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The neutral spine principle

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In any aspect of life to have principles can aid in the simplification of complex scenarios. All too often, principles can be easily mislaid when the detail of a situation becomes consuming. Such micromanagement, whilst in itself not problematic, in the absence of principles becomes extremely confusing; the outcome commonly being paralysis by analysis.

Some examples of useful (though not universally accepted) principles in bodywork and movement therapies could include the SAID principle (Baechle and Earle, 2000; Chek, 2001), the principle of movement emanating from the core (Gracovetsky, 1988; Chek, 2001; Richardson et al., 2004), the form principle (Baechle and Earle, 2000; Chek, 2001), the principle of structure function inter-relationship (Ward, 1997), the principle of balance or the Yin-Yang principle (Hicks et al., 2004), or the topic of this editorial, *the neutral spine principle* (Baechle and Earle, 2000; Chek, 2001; Lee, 2004; McGill, 2002, 2007).

What exactly is a principle?

The word ''principle'' (according to http://www.thefreedictionary.com/principle) may be defined as:

(1) A basic truth, law, or assumption
(2) A basic or essential quality or element determining intrinsic nature or characteristic behavior
(3) A rule or law concerning the functioning of natural phenomena or mechanical processes

Like any assumption, a principle should be tested as far as it allows. There are various ways to test a principle. It can be isolated and tested in isolation; how many people with non-neutral curves have back pain, versus how many with neutral curves, and how many from each group are in pain. Alternatively, it can be tested in a real-world environment with multiple other interacting factors. Either of these environments may or may not reveal the truth or the falsehood of the assumption that maintaining a neutral spinal position is optimal; in which case, the only thing that can serve us is the experience of using it.

Ultimately, it may be worth considering that unless a better principle replaces the principle under scrutiny, that principle remains in the ascendency.

What exactly is neutral?

Neutral literally means unpolarised. When the spine moves into flexion it is moving out of neutral, when it moves into extension, it moves out of neutral. Indeed any ''motion vector'' which moves the spine away from its optimal postural position could be considered a non-neutral spine.

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In this way, it might be easier to classify what neutral isn't rather than what it is!

Where exactly is neutral?

As far as any joint is concerned, the neutral position may be defined as *one in which the joints and surrounding passive tissues are in elastic equilibrium and thus at an angle of minimal joint load* (McGill, 2007). Other factors that may be considered as part of the definition include: the holding of a position in space in which translation of load is optimal through the structures of weight bearing, and/or where the length—tension relationships about the motion segment(s) are balanced, and/or where the optimal instantaneous axis of rotation can be maintained within the motion segment(s). Describing neutral provides a similar challenge to defining posture; "the position from which movement begins and ends" being as good as any. So this is why Panjabi (1992) and others have opted to describe a "neutral zone".

The neutral zone

The neutral zone can be defined as a small range of movement near the joint's neutral position where minimal resistance is given by the osteoligamentous structures (Lee, 2004). In other words, it is a constantly moving position of a living joint, which is characterized by creating the least possible stress to the surrounding passive subsystem of that joint.

Out of neutral

What happens if the joint is out of neutral? In the first instance, very little should "happen"; simply the tissues on one side of the joint will be in a relatively shortened/compressively loaded position, while the tissues on the opposite side of the joint will be in a relatively lengthened, distractively loaded position.

Under natural conditions, the result of this is that the nervous system is made aware of this imbalance via the type 1 mechanoreceptors, which communicate directly with the tonic (inner unit) musculature around the joint and encourage a return toward neutral. However, under not-so-natural conditions of forced concentration in front of a computer screen, or at a desk, deadlines, targets, or under the influence of social or pharmaceutical drugs (among many other examples), the nervous system may not respond in the way it should, i.e. to correct the imbalance.

If this occurs then, across time, the shortened compressed tissues will undergo dehydration, contracture, will shorten and become less able to translate loads, while the lengthened, tractioned tissues will also undergo dehydration, creep, will lengthen and will lose tensile strength (McGill, 2002), and will become less effective at passively restricting excessive movement at the joint, and consequently may lose mechanoreceptive efficacy.

Neutral zone concerns

This raises some concerns with respect to the concept (or perhaps just the definition) of a "neutral zone".

If the neutral zone is defined as *a small range of movement near the joint's neutral position where minimal resistance is given by the osteoligamentous structures* (Lee, 2004), then a spine which has been held in a position of relative flexion for 15 or 20 years, for example, will have a neutral zone that has migrated anteriorly, compared to someone who has maintained a neutral spine during that same time frame.

The neutral spine principle

The neutral spine principle is a rehabilitative and performance conditioning principle (Lee, 2004; Comerford and Mottram, 2001; McGill, 2002; Chek, 2001; Baechle and Earle, 2000) which suggests that in early stage rehabilitation and the learning phase, postural conditioning, strength-endurance, and strength development phases of conditioning, the capacity to both maintain a neutral spine, and to be able to dissociate the spine from the hips, is a foundational movement skill.

Why should being in a neutral spine be of any benefit?

Different authors and researchers have attempted to estimate how the loading of the motion segment (the disc and facet joints) should be shared in a functional spine.

Adams et al, (2006). describe weight bearing through the spine and indicate that some early research suggested that the zygapophyseal (facet) joints carried approximately 20% of the load and the disc 80%. More recent studies have suggested that the facet joints can bear up to 40% of the applied load, while other researchers have suggested that, in the lumbar spine at least, the facet surface orientation means that no weight can be borne through these structures. This will be further discussed below (Figures 1 and 2).

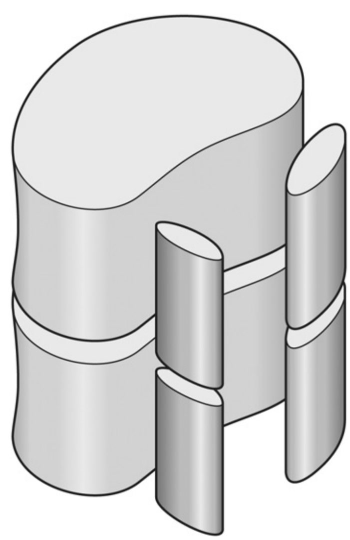

Figure 1 The spine has classically been viewed as a tripod mechanism with the anterior pillar consisting of the discs and vertebral bodies, and the posterior pillars being the facet joints.

