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# Lumbar posture biomechanics and its influence on the functional anatomy of the erector spinae and multifidus

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Background: Lumbar posture has a significant impact on the functional biomechanics of the erector spinae and multifidus muscles, which has implications for the loads placed on the tissues of the lumbar spine.
Objectives: The objective of this review is to discuss the effects of lumbar posture on the functional biomechanics of the different divisions of the erector spinae and the multifidus muscle and its importance when developing clinical interventions.
Methods: This review used the search engines PubMed, EBSCO, CINAHL and SCOPUS to identify studies investigating erector spinae and multifidus muscle architecture and the influence of lumbar posture on the biomechanical properties of these muscles and the resulting impact on spinal loading.
Results: Changes in lumbar curvature alter muscle fascicle obliquity, lever arm distances, the length–tension relationships and muscle volume of the different divisions of erector spinae and multifidus, which impact on the spine's ability to resist moments and shear forces.
Conclusion: Changes in lumbar posture influence the functional biomechanics of the different divisions of erector spinae and the multifidus muscles. Therapists should develop low back interventions that avoid end range of lumbar postures and optimise the functional biomechanics of the erector spinae and multifidus muscles and minimise loading on the lumbar spine.

**Keywords:** Erector spinae, Multifidus, Lumbar spine, Posture, Spinal loading, Biomechanics

## Introduction

The erector spinae and multifidus muscles are thought to play an important role in the prevention of back injuries, and these muscles are often targetted during the rehabilitation of patients with such injuries. For example, during vocational activities such as lifting, the erector spinae and multifidus muscles are the major contributors to the extensor moment (EM) and serve to resist anterior shear forces acting on the lumbar spine.[1] In sports activities, such as rowing, these muscles work between 50 and 80% of their maximum during the drive phase of the stroke, an action often repeated up to 1800 times during a training session.[2,3]

A number of low back intervention programmes have been developed to improve the strength and function of the erector spinae and multifidus muscles. However, a limitation often associated with these programmes is that they assume the erector spinae to be a single muscle that extends the length of the lumbar spine and ignore the biomechanical role played by the different divisions of the erector spinae and the multifidus muscle.[4,5]

The posture adopted by the lumbar spine during activities of daily living and in the rehabilitation of back pain patients influences the risk of injury and effective treatment. Changes in lumbar curvature alter erector spinae and multifidus fascicle obliquity, lever arm distances, the length–tension relationships and muscle volume,[6–9] impacting on the spine's ability to resist moments and shear forces.[6,8]

Epidemiological evidence suggests a strong association between low back injury and occupations involving manual handling and sports activities where individuals adopt extreme trunk flexion.[3,10,11] As lumbar flexion increases, ligamentous and anterior shear forces on the lumbar spine increase.[1,12–14] In contrast, those activities that place the lumbar spine at end range of lumbar extension often lead to high compressive forces and excessive loading on apophyseal joints, pars interarticularis and posterior intervertebral disc.[15,16]

Understanding the influence of lumbar curvature on erector spinae muscle architecture and its role in

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controlling bending moments and forces on the spine is necessary when developing effective low back injury prevention and rehabilitation programmes. Thus, the purpose of this review is to discuss the effects of lumbar posture on the functional biomechanics of the erector spinae and the multifidus muscle, and its importance when developing clinical interventions. The review is restricted to a discussion of movements in the sagittal plane, as this is where the largest body of evidence lies.

## Methods

Four electronic databases (PubMed, CINAHL, EBSCO Megafile Premier and SCOPUS) were used to identify studies investigating erector spinae and multifidus muscle architecture and the influence of lumbar posture on the biomechanical properties of these muscles and spinal loading. Individual and group data gathered from previous studies[2,17] were also used to illustrate the functional biomechanics of the erector spinae and multifidus muscles.

## Why is Lumbar Posture So Important?

A number of daily activities involve trunk flexion. The degree of lumbar flexion during these activities not only influences the bending moment on the spine but also the structural characteristics of the spine and its vulnerability to injury. For example, biomechanical studies suggest that during the final 20% of lumbar flexion, there is an exponential increase in the recruitment of spinal passive tissues (e.g. posterior ligamentous system).[18,19] This recruitment of passive tissue not only heightens the risk of injury to these structures but also leads to changes in the anterior obliquity of the fibres of the supraspinous ligament leading to increased anterior shear forces.[1,14] Furthermore, anterior rotation of the vertebrae towards end range of lumbar flexion increases lumbar disc loading.[1,12–14] Bending moments between 60 and 120 N m have been shown to cause damage to the ligaments of the spine and anterior shear forces between 700 and 1000 N are considered hazardous to the spine.[15,20–22] The National Institute of Occupational Safety and Health (NIOSH) suggests a compressive force ‘action limit’ of 3400 N and a ‘maximum permissible limit’ of 6400 N for the prevention of low back injury.[23]

