ANALYSIS AND INTERPRETATION OF GAIT IN RELATION TO LUMBO PELVIC FUNCTION

S. A. Gracovetsky, PhD
Concordia University
Montreal, Canada

INTRODUCTION

Human gait is unique from an evolutionary perspective, although the reasons for it and the advantages it brought are still a matter of conjecture. A mechanism to explain how the human spine evolved from our fish ancestors was proposed in 1985. This early theory of the spinal-engine did not describe the specific interactions of the spine with the legs and the upper extremities. The purpose of this paper is to review and generalize the theory to merge spine, legs and upper extremities into a single machine capable of achieving what is termed human gait.

Lovett (1903) discovered that a lordotic spine, when bent to either side, induced an axial torque, a phenomenon dubbed "coupled motion" and studied in detail by Panjabi and White (1971). Nachemson (1963) analyzed the conditions under which the lumbar disk could be damaged by excessive compression. Farfan (1973) argued that excessive torsion was responsible for disc pathology. Following these leads, a considerable amount of experimental and theoretical work established that disc injury results from a combination of both compression and torsion, with torsion being perhaps the most damaging element. Since lower back injuries are among the non life-threatening diseases representing the greatest burden socially and economically, many were quick to interpret the experimental data to mean that indeed compression and torsion ought to be avoided in the work place. However, administrative guidelines proposed by NIOSH (1981) to take these findings into account did not result in any kind of reduction or slowdown in the incidence of lower back injuries.

And if torsion were indeed the primary source of disc pathology, why did we acquire a spine that allows for high levels of torsion? If so, then the 33 vertebrae prone to disc disease ought to have been replaced through evolution by stronger components. The fact that we did not evolve in such a manner suggests that the high incidence of torsional injury ought to be compensated by some fundamentally important advantage for our species.

It was essential to have access to more precise descriptions of dorsal and sacral musculature in order to relate spinal motion and the motion of the legs. By the early 1980s, Bogduk and Twomey (1987) had refined Gray's description of spinal musculature to a point where it was possible to realistically analyze spinal motion through mathematical modeling. We proposed that the properties of spinal movement ought to be determined by the need to survive, that is, to execute tasks in such a way that the stress within all structures ought to be minimized and equalized. This seemingly broad

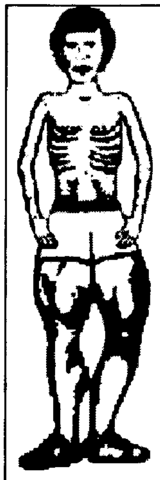


Figure 3–a (left). The second law of thermodynamics would have selected individuals with well-developed legs and relatively reduced upper extremities.
3-b (above). Dinosaurs appear to have followed the second law of thermodynamics in a leg based locomotion system.

The benefits of having explored the leg-based hypothesis are numerous. Among the most important, it can be noted the considerable energy transfer taking place between many segments of the body and the earth gravitational field; the need to store energy in the collagen structure was also explored; the existence of a relation between the topology of the ground surface and the maximum sustainable running velocity; the attempt of the body to somehow compensate for the different foot/ground interface (Snell 1983 – See Figure 4).

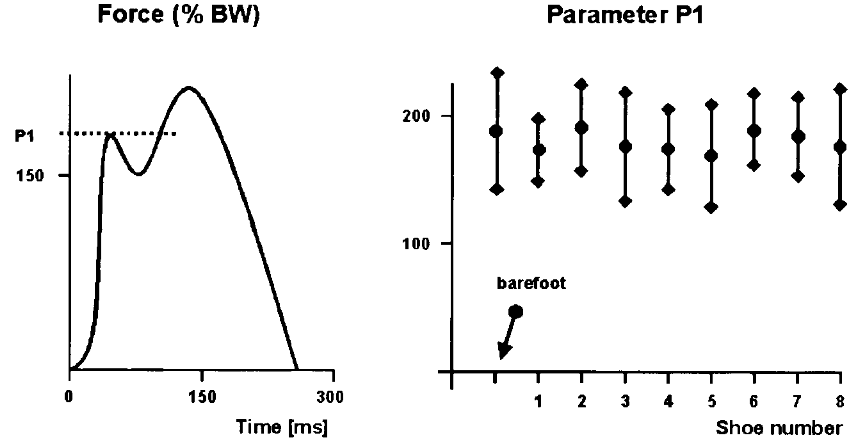


Figure 4. Snell et al measured the impact force of ten volunteers running at 4m/s on a force plate for 8 different shoes and barefoot. **(left)** force plate data of one run. **(right)** statistical results for each shoes averaged for the 10 volunteers. Notice the strong consistency of the data.

Snell demonstrated that given a ground surface and a horizontal velocity, the heel strike pulse was relatively independent of either the shoe used or the volunteer's physical characteristics. That indicates the need to continuously adjust the relative motion of ankle, knee and pelvis to insure that the recovery pulse falls within strict guidelines. The question is why human need such sensitive control system, thereby suggesting that the leg is not a simple interface with the ground but a sophisticated mechanical filter.

HYPOTHESIS 2: THE SPINE DRIVES THE PELVIS TO ROTATE.