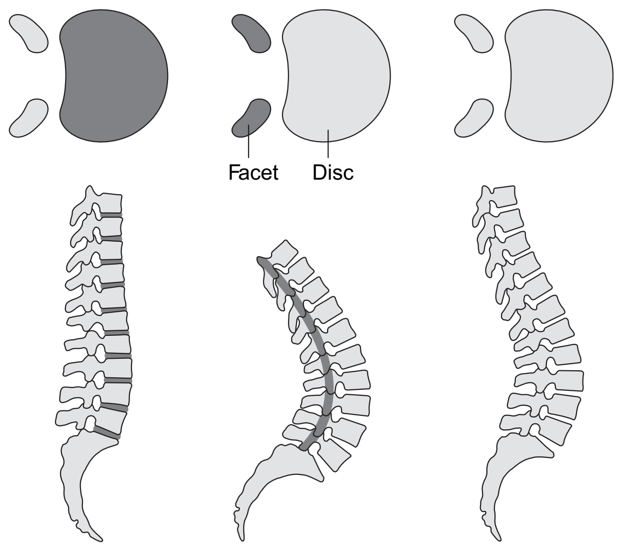

Figure 2 When there is greater flexion in the spine, there is greater loading on the disc, while when there is greater extension in the spine the load shifts toward the facets. Maintaining a neutral spine is the best way to load share between the 3 pillars of the tripod mechanism.

The implication, then, is that if too much of the loading is passed through the disc, it will break down ahead of the facets and vice versa.

Load sharing

Very simply put, if any one part of the biomechanical chain is utilized in favor of sharing the load, it will undergo greater cumulative microtrauma and is most liable to undergo changes in tensile strength and eventual degenerative change.

A simple example of this is the lumbo-pelvic rhythm, where overuse of a lumbar strategy (flexion through the spine in forward bending) will increase risk of lumbar injury, whereas those with a hip strategy (flexion through the hip in forward bending) will increase risk of hip injury (see Figure 5 below).

Similarly, within the spine, if one component is used to bear load alone or take greater load than it is designed to, the result will be greater cumulative microstress and the potential of subsequent degenerative change to that over-stressed component.

The concept of cumulative microtrauma, or cumulative trauma disorders, or repetitive strain injuries has been thoroughly discussed in the literature; including a recent JBMT editorial (Wallden, 2009). Such a process of accumulating microscopic stress in the tissues can result in a decline in tensile strength (McGill, 2002), which culminates in greater vulnerability to injury from ever decreasing loads, such as lifting a small child, to weeding a flower bed, to sneezing, to tying a shoe-lace, to sleeping in a draught (where consequent changes in muscle tone may exert a compressive load through the spine).

In practice, it is most commonly these kinds of scenarios that are presented by patients as the causative factor in their back pain, yet the discerning therapist would presumably recognize the highly implausible nature of these claims; especially if they recognized that the disc will withstand loading at greater intensities than the bones themselves can handle and, indeed, remained intact after all the vertebrae had been reduced to a series of crush fractures in research on monkeys (Gracovetsky, 2003). So how is it that picking up a pencil, or bout of hay fever can rupture a healthy disc?

This seems implausible based on our knowledge of disc strength.

Nevertheless, a pencil or a sneeze may become the proverbial *straw that breaks camel's back* in an unhealthy disc. That last little bit of stress to an already severely compromised and weakened tissue means that even a pencil or a draught can become ''the last straw'' as far as the spine is concerned.

How might such a process of cumulative microtrauma result in such a significant weakening of the immense tensile strength of the annulus of the disc, for example?

This is an important question, as it is clear that the disc is an incredible translator of mechanical forces. So, how could simply sitting with a flat-backed posture, even for a number of years, result in a breakdown of the annulus fibrosis; a structure which not only has its own immense strength, but that is swaddled in paraspinal ligaments which can withstand loads of up to 1260 kg (Kerr, 1999) per square centimeter; a tensile strength greater than steel? Compare this to the 5 kg per square centimeter (Kerr, 1999) that muscle can translate and it gives you a feel for the raw strength of these passive structures. And bear in mind that the muscles are able to absorb forces as much as 33 times bodyweight in sprinting according to Lees (1999).

There are a few considerations that may shed some light on this:

First, the nervous system will always migrate the body to its position of strength. When someone has adopted a specific posture for a prolonged period of time and in this instance (where we are using the example of a flat-backed [hypolordotic] sitting posture), the lumbar erectors will lengthen by laying down sarcomeres in series and/or become stronger in their outer-range; which will alter static and dynamic length—tension relationships about the lumbo-pelvic region, respectively (Chek, 2001; Sahrmann, 2002).

The upshot of this may be that the faulty seated posture is transposed into activities of daily living (e.g. lifting, twisting, squatting, walking) and into sports or other more highly loaded activities.

If we just pick one of these activities, such as walking, and consider how this may affect the lumbar spine of someone with a flattened lordosis, it will provide a useful illustration for how structures as strong as discs, ligaments, joint capsules, and so on, become affected by cumulative microstress.