It would also appear that sustained or repeated trunk flexion increases the potential failure tolerance of spinal structures and the likelihood of low back injury. Gallagher *et al.* showed that the probability of failure of the lumbar vertebra increased significantly if the lumbar spine is repeatedly loaded at end range flexion.[24] Biomechanical studies that have repeatedly loaded the spine to end range of lumbar flexion have also shown an attenuation of the erector spinae muscle responses, and an increase in spinal ligament and intervertebral disc creep.[12,25–27] Furthermore, Solomonow *et al.* showed in animal studies that it took several hours of rest for the multifidus muscle to recover following 50 minutes of repetitive cyclic loading.[26,27]

## Functional Anatomy and Biomechanics of the Erector Spinae and Multifidus Muscles

The erector spinae and multifidus muscles are the primary muscle groups responsible for controlling lumbar motion and forward inclination of the trunk. It is estimated that the erector spinae and multifidus contribute up to 85–95% of EM during manual handling tasks, with these muscles playing an important role in resisting anterior shear forces during lifting and lowering.[1] Detailed anatomical studies suggest that the erector spinae is not one continuous muscle but consist of a thoracic (longissimus thoracis pars thoracis and iliocostalis lumborum pars thoracis) and a lumbar (longissimus thoracis pars lumborum and iliocostalis lumborum pars lumborum) division.[28,29] Each division of the erector spinae has distinct geometry in relation to the lumbar spine, which is influenced by changes in lumbar posture.[28,29]

The upper erector spinae consist of the thoracic fibres of longissimus and iliocostalis lumborum. Its muscle fascicles arise from the thoracic transverse processes and lower seven ribs and span the entire lumbar spine forming the erector spinae aponeurosis.[30] The erector spinae aponeurosis has no direct attachment to the lumbar vertebrae[31] and connects to the posterior pelvis and sacrum.[30] In upright standing, the upper erector spinae has the greatest moment arm of all the lumbar extensors muscles,[8,32] which allows it to generate a large EM at a relatively low compressive cost.[30,33] As the upper erector spinae fibres run almost parallel to the long axis of the lumbar spine, they have limited influence on shear forces.[1,4,29]

The lower erector spinae consist of the lumbar fascicles of longissimus thoracis and iliocostalis lumborum.[29] The lower erector spinae has two distinct architectural differences that differentiate it from the upper erector spinae. First, it connects to the lumbar vertebra and this enables the fascicles to directly exert forces on the vertebrae to which they attach. Second, the lower erector spinae are more obliquely orientated than the upper erector spinae and therefore are better suited to generating forces that oppose anterior shear.[1,29] Lower erector spinae obliquity is more pronounced at the level of L4 and L5, and in this region the fascicles of the muscle are capable of generating 40–49% of their total resultant force in the posterior direction.[29]

Acting at a segmental level, the multifidus muscle is another key muscle in the lumbar region.[34,35]

The multifidus consists of multiple overlapping layers of fibres that can be clearly divided into five bands.[35,36] Each fascicle arises from a common tendon attached to the spinous process of individual lumbar vertebrae with fascicles attaching to the mamillary process of the inferior vertebrae, the iliac crest and the sacrum.[28] Fascicles of multifidus arise from a common tendon and create a force vector that acts vertical and perpendicular to the spinous process (see Fig. 2A). This orientation and the segmental innervation of fibre bands[35] not only allows the multifidus to control lumbar curvature at a segmental level but provides good mechanical advantage when applying an anti-flexion (extension) moment.[28,34,37]

The multifidus exerts a relative small horizontal force vector when compared to the lower erector spinae and the obliquity of its fascicles varies between segments. However, the net effect of its fascicle arrangement in upright standing is to produce anterior shear on the L5–S1 segment.[4] The multifidus has twice the physiological cross-sectional area of other erector spinae muscles, despite having a similar mass. This relatively large cross-sectional area, in combination with its short fibre length, enable the multifidus to produce large forces over a short range of motion.[38] These properties make the multifidus better suited to intersegmental stabilisation, as opposed to generating large amounts of lumbar motion.[38]

## Fibre Type of the Erector Spinae and Multifidus

Although there are distinctive morphological differences between the divisions of erector spinae, fibre type distribution would indicate that all divisions of the muscle are designed for endurance.[39] Fig. 1 illustrates the percentage of type I fibres of the erector spinae and multifidus muscles reported in studies involving people with no known history of low back pain.[39–42]

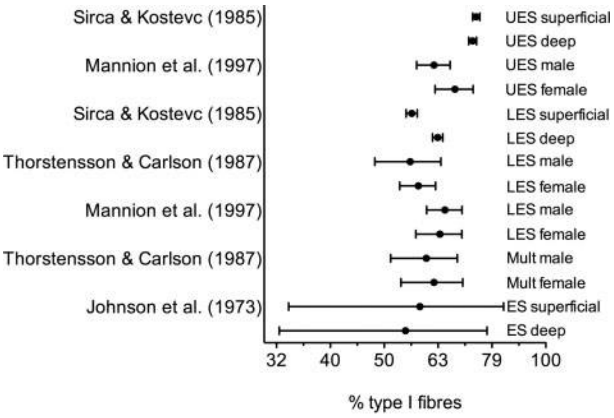

**Figure 1 Studies reporting the percentage of type I fibres (mean and confidence intervals) of the upper erector spinae (UES), lower erector spinae (LES) and multifidus (MULT) muscles in subjects with no history of low back pain.**

