on toe-off. It

Text box 2. Biaxial Propulsion and Calcaneocuboid locking

During the late 1970s, the Danish anatomist Finn Bojsen-Møller described the interrelationship of the loading mechanism of the calcaneocuboid joint that is secondary to the timely tightening of the plantar fascia. Reliant on weight flow through to the first web space, the overall effect of this complex, yet essential mechanism produced stability of the rearfoot and midfoot via compression of the calcaneocuboid joint prior to heel lift.

During his investigations, Bojsen-Møller also examined the metatarsal parabola ($2 > 1 > 3 > 4 > 5$ or $2 > 1 = 3 > 4 > 5$), which revealed an anterior protrusion of the 2nd metatarsal; a seemingly consistent feature associated with the normal foot. In effect, two different axes of propulsion at the MTP joints were observed to exist. One passing transversely through the heads of the first and second metatarsal (transverse or high gear axis) and the other passing obliquely through the second through to the fifth metatarsal heads as the (oblique or low gear axis).

Further investigation of these propulsive axes revealed a number of functional advantages, and in particular the transverse axis. By evaluating the distance between each axis from a central point of the ankle joint, the distance to the perpendicular bisection of the transverse axis was documented as being greater (approximately 15–20%) when compared to the same distance to the perpendicular bisection of the oblique axis. Therefore, during high gear (transverse axis) propulsion in which weight flow is directed medially, the forefoot was observed to be functionally pronated (partly through the action of the peroneus longus). It is hypothesized that the position of the forefoot brings the dorsal border of the calcaneus and calcaneal process of the cuboid together. This in turn, provides an osseous block to further motion creating stability and is referred to as the “closed-packed position.”

The greater distance from Bojsen-Møller’s central point of the ankle joint to the perpendicular bisection of the transverse axis was assumed to produce a taut attitude of the plantar fascia. This provides further compression of the cuboid on the calcaneus that results in the crucial stability required for propulsion. Conversely, during lateral weight flow (oblique axis or low gear propulsion), it was hypothesized that because of the inverted position of the foot, the calcaneocuboid joint failed to obtain the closed-packed position as previously described. This is thought to be coupled with an insufficient tightening of the plantar fascia due to the shortened distance associated with oblique axis propulsion. As a result, it can be assumed that the lateral aspect of the forefoot would absorb the majority of the forces.

is worth noting that biaxial propulsion is just one of the many autosupport mechanisms of the foot, and is dependant on timely motions and activation of other mechanisms. For example, if someone had a limited first MTP joint then it is likely to disrupt weight flow and failure of appropriate support - and of course this will happen whether barefoot or shod if the biomechanical dysfunction is already present (Curran 2010b). Nevertheless, barefoot gait poses no restriction on MTP range of motion; so decreases likelihood of compromise to this mechanism. Perhaps some of these mechanisms go some way to explain why unshod gait is typically more biomechanically efficient.

Conclusion

The body is majestically complex – even in its biomechanical make-up alone. If I were a mechanic working, as fascinating as it may be, with *planes, trains and automobiles*, I think I would look over my shoulder with some envy at the biomechanics who worked with chains, trains and contractile fields.

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