Gracovetsky (1988, 1997) explains that the ground reaction forces returning through the lower limb after heel-strike travel into the lumbar spine creating loading through both the discs and the facets up the length of the spine ipsilateral to the heel-strike. For example, a left heel-strike will drive ground reaction forces through the left leg into the spine on the left hand side compressing the facets on the left side of the spine, and due to the contralateral coupling of the arms and legs in gait (Van Emmerick et al., 1999) there will be a relative left rotation of the lumbar

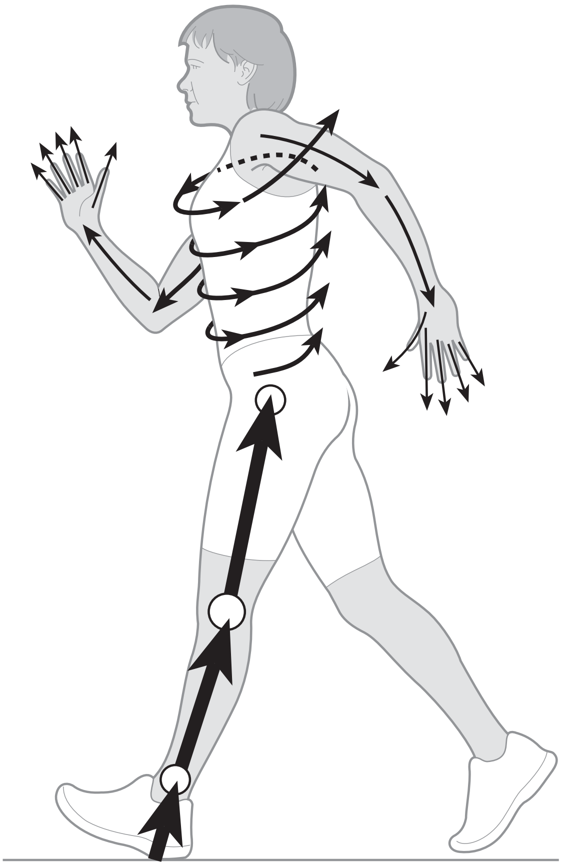

Figure 3 On heel-strike, there is a significant ground reaction force which travels up through the lower limb and into the spine. At each of the viscoelastic structures en route, a certain proportion of this energy is captured and stored in the collagen fibers allowing brief deformation and recoil. Ultimately the ground reaction force travels up through the spine de-rotating each segment as it goes and passes into the upper extremity where, finally, it is expressed as kinetic energy in the hands. When the movement of the hands meets resistance from the elasticity of the supporting musculature and connective tissue, an elastic recoil begins to swing the arm in the opposite direction, thus counterbalancing the forward swing of the ipsilateral leg as it enters its swing phase.

spine creating torsional stress through the oblique fibers of the annulus fibrosis. This loading of the facets and stretching of the annulus results in a storing of potential energy within the viscoelastic collagen fibers which will recoil to drive the spine into right rotation and, with it, draw the right leg through its swing phase. This mechanism that allows this is otherwise known as *the spinal engine* (Gracovetsky, 1988) (Figure 3).

The importance of this understanding becomes clear when we look at both the loading and the concept of load sharing in the context of human gait.

The average person takes around 10,000 steps per day (Morris, 1985). This means that the spine undergoes a compressive load with each heel-strike and toe-off, somewhere between 1 and 3 times bodyweight. If we take an average 70 kg adult male, who has sat at a desk for many years with a flat-backed (hypolordotic) posture and look at how this 70 kg load may affect his lumbo-pelvic integrity, we find that multiplying the steps taken on an average day (10,000) by his bodyweight (70 kg) which may be further multiplied by between 1 and 3 times due to the compressive penalty of the up and down sine-wave motion of gait, we reach a total of somewhere between

$$10,000 \times 70\,\text{kg} = 700,000\,\text{kg} \times 1 = 700,000\,\text{kg}$$

...and...

$$10,000 \times 70\,\text{kg} = 700,000\,\text{kg} \times 3 = 2,100,000\,\text{kg}$$

Clearly, this is a lot of loading, but let us not forget that this is only the walking. If we were to take the kind of person that may be engaging in the activities prescribed by Liebenson in this section and issue of JBMT, then with each step they take, as a runner, they will be loading between 3 and 7 times bodyweight through their spine with each step (Lees, 1999). If this person also plays sports, or lifts children, or has a manual job, the loading will be multiplied dramatically again. Importantly, these are the kinds of loads that a spine must handle *per day*. If we want to look at the same loading across longer periods of time — just based on the lower figure of 700,000 kg, which is only based on the walking loads put through the spine, we can see some startlingly large figures begin to emerge.

$$700,000\,\text{kg} \times 7\,\text{days} = 4,900,000\,\text{kg}$$

$$700,000\,\text{kg} \times 31\,\text{days} = 217,000,000\,\text{kg}$$

$$700,000\,\text{kg} \times 365\,\text{days} = 2.555^8\,\text{kg}$$

$$700,000\,\text{kg} \times 10\,\text{years} = 2.555^9\,\text{kg}$$

Suddenly, from being impressed at the immense strength of the discs, ligaments and other tissues of the body, it becomes painfully clear why slight aberrations in posture which create greater loading through one of the weight-bearing structures (in this scenario, the posterior disc), can result in dramatic weakening and diminished tensile strength leaving the disc exposed to injury from a simple low load activity, like picking up a pencil.

Weight bearing in the spine

To revisit Bogduk's (2005) synopsis of weight bearing through the spine, we can look at how the assumption that weight bearing occurring through the ''tripod mechanism of the spine'' proposed by Kapandji (1974) and others, may be incorrect. Bogduk (2005) described earlier research in which load sharing was suggested to fall around a 60:20:20 ratio (disc to facet left to facet right) in the tripod mechanism. However, Bogduk's conclusion based on the most current available evidence was that, in fact, the disc may be the only weight-bearing structure; the facets remaining completely uninvolved.

What ramifications does this have for our flat-backed office worker? It would, at first glance, appear to indicate that he is ''back to square one''. If the disc is the only weight-bearing structure and the disc has ruptured, when he bent to pick up a pencil, then may be it was simply ''meant to be''... perhaps a genetic aberration?

However, even if the posterior column (the two zygapophyseal joints) does not take responsibility for axial loading, then loading through the anterior column (discs and vertebral bodies) that is more anterior than the centre of balance of the disc (i.e. spinal flexion) will always cause posterior migration of the nucleus; thereby creating sustained tensile loading to the weaker postero-lateral aspects of the disc.