The spinal-engine theory attempts to explain how the spine contributes to human locomotion. In substance, the lordotic spine converts a lateral bending movement into an axial torque driving pelvic rotation (Figure 5A). This is the so-called coupled motion of the spine.

The theory predicts that legless individuals would "walk" on their ischium by keeping a normal spinal motion and normal EMG pattern for the trunk musculature. This has been verified on individuals, such as the young man shown in Figure 5B (Gracovetsky, 1988).

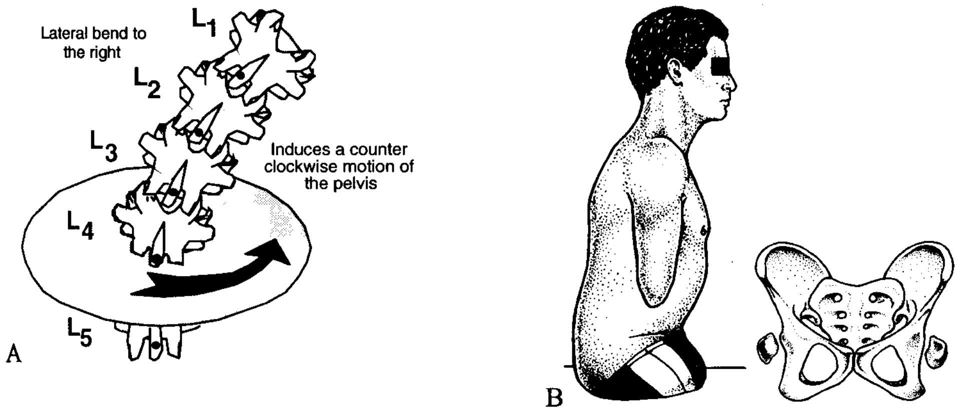


Figure 5 **A** The spinal engine theory hinges on the concept of the coupled motion of the spine, whereby a lateral bend of the spine induces an axial torque driving the pelvis. **B** Lateral view of a subject with no legs and reduced upper extremities. Radiographic AP view of the pelvis showing clearly the absence of lower extremities.

Kinematics and EMG studies demonstrated the striking similarities between his pattern of motion and that of a normal gait, except for the amplitude of the movements. The contribution of the spine was found to be consistent with the findings of Gregerson and Lucas in 1967 (Figure 6).

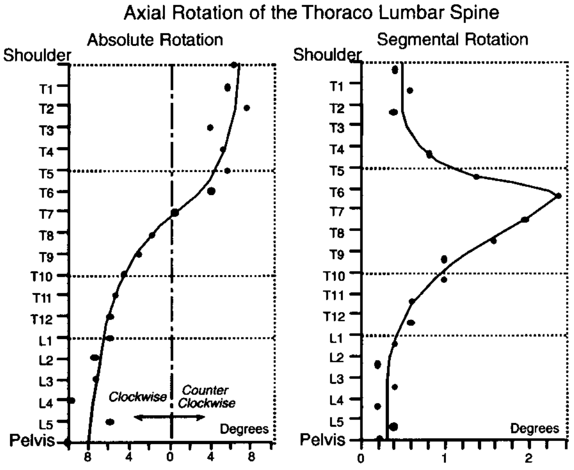


Figure 6: Gregerson and Lucas implanted pins in the spinous processes of the thoracolumbar spine and measured their motion (axial rotation) during gait. Note the important contribution of the thoracic spine to the counter rotation of pelvis and shoulder.

Absolute rotation: measured rotation with respect to T7 .

Segmental rotation: rotation of each intervertebral joint with respect to its inferior neighbor.

Hence, there appear to be no contradictions between the proposed theory and the available data. This does not mean that the theory is correct. It simply means that it has not been proven wrong to date.

WHY THE LEGS?

Human bipedal locomotion can be achieved without legs. Indeed, we can "walk" on our knees without any fundamental modifications to our spinal motion, except perhaps for an enhanced amplitude of movement; this demonstrates that the part of the leg below the knee is secondary in locomotion, a feature exploited by the makers of prostheses. However, besides amplifying the motion of the pelvis, there is a more fundamental reason for the evolution of the lower extremities.

Increasing velocity requires increasing the power available for locomotion. To increase power means to increase muscular mass. The expansion of *erectores spinae* is restricted by the contents of the abdominal cavity; and therefore, the increase in muscle mass must be located outside the trunk, such as with the hip extensors (Gracovetsky 1990). The hip extensors' power is returned to the spinal-engine via the ligamentous structure described by Van Wingerden et al (1993) in their study of the SIJ.

One problem remains: The unsupported spine collapses under a mass of two kg or so. Yet, this apparent weakness allows fine movements requiring little energy expenditure to occur, a very desirable feature. However, in order to use the greater power produced by the hip extensors, the spine must first be strengthened, as will be seen later on.

WHY THE UPPER EXTREMITIES?

That question is more difficult to answer. The conservation of angular momentum requires that pelvis and shoulder counter rotate to prevent the foot from transferring torque to the ground. A possible reason for having zero torque at the foot/ground interface may be traced to the origin of vertebrate locomotion. As the fish came to land, the animal planted his pectoral fins into a presumably muddy soil that could not sustain any torque. Consequently, the animal learned to locomote without transmitting any torque to the ground, a feature inherited by our species.