Bogduk (2005) explains that the facet joint orientation, being in the sagittal plane in the lumbar spine, does not allow for weight bearing through these structures. However, it is worth noting that the L4—5 and, in particular, the L5—S1 facets — the levels of the spine which account for somewhere in the region of 97% of all spinal injuries (McKenzie, 2003) — are commonly orientated in a position to allow weight bearing. Additionally, hydrostatic pressures within the joint may account for some of the loading the posterior columns can bear without direct weight-bearing contact of the joint surfaces themselves.

Bogduk (2005) goes on to qualify his assertion of 100% weight bearing through the disc by stating that for the facet joints to participate in weight bearing, an aberration in their orientation must occur. A clinical example of just such an aberration may be the lower crossed syndrome — or, put another way, a spine that is held in sagittal extension and therefore is *out of neutral*.

One further consideration is that Bogduk's discussion is based on assessment of a static upright spine, however, as discussed above, Gracovetsky shows, in simple everyday tasks, such as walking, the spine naturally migrates between rotated and laterally flexed positions as well as axially flexing on the heel-strike (resulting in sagittal extension) and axially extending during mid-stance (resulting in sagittal flexion) (Figure 4).

In summary, the disc may take 100% of the load under normal static upright, neutral spine conditions. However, if the spine moves into sagittal flexion (a hypolordotic spine), the loading in the posterior disc will increase and reciprocally, if the loading moves into sagittal extension (a hyperlordotic spine) the loading through the facet joints will increase.

Hence, the point of balance is where the load on the disc passes directly through the centre of the nucleus pulposus; which means, like sitting on a Swiss ball, the hypothetical neutral spinal position is rarely achieved, achievable, nor maintained in activities of daily living; instead the neutral spine should be viewed as a conceptual axis about which the spine functions most optimally.

Counter arguments to the neutral spine principle

There is a current paucity of high-quality research to provide support for the neutral spine principle. Christensen and Hartvigsen (2008), for example, performed a systematic critical review of published papers detailing associations between spinal curves and health.

The findings of the review were that evidence from epidemiological studies does not support an association between sagittal spinal curves and health, including spinal pain.

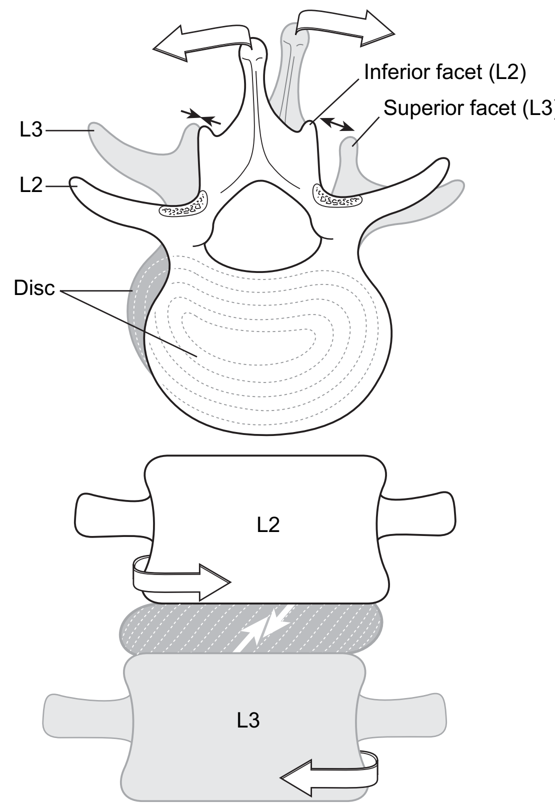

Figure 4 As the superior vertebra (in this case L2) moves into left rotation on the vertebra below (L3) the viscoelastic annular fibers of the disc undergo elastic elongation; storing energy which will recoil with the next step of gait. Similarly, the right inferior facet of L2 will approximate, compressing the joint cartilage against the joint cartilage of the right superior facet of L3. This compression will also recoil with the next step of gait, providing a highly efficient means of locomoting in a gravitational field. If speed development is a goal, as in Liebenson's accompanying article, then spinal neutral must also be a goal.

In very much the same way that a similar epidemiological paper produced by Ross et al., in 2007 stated that there was no connection between sitting and back pain, a paper which essentially suggests no connection between posture and back pain feels intuitively wrong.

Should one analyse further to see if the intuition is correct? Or simply accept that the figures stack up and therefore accept the epidemiologist's conclusion?

Of course, the answer is a matter of personal preference. Nevertheless, common sense would seem to suggest that if something doesn't ''feel'' right, it may demand further examination.

Negentropic, homeostatic mechanisms and adaptive capacity

Living systems exhibit a negentropic capacity to maintain some level of homeostatic balance. When there is a stressor to that system, depending on the intensity and volume of stress, the system will seek adaptive measures to allow continued function without its own breakdown or demise (Sole and Goodwin, 2000).

A healthy or stable system typically has greater adaptive capacity than a system that has been under high volumes of stress (cumulative or otherwise), or that experiences a sudden high intensity of stress (Wallden, 2008).

The SAID Principle (specific adaptation to imposed demands) suggests that a living system will adapt to the specific demands imposed upon it. For example, someone who trains in the gym, or who runs long distances, will note adaptations in their body that are specific to the demands they are imposing upon it (Baechle and Earle, 2000).

However, if the expected adaptations are not forthcoming, or if injury and pain occur as a result, then the system has reached its adaptive limit and is now ''maladapting'' or has reached the exhaustion phase in Selye's stressor model (Selye, 1978).

This same mechanism occurs in the spine when it is kept too flexed (as in our example above) or too extended, for too long. Initially there will be adaptation to help the system to cope with prolonged sitting postures, for example, but ultimately that adaptation may reach a point when the capacity to further adapt has been exhausted and the structures under load (the posterior annulus and posterior ligamentous system in this instance) will collapse.

Determining a patient's level of adaptive capacity

With this understanding, as a consulting therapist or movement specialist, it would next be most useful to have a knowledge of where our patients' systems are at in terms of adaptive capacity.

With respect to the neutral spine principle, a simple, non-invasive, means of assessing the spinal position is to use inclinometry (Ng et al., 2001; Saur et al., 1996). When we measure spinal curvature, we can gain an insight into how the patient habitually adopts their own unique ''neutral position'' and what this may mean in terms of loading to different structures in and around the spine. This, then, allows us a general view as to what the current spinal curvature is versus the optimal spinal curvature.

According to Chek (2001) and Schafer (1987), the optimal spinal curvatures have been mathematically calculated to fall between 30° and 35° for the lumbar lordosis, the same for the thoracic kyphosis and the same for the cervical lordosis. Other references, suggest that the figures may be different, but this may be due to differing measurement techniques, and looking for normality rather than for functionality or for ''optimum''.

For example, clinically it is common to find that the lumbar curve is flattened. A brief analysis of patients to recently attend our clinic ($n = 28$) shows that 82% of them had a lumbar curve that was flatter than the reference range (<30°), 14% of them were within the reference range (30°–35°) and only 3.5% were above the reference range (>35°).

In this instance we would expect that 82% would have increased loading into the anterior pillar of the spine (the discs) and would therefore be more prone to posterior disc bulge or to other posterior myoligamentous strain, based on the neutral spine principle. Fourteen percent might be expected to have more optimal loading through the spine, while 3.5% would be expected to have greater compressive loading through the posterior elements, the facet joints.

These clinical findings, then, would correlate well with the finding by Boos et al. (1995) that somewhere between 76% and 96% of people have posterior disc bulges when assessed using MRI.

In fact, Boos et al. (1995) found that not only was there a 96% percent level of disc bulge in those who had symptoms of disc injury, but that those without any history or back pain and who were totally asymptomatic had a 76% incidence of posterior disc bulge on MRI scan too.

This is a classic example where a lack of insight may result in 'normal' being mistaken for 'functional' or even for 'optimal'. The norm is that at least three quarters of people (even without any history of back pain) will have a disc bulge when scanned, yet is this functional? Clearly not. It may be a 'functional compensation', but it is not nearly as functional as a healthy intact disc; which would be optimal.

In a similar way, it is 'normal' for people to have flat backs, but this does not make it functional (other than as a compensation), and certainly does not make it optimal – especially in view of the loads the spine must bear (described above).

When assessing the spinal function of people from industrialized nations, then, the progression will tend to look like this:

Dysfunctional → Functional with compensation →
Functional without compensation → Optimal

The norm (or the modal distribution) will fall toward the left hand side of the progression. Our objective as movement therapists is surely to not only treat dysfunction, or to assist with compensation – nor even just to return patients to optimal, but to prevent them from slipping toward the left; avoiding dysfunction and optimizing function without compromise.

Conditioning in the neutral spine

Many of the leading rehabilitation specialists utilize the neutral spine principle in their rehabilitation protocols. Lee (2004), for example, states that attempting to teach exercises that isolate the local muscles, such as transversus abdominis or deep multifidus, without first teaching the patient to maintain a neutral spinal position can lead to frustration and disappointment for the therapist and patient.

One reason for this is that the spinal posture in which the transversus activity is greatest is the neutral spinal position (Richardson et al., 1999, 2004; Lee, 2004). Other reasons include those discussed above with respect to load sharing.

Comerford and Mottram (2001) also favor use of neutral spinal position in their motor control re-education, as does McGill (2002, 2007) stating ''it appears that the safest and mechanically justifiable approach to enhancing lumbar stability through exercise entails a philosophical approach… that ensures a neutral spine posture when under load…'' (McGill, 2007).

Chek (2001) also utilizes a neutral spine principle in his rehabilitation programs and, importantly, discusses the relevance of this to motor learning when performing more functional movement patterns and those which place the spine under higher loading, which may be e-concentric, ballistic, perturbatory or plyometric in nature.

On this same note, McGill (2007) suggests that whereas steady-state motor patterns are important for daily activity, the health of reflexive motor patterns is critical for maintaining stability during sudden events.

Making a mummified meal of things

One objective of the neutral spine principle, which is oft-overlooked is to provide a platform from which, or as suggested above an ''axis around which'', movement can effectively occur.

Too frequently, the mix of training neutral spine philosophies at back school, to those who are highly suggestible due to pain behavior, results in a virtual mummification of the spine and a robotic appearance to movements.

In the long term, this is neither helpful, nor functional — especially where a return to sports or to activities of daily living is sought. A spine held in its neutral position by overactive local and global muscles will result in increased compressive loads, increased waste metabolite production, decreased venous and lymphatic drainage and an entire cascade of events following from there including compromised repair and trigger point development to name a few.

Strengthening your position

Nevertheless, the neutral spine principle is more than just teaching the patient ''where'' a neutral position is, it is about training the patient to be strong in the neutral spinal position. This is important as the body will always migrate toward its position of strength.

Being strong in the neutral spinal position requires training and not just holding a position against gravity, but holding a position against external loads, such as dumbbells, barbells, kettlebells, medicine balls, cables or any other kinds of effective resistance training device.

Why is this so? First and foremost, to create an adaptive response in the strength fibers of any given muscle requires a certain intensity of load. In strength conditioning, it is now well documented that moving a load that one can take through the desired range of motion between 8 and 12 times before fatigue (what would be termed an ''8—12 rep max'' load) will optimize strength gains and hypertrophy responses within the muscle (Chek, 1996; Poliquin, 2006; Baechle and Earle, 2000).

The question is, do we want strength gains in the muscle, or just better control? McGill (2007) suggests that having a stronger back has no prophylactic value. However, the reference cited in this instance only assessed back strength as a potential contributing back pain variable, irrespective of the position of strength. If someone is immensely strong, but in a flat (hypolordotic) spinal position, they are at just as much, if not more, risk of disc injury as the next person who has a weak and flat lumbar spine.

However, if strength is built in the neutral spine position, then length—tension relationships are optimized through the trunk because the muscles about the trunk become strongest in their mid-range as opposed to their inner-range on one side of the spine and their outer-range on the other side of the spine. The end result of optimal length—tension relationships in the spine includes greater capacity to generate force, lower levels of shear forces and optimization of length—tension relationships at proximal appendicular joints; which will almost invariably be passed on through the limb to the periphery. In the neutral spine posture transversus abdominis activation is optimized and, importantly, outer unit dominance patterns, such as rectus abdominis dominance, hamstring dominance, upper trapezius dominance and external oblique dominance are all-but nullified.