Modern measurements of the torque transmitted at the foot/ground interface demonstrated that it is very small indeed.

MERGING THE CONTRIBUTIONS OF THE SPINE WITH THAT OF THE LEGS AND THE UPPER EXTREMITIES IN LOCOMOTION.

In order to explain the contributions of the spine and legs in human gait, we must keep in mind the need to axially rotate the pelvis. This is achieved by a complex sequence of events that can be summarized as follows:

1- In running or walking, the hip extensors fire as the toe pushes the ground. The muscle power is directly transmitted to the spine and trunk via two distinct but complementary pathways:

1.1 For *biceps femoris* (BF): The *sacro-tuberous* ligament extends the action of the *biceps femoris* all the way up the rib cage (Figure 7A). In addition, this ligament crosses over the *posterior superior iliac crest* and continues on as the *lumbar intermuscular aponeurosis* (LIA) Bogduk & Twomey (1987). The LIA has a direct link with the lumbar transverse processes via *iliocostalis lumborum* and *longissimus lumborum* (LL), (Figure 7B), as well as the spinous processes via *multifidus* (*Mult*).

1.2 For *gluteus maximus*: *Gluteus maximus* (GM) is connected to the *lumbodorsal fascia (LF)*, itself linked with *latissimus dorsi (LD)* and the upper extremities (Figure 7C).

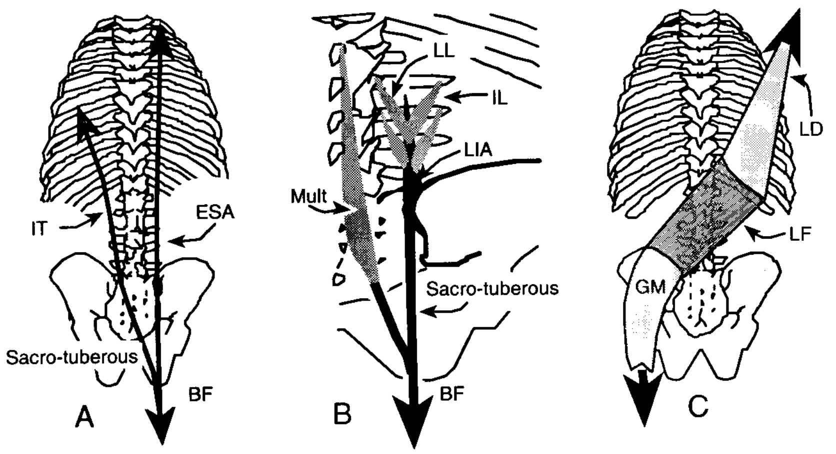


Figure 7: A The *biceps femoris* is directly connected to the upper trunk via the *sacro-tuberous* ligament, the *erectores spinae* aponeurosis (ESA) and *iliocostalis thoracis* (IT). B Enlarged view of the lumbar spine area showing the link between *biceps femoris* (BF), the *lumbar intermuscular aponeurosis* (LIA), *longissimus lumborum* (LL), *iliocostalis lumborum* (IL) and *multifidus* (*Mult*). C Relations among *gluteus maximus* (GM), *lumbodorsal fascia* (LF) and *latissimus dorsi* (LD).

As a consequence, firing the hip extensors extends and raises the trunk in the sagittal plane. The chemical energy liberated within the muscles is now converted, by the rising trunk, into potential energy stored in the gravitational field. When a person is running, so much energy needs to be stored that the necessary raise in the center of gravity forces the runner to become airborne (Figure 8-a).

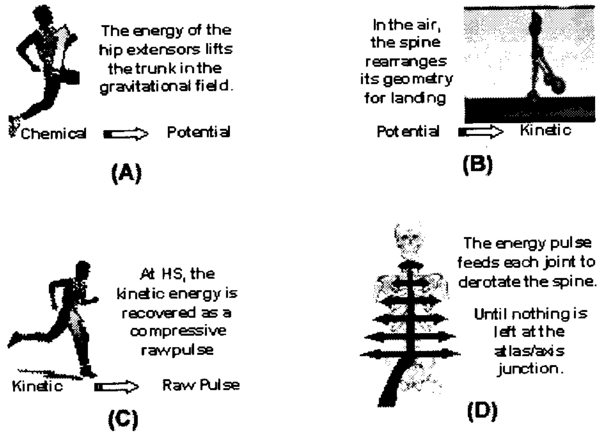


FIGURE 8 - A, B, C, D

The four stages of the energy conversion process implicating the legs.

2- During flight (running) or single-stance phase (walking), the force of compression applied to the spine is minimum (Figure 9).

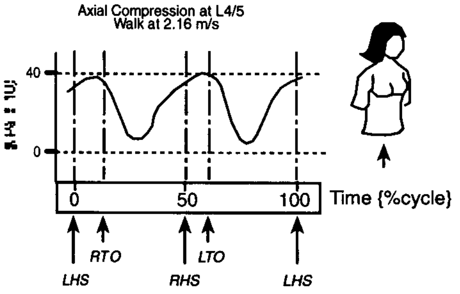


Figure 9. Axial compression on the L4/5 joint. The compression is maximal after heel strike (pulse delayed as it travels upwards) and minimum during the double- stance phase. *LHS:* left heel strike. *RTO:* right toe off.

The spine can assume the proper lateral bending shape in preparation for landing (heel strike). To increase the stride, the *acetabulum* is brought forward by the rotating pelvis. Little force is required to alter the spinal shape, and hence this process is not taxing the *erectores spinae*. The trunk now falls back towards the ground, and in so doing converts its potential energy into kinetic form.

3- At heel strike, a compressive pulse is generated at the foot/ground interface. This compressive pulse can be quite large. When running at 3.8 m/s, pulses can reach 9.55 g (Clarke et al 1985). This compressive pulse recuperates the trunk's kinetic energy (Figure 8-b).

4- The pulse travels up the leg and pelvic SIJ into the spine. To ensure synchronization with the spinal motion, the pulse is reshaped and delayed by the viscoelastic structure of collagen at the knee, the hip joints, the *sacro-tuberous* ligament and the *lumbodorsal fascia.* This filtering process is essential to provide a perfectly matched pulse to the spine kinematics regardless of ground-surface hardness so that a maximum transfer of energy occurs. The consequences of a mismatch can be appreciated when running on soft sand: the kinetic energy of the falling trunk is dissipated into the shifting sand; the weakened pulse cannot be properly reshaped by the knee and the resulting mismatch with the spine further increases the energy loss. To compensate for that loss, the runner fires his (inefficient) abdominals to maintain the necessary pelvic rotation, rapidly resulting in exhaustion. The relation between the elasticity of a running surface and shoes is of particular concern for high performance athletes who know that some surfaces are "faster" than others (Figure 8-c).

5- The energy carried by the compressive pulse is sequentially delivered to each intervertebral joint in ascending order so that no energy is left at the upper cervical and head interface. It is widely believed that the disk acts as a "shock absorber" attenuating the heel strike impact before it reaches the head. This popular view is partially true except

that the pulse energy is not absorbed (lost) into heat but is converted (used) by the coupled motion of the spine to rotate the IV joint (Figure 8-d).
Indeed, the timing is critical. The intervertebral joint must first be bent laterally and fully rotated axially to advance the *acetabulum* into the direction of locomotion. Only then, as the spine begins to unwind, can the pulse reach the spine. Like a child on a swing reversing its motion just before receiving a push, the unwinding spinal motion is accelerated by the kick of energy it receives from the compressive pulse. Improper timing may be hazardous as the out-of-sync pulse may increase the torque supported by the intervertebral joint beyond physiological limits. Such an event may occur when the ground surface is either higher or lower than expected.

Gait experiments by Cappozzo in 1983 (Figure 10) suggest that the torque through L4 can exceed the 20 Nm quasi-static limit of lumbar intervertebral joints (Farfan 1973).

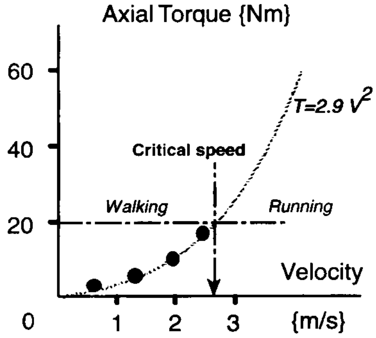


Figure 10 The measured torque across L4/5 during walking has been extrapolated for higher velocities.

By compressing the IV joint, the heel strike pulse stiffens the spine and increases its torque strength beyond the critical 20 Nm limit. The high level of torque is necessary to arrest and reverse the lateral bending of the trunk, while spinal lordosis induces the high axial torque needed to drive the pelvis.

This sequence of events is repeated for each IV joint as the compressive pulse propagates upwards, and the energy delivered to the IV joints of the thoraco-lumbar spine is used to counter rotate shoulders and pelvis. This provides the basic movement of locomotion, which is amplified by the legs. Hence, the hip extensors can be seen as axial rotators of the spine, pelvis and shoulders.

6- The weakened compressive pulse exits the thoracic spine and travels into the cervical spine. Using the same principles as before, the pulse generates an axial torque. However, the peculiar shape and arrangement of the cervical facets reverses the direction of this induced axial torque. The net effect is to oppose and de facto cancel the motion of the shoulders so that the head remains steady. It is speculated that this arrangement evolved out of the necessity of stabilizing the motion of the head (semi-circular canal and eyes sensors) during gait.

The legs have the required muscle mass to release enough chemical energy for running or walking. The legs also provide contact with the ground and modulate the timing, duration and amplitude of the energy pulses generated at heel strike before transmitting them to the spine. The spine capitalizes on this energy to fuel its axial rotation, which in turn rotates the pelvis. Thus the legs perform these functions to assure gait modulation and velocity for a wide range of ground conditions.

DEROTATING THE SPINE. THE ROLE OF GLUTEUS MAXIMUS AND THE UPPER EXTREMITIES.