As Richardson et al. (2004) state, when the spinal curves are maintained, this is the most energy efficient position for the body to stay upright against forces of gravity and other extrinsic forces it may encounter.

But back to the question of strength training in this neutral spine position, how can it be of benefit? Sahrmann (2002) shows that when there is a laying down of sarcomeres in parallel and/or a hypertrophy of muscle fibers due to training effects, so the number and size of series elastic components also increase. Series elastic components act much like a coiled spring; hence, the more of them there are, and the bigger the spring, the more resistance that muscle has to stretch. The implications of this are discussed below.

A further benefit of hypertrophy training is that when there is an increase in muscle fibre size and/or number (hyperplasia) the hydraulic amplifier mechanism of the spine is enhanced; meaning that the intracompartmental pressures with the posterior compartment of the thoracolumbar fascia will be increased creating an increased rigidity to the spine; minimizing risk of being caught ''off guard''. We would do well to remember also that some of the original research into the role of multifidus in low back pain demonstrated that within 24 hours of the onset of pain, the cross-sectional diameter of the lumbar multifidus had dropped to 69% ($\pm$8%) of its original diameter (Richardson et al., 2004). This dramatic change cannot be attributed to atrophy, but only to inhibition of the muscle, reducing resting tone and hence resting cross-sectional area. This just highlights the importance and relevance of good resting tone and the hydrostatic function even of ''resting'' muscle in spinal stability.

What this means is that by inducing a hypertrophy response we have the benefits of increased strength when called upon, increased resting cross-sectional diameter enhancing the hydraulic amplifier mechanism, increased size and/or number of series elastic components resisting stretch and, hence, we have built for ourselves a significant contribution to the ''passive'' stability of the lumbar spine, by working with the ''active'' component of the joint stability subsystem.

So, much the same as when McGill (2007) suggests: *the health of reflexive motor patterns is critical for maintaining stability during sudden events*, perhaps even more significantly, the passive subsystem offers protection and biofeedback *sooner* than the active subsystem can reflexively activate. As we've discussed above, when the active

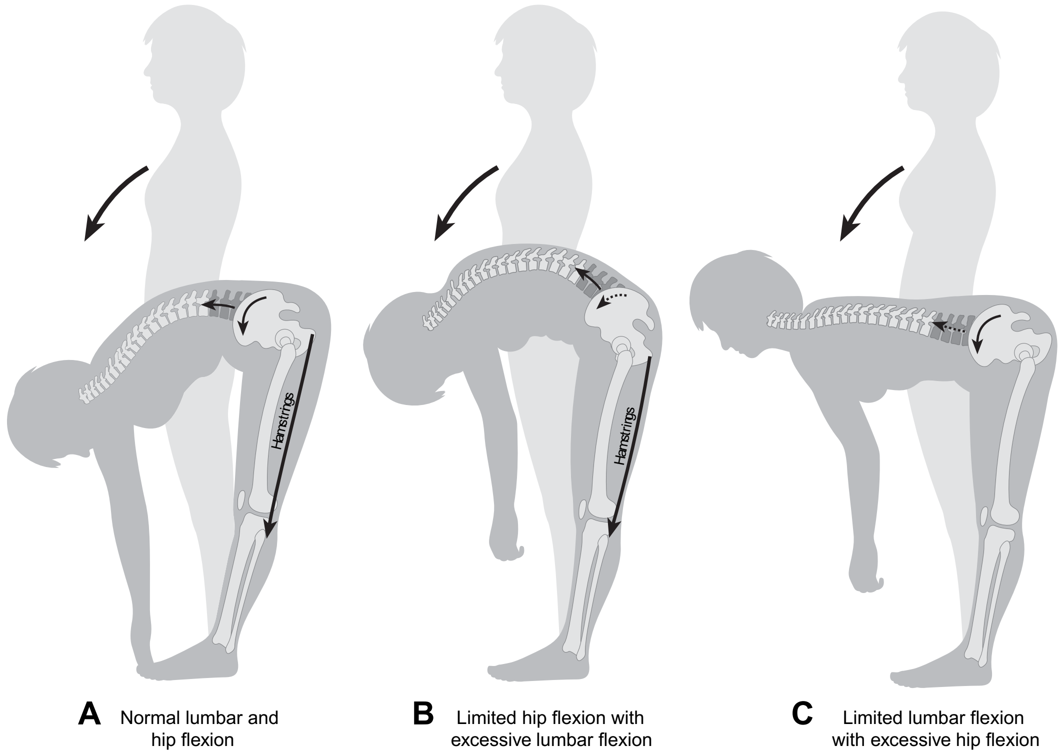

Figure 5 During functional activities, such as gait, there are stretch—shortening cycles through the annulus of the disc and facet joint capsules, and compression—recoil cycles through the cartilage on the facet joint surfaces. Increased loading anteriorly or posteriorly may have profound consequences across a period of time.

system is in a functionally hypertrophied state, it will contribute significantly to this protective passive subsystem effect; something that can be achieved relatively rapidly, especially in comparison to the 300—500 days to heal and adapt often quoted for the connective tissue or the passive subsystem classically described Chek (2001).

Load sharing and load transfer

So, we have discussed load sharing between facets and discs, or between connective tissues and muscles, and to a degree how that load may be transferred up through the tripod mechanism of the spine, however we haven't discussed how this might be applied to lifting.

There is much controversy over how to effectively and safely lift an object; and this may be for the reason that the way to effectively lift an object may, in fact, be completely the opposite of how to safely lift it!

Gracovetsky (1988), for example, has demonstrated conclusively that the most effective way to lift a heavy object is to use a flexed lumbar position, while the likes of McGill (2002, 2007) and Chek (2001) recommend maintaining a neutral spinal position in lifting. Why is there such a discrepancy? And who is correct?