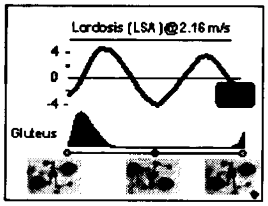
G. Maximus and the hamstrings are generally perceived as extensors of the hip. That view is certainly true, but incomplete. These muscles can derotate the spine either directly or indirectly. The two basic functions of the muscles is as follows:

FOR THE EXTENSION OF THE SPINE:

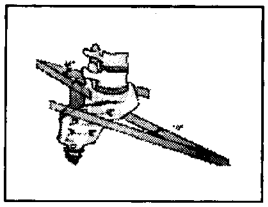
At heel strike, the spine is flexed in the sagittal plane and lordosis is restored as demonstrated by data showing the variation of the lumbosacral angle (between L5/S1 and T12/L1). The variation is about 8 degrees for a velocity of 2.16m/s (Figure 11). The mechanism by which the spine extends is the same that insure derotation.

The extension of the spine is facilitated by the peculiar geometry of the SI joint that locks whenever the spine extends (Figure 12). The sacrum can be seen to rotate around an axis passing roughly through the middle of the joint. When the upper part of the sacrum extends, the SI joint will jam because of the peculiar angulations of the SI joint. When the lower part of the sacrum is tucked in, the SI joint will also jam because of the reversal of the angulations of the SI joint. G. Maximus can be seen as pulling on essentially two parts. The first one attached to the ilium will extends the spine via the iliocostalis lumborum and the longissimus lumborum (Figure 16) and hence contribute to the jamming of the sacrum in its upper part. The second part of G maximus pulls on the sacrum and tucks it in thereby contributing to the extension torque of the spine pelvis complex and insuring that the lower part of the SI joint will lock in place. Closure of the ilium is insured by the pyriformis.

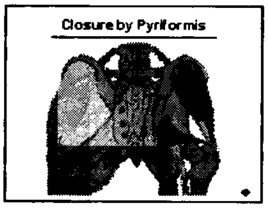
The hamstrings have the same impact except that they act on the thoracis part of the spine via the sacro-tuberous ligament and the iliocostalis thoracis (Figures 7-a, b).



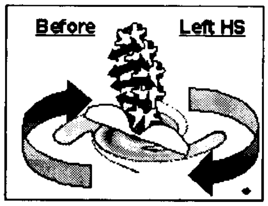
(11)



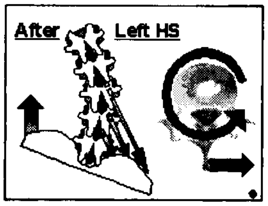
(12)



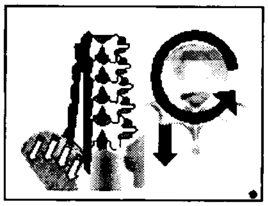
(13)



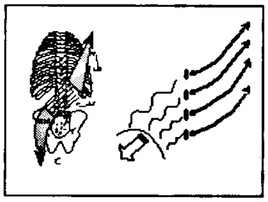
(14)



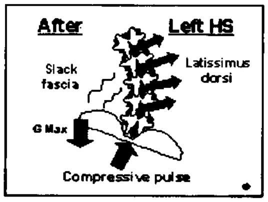
(15)



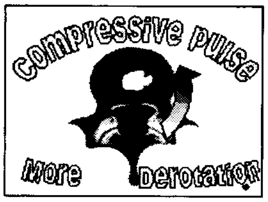
(16)



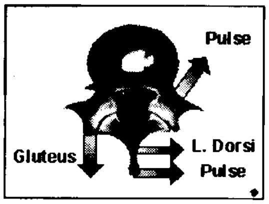
(17)



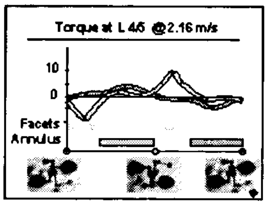
(18)



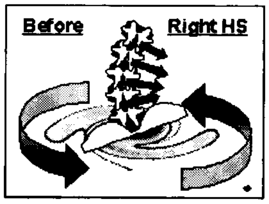
(19)



(20)



(21)



(22)

FOR THE DEROTATION OF THE SPINE:

Just before the LHS (left heel strike), the spine is flexed to the left and the spinous processes rotate in a clockwise manner (when viewed from the top – Figure 14).

Immediately after LHS, the pelvis continues to tilt while absorbing the compressive pulse traveling up the leg. The right ilium is rapidly lowered. The visco elastic properties of collagen of the lumbodorsal fascia renders the fascia instantaneously very rigid and a pull is applied to the spinous processes toward the right and downward, thereby insuring both extension and derotation of the intervertebral joint. It must be noted that the PSIS is way behind the spinous processes of L5 and L4, enhancing the effect (Figure 15).

After LHS, the pull of iliocostalis lumborum and longissimus lumborum acting via the lumbar intermuscular aponeurosis forces the spine to derotate. Indeed the force is applied to the transverse process generating a counter clockwise torque (Figure 16 – use Figure 7-b for definition of the anatomical structures).
At the same time, the right portion of latissimus dorsi contracts. This pulls together the arms AND the tip of the spinous processes of the lumbar spine (Figure 17). It is indeed important to realize that the inertia of well developed upper extremities reversing their motion is critical in permitting latissimus to exert a pull on the spinous processes (Figure 18). The left portion of the lumbodorsal fascia is slack since the left pelvis is only beginning to drop. Hence the pull of the right portion of the fascia is very effective since it is not impeded by any compensation effect of the left portion of the fascia.