Probably the truth is that both are correct and here's why: Gracovetsky's argument is that in order to even lift the loads that they do, Olympic lifters must utilize both the leg muscles and the lumbar erectors to get the load off the ground.

Gracovetsky (1988) calculated that the lumbar erectors themselves do not have the strength to be able to lift the kinds of loads that Olympic lifters lift. Hence, to get these heavy loads off the ground the most refined and elite lifters in the world utilize the legs and allow their lumbar spines to go into kyphosis in order that the thoracolumbar fascia is an effective force transducer from legs to trunk. If the spine is left in neutral, then the thoracolumbar fascia remains on slack, the force from the legs cannot be effectively transferred into the trunk and the lift is ineffective at best, dangerous at worst. This sounds like a water-tight case.

However, one problem with taking this view is that just because the elite lifters do this, does not mean it's the safest way to lift for the rest of the population. Since only a fraction of people ever make it to an Olympic games for the sport of Olympic lifting, they are not likely to be representative of the general population who do not reach that level of sporting attainment. Additionally, the likelihood is that anyone who makes an Olympic games has a very functional spine; perhaps even an optimal spine. For every person to reach this level of achievement there will be many more who ended up in casualty or on the surgeon's table with ruptured lumbar discs.

What we first must ask is "how many of the people we work with are likely to have a posterior disc bulge?" The answer, of course, is somewhere between 76% and 96% according to Boos et al. (1995). Therefore, is it preferable to teach an "effective" lifting style (with lumbar flexion which will likely rupture the disc) or a "safe" lifting style (maintaining neutral) which will minimize anterior loading of the disc and therefore posterior migration of the nucleus? The answer, I hope, is obvious.

Table 1

Finding	Corrective mobilization	Corrective stretch	Corrective exercises
Thoracic curve increased general	Foam roller longitudinal/ transverse	Swiss ball rectus abdominis stretch	Prone cobra
Thoracic curve decreased general	—	Prone Swiss ball hang stretch	Crunch, breathing squat
Lumbar curve increased in general	Foam roller longitudinal with hip flexion	Knee-hug stretch	Lower abdominals, forward ball roll, supine hip extension
Lumbar curve decreased in general	Foam roller longitudinal with noodle (placed deep to umbilicus), McKenzie extension push-up	Swiss ball rectus abdominis stretch	Prone jack-knife, alternating superman, prone trunk and hip extension
Inclinometry angle increased at CT (kyphotic)	Foam roller longitudinal/transverse, Lewit CT mobilization	Rectus abdominis stretch of Swiss ball	Breathing prone cobra, The fish, Prone cobra decompression, front squat
Inclinometry angle decrease at CT (flat)	—	Prone Swiss ball hang stretch	Crunch, Horse stance dynamic
Inclinometry angle decreased at TL (flat)	Foam roller longitudinal with noodle (placed toward TL)	Preacher stretch, McKenzie extension push-up (with towel taut over TL)	Prone cobra, prone trunk extension (Roman chair/Swiss ball)
Inclinometry angle increased at TL (kypho-lordotic)	—	Oblique abdominal stretch over Swiss ball, Iliopsoas stretch, knee-hug stretch (pelvis off ground)	Oblique crunch, breathing squat, Forward ball roll, any exercise with neutral spine
Inclinometry angle decreased at LS (flat)	Foam roller longitudinal with noodle (placed toward LS)	McKenzie extension push-up (with towel taut over LS)	Prone hip extension, prone pelvic tilt
Lumbar curve increased at LS (lordotic)	—	Knee-hug stretch pelvis on ground	Prone jack-knife, lower abdominal series (dead-bug)

Note: All of the exercises described above will help to move the spine in the correct direction, based on the neutral spine principle, but *any* exercise done in a neutral spine position will do the same.

To supplement further, the question over whether or not to progress the neutral spine technique beyond the rehabilitation setting and into performance conditioning is another hotly debated topic.

Again, Gracovetsky's (1988) description seems conclusive; especially when one considers that it is at around 45° of trunk flexion or 90% of lumbar flexion — just as the posterior ligamentous system is beginning to undergo significant stretch stimulation, that the lumbar erectors are reflexively inhibited by the nervous system to minimize compressive penalty through the spine and the body switches to the hip extensor mechanism (and the ligamentous tension generated by the hamstrings, through the sacrotuberous ligament into the deep lamina of the posterior layer of the thoracolumbar fascia and gluteus maximus, via the superficial lamina of the posterior layer of the thoracolumbar fascia) in conjunction with the hoop tension generated by the transversus abdominis (via the middle layer of the thoracolumbar fascia) to stabilize the lumbo-pelvic region.

However, this again, depends on how confident the trainer, coach or therapist is that the patient falls in the 4–24% of people who do not have a pre-existing disc bulge. In addition, the experienced strength and conditioning coach will be aware that muscles are around 1.2 times stronger during an eccentric contraction than in a concentric contraction. Taking into account both safety and effectiveness, it would seem then to make sense, at the very least to start the lift from a neutral spinal position; ensuring a centralized nucleus at the beginning of the lift. As the lifter engages the weight and begins to lift it, it may indeed be that the load is too much for the lumbar erectors to overcome (as calculated by Gracovetsky, 1988), however, if those lumbar erectors are already engaged in an isometric contraction and in a neutral spinal position, they will contract eccentrically as the spine

Figure 6 Foam roller longitudinal with lumbar noodle. Use of a longitudinal foam roller aids in creating creep to the anterior longitudinal ligament for those with increased thoracic kyphosis and the posterior ligamentous system for those with increased lumbar lordosis. The addition of a 2-inch noodle, deep to the umbilicus, is useful for those with a flattened lordosis to create creep in the anterior longitudinal ligament in the lumbar spine.

Figure 8 Swiss ball rectus abdominis. This is an important stretch for most people as the rectus is so commonly dominant in back pain populations and in those with upper crossed syndromes. A tight rectus abdominis will increase the first rib angle and the flexion at the CT junction.

is drawn into flexion; the strongest way they're able to work.

Ultimately, this second version of lifting technique would seem to realize both the requirements for minimizing unnecessary stresses through the disc, while activating the lumbar erectors in their most effective contractile state, and utilizing the thoracolumbar fascia mechanism by default if required (Figure 5).

One further lifting consideration which is important to ascertain is the lift duration. As Gracovetsky (2008) explains, the collagen found in the connective tissues of the spine will undergo an initial creep effect in around 0.33 seconds. Therefore if the lift is an explosive Olympic lift, the connective tissues may be effective in stabilizing the spine for its duration. However, if the lift is carried out at a slower tempo, or repetitively (as is often the case in strength and conditioning programs), taking a neutral spine strategy makes a lot more sense.

Therapeutic considerations

If the neutral spine principle is to be adopted in practice, despite some evidence questioning its value, then it is important to have tools to both measure the patient's start point, and to measure the efficacy of any interventions made.

For the pain patient, utilization of pain scales may be one measure that is of practical use to screen for progress. However, as Liebenson (1999) points out, it may not be useful in the longer term to focus the patient on their pain — even if this is what they would like to focus on in the first instance. Additionally, of course, patients who we work with that are not in pain, or perhaps do not have back pain will need a different way of measuring progress.

Instead, a focus on moving the individual toward optimal function is of great psychological and motivational benefit. This strategy can then be applied to groups who are in pain and those who are looking to optimize performance, or both.

Figure 7 Prone cobra. The prone cobra is useful for increasing load on the thoracolumbar extensors specifically, and the scapula retractors.

Figure 9 Forward ball roll. This exercise, reviewed in the paper presented in this section [Duncan M. (2009) Muscle activity of the upper and lower rectus abdominis during exercises performed on and off the Swiss ball], is ideal for activating the abdominal wall, with a bias toward the upper abdominals. If a neutral spine is maintained it will aid correcting any muscle imbalance about the pelvis.

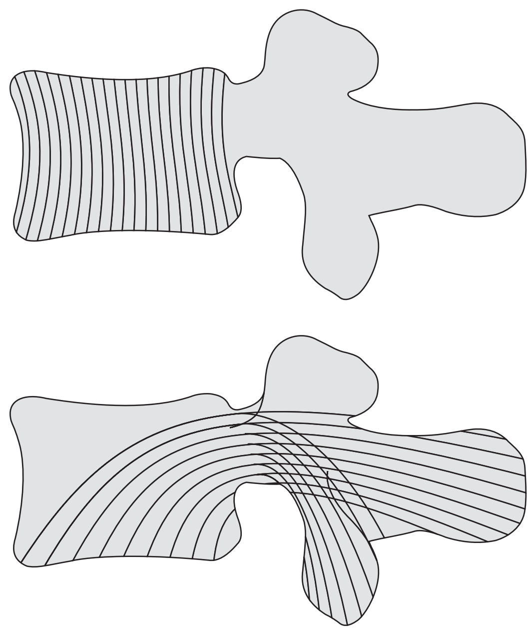

Figure 10 Since the trabeculae are known to form along the lines of stress, they reveal the function of the tissues and identify the facets as load-bearing structures; whether this load is axial, rotary or a combination of multiple vectors. An extended spine will always increase loading in the facet joints.

Spinal inclinometry

Spinal inclinometry is probably the most accessible and non-invasive method of assessing spinal posture, and it offers clinically useful gauge in terms of intra-rater reliability (Saur et al., 1996; Ng et al., 2001).

Based on the figures discussed above, we would be looking to measure angle of inclination at the lumbo-sacral junction, the thoracolumbar junction and the cervico-thoracic junction. (Measurement with inclinometers is of little value at the occipital-atlantal joint, so is not usually performed at this level.)

To calculate the total lumbar curve, the scores from the lumbo-sacral junction and the thoracolumbar junction should be added together. This curve should equal between 30° and 35°.

To calculate the total thoracic curve, the scores from the thoracolumbar junction and the cervico-thoracic junction should be added together. This curve should also equal between 30° and 35°.

Since we are looking for uniformity of the spinal curves, we want to see approximately half of the total (30°–35°) at each of the junctional areas, i.e. each should measure between 15° and 17.5°. Anything above this score indicates an increased curvature at that point in the spine (and a greater compressive loading of the posterior elements) and anything below this score indicates a flattening of the curve at that point (and a greater compressive loading of the anterior elements).

Table 1 shows the potential findings and potential ''fixes'' in the guise of corrective stretches mobilizations or exercises (Figures 6–9).

When these interventions have been put in place, progress may be monitored at certain fixed points across a rehabilitation or conditioning program to enhance motivation and to ensure effective interventions that have been deployed – and, indeed, that they haven't been ''too'' effective and over-corrected the imbalance originally measured.

Conclusion

Though there may still be an excess of philosophy and paucity of high-quality research surrounding the neutral spine principle in its relation to gait, to lifting and to other activities of daily living, clinical experience suggests that it is a very useful clinical management tool.

Despite the fact that much of spinal gravitational loading will go through the disc, it is clear from simply observing the trabecular formation of the facets that they are designed to take some significant loads; which can only be increased in relative extension and decreased in relative flexion of the spine (Figure 10).

While Christensen and Hartvigsen's (2008) study struggled to find a correlation between sagittal spinal curves and spinal health, it did not and could not control for all of the other factors which may determine whether or not an aberrant spinal posture may result in pain; from nutritional status, to hydration levels, to immune status, to adrenal function, to blood sugar regulation, to gut permeability, to sleep–wake cycles, and so on and so on; all factors that may either impair rate or optimize it.

Those who have a poor capacity to heal, for whatever reasons, are those most likely to breakdown when sagittal curves are disrupted, while those who have a good capacity to heal (or to compensate) are most likely to survive an aberrant posture. Nevertheless, any aberration in posture, or in motor control will ultimately result in greater accumulation of stress in the system than an optimal posture.

If we can assume that optimal posture is both measurable and achievable, then the only question remaining is ''Is it desirable?''

That is a personal question, and one which only you and your patient can answer together.

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