In addition, since the twisted spine is being extended, the facets are being locked. It is at that time that the heel strike compressive pulse arrives and forces the facets of adjacent vertebrae together, thereby enhancing the derotation effect (Figure 19). Hence to summarize, there are four distinct forces applied to the intervertebral joint generating a consistent torque derotating the spine (Figure 20)

As the pelvis returns to the horizontal, the spine returns to a vertical position. This however does not imply that no torque is being transmitted for further spinal derotation. It can be calculated that as the facets get aligned and hence ineffective for torque transmission, the annulus fibrosus is at full torque strength because the axial rotational velocity is maximum (Figure 21). The visco elastic collagen stiffens thereby insuring that the torque transmitted by the annulus is maximum.

The final sequence is illustrated in Figure 22, just before the right heel strike the ground. The process is then repeated.

DISCUSSION ON SOME OVERRIDING ENERGY CONSIDERATIONS

The spine-pelvis-leg system is optimized to permit locomotion at minimal energy expenditure. This entails a delicate exchange between the three basic forms of energy existing at any given moment. That is kinetic, potential and elastic. The term elastic is used to describe the ability of ligaments to store energy by being deformed and then to restore (most) of that energy at the appropriate time.

Amongst the most important energy storage elements are the intervertebral disk and the various tendons such as Achilles. For instance, the coupled motion of the spine is made efficient by the remarkable energy storage capacity of the annulus and the surrounding soft tissues. That is, for a velocity of 2.16m/s, it can be calculated that the energy stored at L3 during flexion (about 1.6Nm) equals that stored during lateral bending, and also equals that stored during axial rotation. Hence, at each step, energy flows freely as the spine deforms in space, a view inconsistent with the concept of the disk operating as a "shock absorber".

The pelvis motion is also determined by energy conservation considerations. This can be appreciated by looking at the peculiar hip movement of the racing walk. To maintain foot contact at speed at which running would occur (above the critical speed in figure 10) the high-speed walker must reduce the amplitude of variations of his center of gravity. This, in turn, demands that the pelvis tilt downwards as the supporting leg is vertical.

In normal gait, the amplitude of pelvic tilt is determined by the amount of potential energy that must be stored since the pelvic tilt directly affects the position of the center of gravity. That potential energy storage must be tuned to the kinetic energy to be recovered as well as the elastic energy available within the deformed collagen structures (essentially the Achilles tendon, the deformation of the foot, the lumbodorsal fascia). Energy flows from one form to the next to minimize losses. Some losses are irreducible (7% of the energy stored in the stretch collagen is lost as heat during recovery). Other losses are related to the mechanism of gait management, which is depends upon the integrity of the various structures and the ability of the central nervous system to coordinate the structures.

For instance, a damaged knee will obviously impacts on the efficacy of the leg forcing the muscles to compensate for the corresponding energy losses. What is perhaps less obvious is the mechanism by which the damaged knee ends up reducing the overall energy efficiency. Indeed, the chemical energy liberated by the powerful hip extensors is contained in the pulse generated at heel strike. That energy must be recovered and returned to the oscillating structure. If not, then the energy cost of gait increases significantly, as can be demonstrated by running on soft sand. As the foot sinks into the soft sand, energy is lost at the foot/ground interface. The obliques must fire to induce proper spinal motion and control of the pelvis, and the runner exhausts himself rapidly.

In addition to recovering the energy contained in the heel strike pulse, the leg must transfer that energy back to the spinal engine with minimum loss. But the surface on which the runner evolves is variable (from concrete to grass), and the resulting heel strike pulse has a variable shape and timing. The oscillating spinal engine however demands to be fed with a sequence of energy pulses of very definite shape at very precise time intervals. The problem is one of matching a variable heel strike pulse with the stringent requirements of the spine. There are instances where the matching is imperfect. That situation might arise for example when the walking surface is, say, one inch higher or lower than expected. The resulting random heel strike will reach the spine out of synchronization resulting in a severe impact that might trigger a fall or even a spinal injury.

Transforming the variable (raw) heel strike impulse into a well-conditioned pulse to feed the spinal engine is the basic role of the leg-pelvis system. Matching energy supply and demand is analogous to the role of a refinery that transforms crude oil of variable chemical composition into a preset gasoline of known octane value suitable for a car engine. The leg-pelvis system can be represented as a mechanical filter that shapes, delays and deforms the raw heel strike pulse into a perfectly matched, well timed, compressive pulse traveling up the spine (Figure 8-d). Each spinal level consumes a portion of that compressive energy pulse and transforms it by coupled motion into an axial torque. The energy traveling the main compressive pulse is therefore distributed to all spinal levels thereby powering the pelvis for locomotion and derotating the shoulder motion to stabilize the head. If all goes well, all the energy will be used by the time the pulse reaches the Atlas/Axis joint, and the skull will not be impacted (Figure 8).

DETAILS OF SPINAL MOTION DURING THE GAIT CYCLE.

The leg and pelvic motion have been analyzed at length in the literature. The specific movements of the spine are less well known and have been measured by a high-resolution opto-electronic system tracking the motion of 14 markers placed strategically over the spinous processes and other reference points (Figure 23).

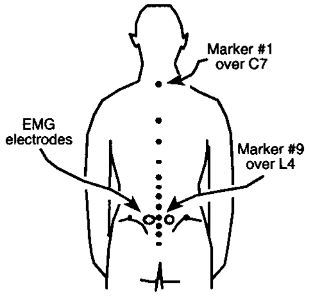


Figure 23 Position of 14 skin markers, 12 above the spine and two above the iliac crest and two EMG surface electrodes (bilateral at the L5 level over *multifidus*).

From it, the kinematics of lumbar intervertebral joints can be estimated (Gracovetsky 1995) (Figure 24), as well as the variations in lordosis during gait (Figure 25).

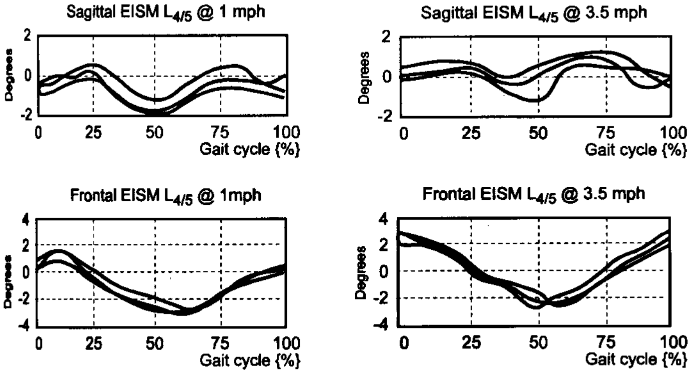
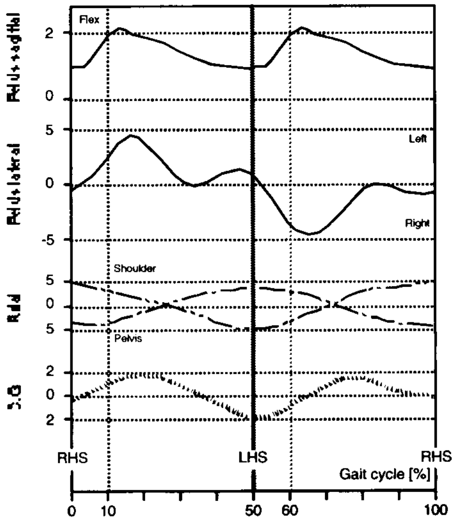


Figure 24 Estimated intersegmental motion (EISM) at L4/5 during a gait cycle for a velocity of 1mph and 3.5mph

From this data, the torque induced at the L4/5 level can be calculated; the relative contributions of the *annulus* fibrosus *and* facets to the total torque transmission are shown in Figure 26.

Indeed, the torque is transmitted by the intervertebral joints via a dual (facets and *annulus*), but complementary, mechanism. The central feature of this arrangement is to spread the generation and transmission of torque over the entire gait cycle. Specifically, when the pelvic rotation is at its maximum, the interlocking facets transmit virtually all the available torque, while during the double-stance phase, the facets are substantially aligned and cannot transmit any torque.



Definitions: *pelvis sagittal and lateral:* rotation of pelvis in the sagittal and frontal planes. *Axial:* rotation of pelvis and shoulder in the horizontal plane. *C.G.:* vertical displacement of the center of gravity. RMS: right heel strike

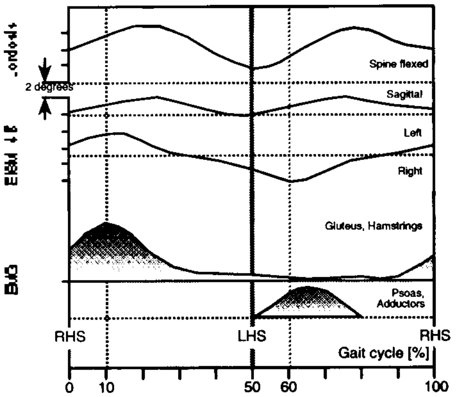


Figure 25 Relative motion of the L4/5 intervertebral joint and changes in lordosis during gait cycle.
Lordosis: variation of the estimate of the lumbosacral angle. *EISM4/5*: estimated rotation of the L4/5 in the sagittal and frontal planes. *EMG:* integrated EMG of muscles.

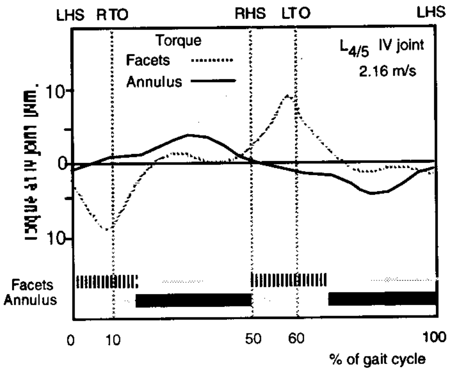


Figure 26 Contribution of *annulus* and facets to the total torque transmitted through L4/5 during gait cycle (walk at 2.16 m/s). The duty cycles of facets and annulus illustrate the complementary nature of these structures in the generation and transmission of torque.

In contrast, the *annulus fibrosus*, made of viscoelastic collagen fibers, responds particularly well to changes in angular rotation velocity. Hence, the torque transmitted by the *annulus* is maximum when the velocity is maximum (double-stance), which corresponds precisely to the instant when the facets' transmission is minimum. Conversely, at heel strike when the facets are most effective, the reversal in pelvic motion brings the angular velocity to zero and the *annulus* becomes inefficient.

Therefore, during gait, the torque needed to drive the pelvis is pulsating through both facets and disc, rhythmically and repeatedly as illustrated by their duty cycles in Figure 24. This prevents the continuous loading of a single structure with the attendant high probability of failure.

This model of a dynamic role for the spine involving torsion and compression during locomotion has important ramifications for the diagnosis and treatment of spinal disorders:

The spine must be impulse loaded. Wearing soles that are too soft is not recommended because they absorb and dissipate the impulse intended for the spine to use for locomotion. The viscoelastic nature of biological material prevents it from sustaining constant loads for extended periods of time. A constant blood pressure would deform and damage the arteries, and prevent the heart from resting. Similarly, the regular sagittal oscillating motion of the spine of the hiker carrying a backpack coupled with the anterior posterior motion of the pelvis prevents the lumbodorsal fascia from continuously transmitting forces. During the double stance, the lordotic spine switches on the erectores spinae muscles and slackens the posterior ligamentous system. Conversely, at heel strike, the posterior ligamentous system being tightened can transmit forces, thereby permitting the erectores to relax and rest. Hence, muscles and ligaments alternatively time share the forces transmitted across the SIJ, delaying the onset of fatigue of the back.

Surgery such as fusion or the implantation of metallic plates and screws intended to stabilize the spinal "column" is not recommended, unless there are no good alternatives.

Diagnosis of spinal disorders ought to be dynamic and not static. In particular, static radiographs are of little use for functional assessment. Normality can be expected to be dependent upon the activity undertaken rather than an absolute decision across the board.

CONCLUSION

We propose that gait is the result of a sequential transformation of energy intended to redirect the quasi-vertical pull of the hips extensors to a horizontal pull capable of rotating the pelvis.

Beginning with the legs, muscular chemical energy is first used to lift the body into the earth's gravitational field
Where the chemical energy is stored in potential form.

When the body falls downwards, this potential energy is converted into kinetic energy that is in turn stored into a compressive pulse at heel strike.

The pulse properly filtered by the knees and the massive ligamentous structure across the SIJ travels upwards and reach the spine with the proper shape and timing.

The energy is then distributed to each spinal joint to counter-rotate pelvis and shoulder, while derotating the shoulders stabilizes the head.

G maximum and the hamstrings can extend and derotate the spine either directly or indirectly.

The derotation requires the presence of well-developed upper extremities.

REFERENCES

1. Bogduk N, Twomey LT 1987 Clinical anatomy of the lumbar spine. Churchill Livingstone, New York.
2. Capozzo A 1983 The forces and couples in the human trunk during level walking. Journal of Biomechanics 16:265-277
3. Clarke TE, Cooper, LB, Hamill CL, Clark DE 1985 The effect of varied stride rate upon shank deceleration in running. Journal of Sports Science 3:41-49
4. Farfan H F 1973 *Mechanical* disorders of the low back. Philadelphia, Lea and Febiger
5. Gracovetsky, S 1988 The Spinal Engine. New York, Springer-Verlag
6. Gracovetsky, S 1990 Musculoskeletal function of the spine. In: Winters J, (ed) Multiple muscle systems: Biomechanics and movement organization. New York: Springer-Verlag, 410-436
7. Gracovetsky, S, Pawlowsky M, Newman N et al 1995 Database for estimating normal spinal motion derived from non-invasive measurements. Spine 20:1036-1046
8. Gregerson G, Lucas DB 1967 An in vivo study of the axial rotation of the human thoracolumbar spine. Journal of Bone and Joint Surgery [Am] 49A (2): 247-262
9. Lovett A W 1903 A contribution to the study of the mechanics of the spine. American Journal of Anatomy 2:457-462
10. McNeil Alexander, 1992, Exploring Biomechanics: Animals in Motion – Scientific American Library ISSN 1040-3213 – Freeman - New York.
11. Nachemson A 1963 The influence of spinal movements on the lumbar intradiscal pressure and on the tensile stress in the annulus fibrosus. Acta Orthopaedica Scandinavica 33:183-207
12. National Institute for Occupational Health and Safety (NIOSH). Work practices guide for manual lifting. DHHS (NIOSH) Publication No. 81-122 Cincinnati, Ohio.
13. Panjabi M, White III A 1971 A mathematical approach for three-dimensional analysis of the spine. Journal of Biomechanics 4:203-211
14. Snell, J.G, Delman N.J, Heerkens Y.F, van Ingen Schenau G.J (1983) Shock absorbing characteristics of running shoes during actual running. Proceedings of the 9th International Congress of Biomechanics. D.A Winter editor. Champain, Human Kinetics publishers.
15. Van Wingerden J.P, Vleeming A, Snijders CJ, Stoeckart R.I 1993 A functional anatomical approach to the spine-pelvis mechanism: Interaction between the biceps femoris muscle and the sacrotuberous ligament. European Spine Journal 2:140-144
16. Vleeming A 1992 Personal communication and in Proceedings of the First Conference on the Sacroiliac Joint, San Diego CA
17. White III A, Panjabi M 1990 Clinical Biomechanics of the Spine. Philadelphia, J.B. Lippincott Company