The erector spinae muscle group has a large percentage of type I fibres, the percentage being larger in females than in males (see Fig. 1).[39–43] Although it is commonly assumed that the deep multifidus fibres are more suited to tonic activity than the more superficial erector spinae muscles, all fibres of multifidus and erector spinae display a similar endurance fibre composition.[42–44] Morphological differences do exist between the upper and lower erector spinae, with both type I and II muscle fibres being up to 30% larger in the thoracic area than in the lumbar spine, which potentially gives the upper erector spinae greater force producing capabilities per muscle fibre than the lower erector spinae.[39] The erector spinae muscles are also highly vascularised, making them better suited to lumbar activities that require high levels of muscular endurance.[45] Given that the type I fibres of the erector spinae are larger in diameter than those found in the peripheral limb muscles, the erector spinae muscles have a greater potential for force production than those of the lower limb.[39,41]

## The Effects of Lumbar Flexion on Erector Spinae and Multifidus Architecture

The clinical manifestation of vertebral movement during forward inclination of the trunk is a flattening of lumbar curvature, which is dependent on the degree of lumbar flexion. This alters the geometry of the erector spinae muscles and their ability to resist and control the bending moment, as well as change the relative compression and anterior shear forces acting on the lumbar spine.[6,8,9]

One of the most notable changes in erector spinae geometry during lumbar flexion is a shift in alignment of the muscles to the compressive axis of the lumbar spine, reducing the length of the moment arm at most lumbar levels (see Fig. 2).[5,8,46] Magnetic resonance imaging (MRI) has shown that when compared to a lordotic lumbar posture, the lever arm length of the upper erector spinae aponeurosis is reduced by between 10 and 20% in full lumbar flexion.[8] *In vitro* studies have also shown reductions in lever arm length of the lower erector spinae, albeit to a lesser extent than upper erector spinae, and this seems to be more prominent in the lower lumbar vertebrae.[5,46] A reduction in lever arm would potentially require more muscle force to counteract a given bending moment, and increase the compressive component of the force vector of the muscle fascicle.[46]

Another morphological change that occurs when moving from a neutral to a flexed lumbar spine is a reduction in the muscle fascicle obliquity of the lower erector spinae relative to the longitudinal axis of the spine (see Fig. 2).[6,9] In a flexed lumbar posture, the fascicles of the lower erector spinae become closely aligned to the spinal vertebrae, reducing

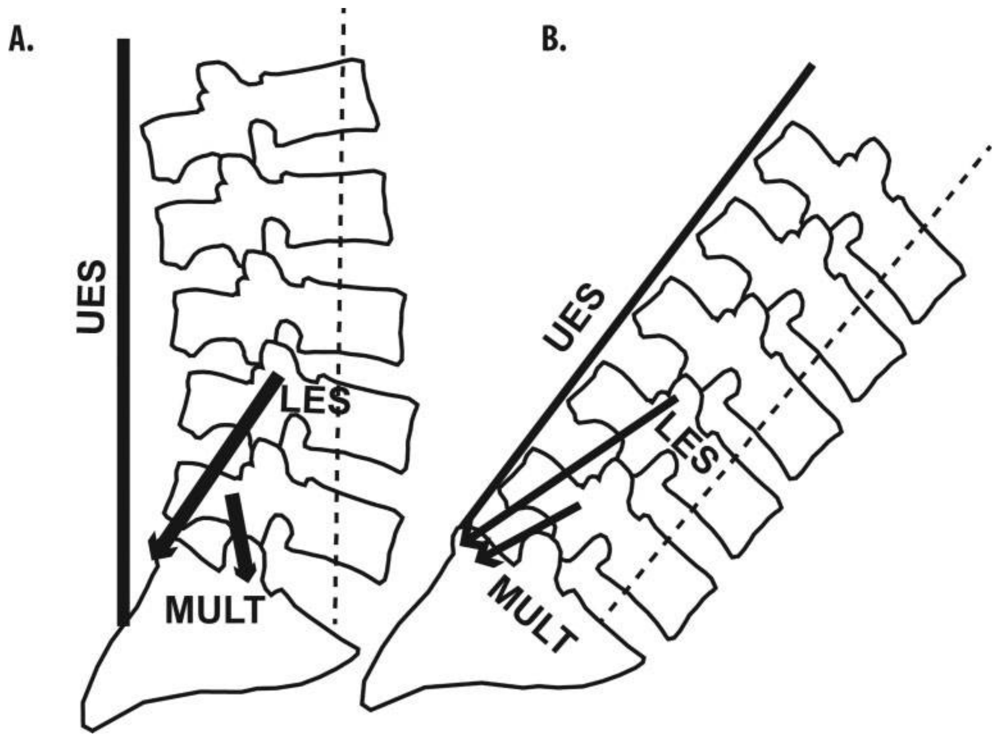

**Figure 2 Schematic diagram of changes in muscle volume (line thickness), fascicle orientation, and the length of the upper erector spinae (UES), lower erector spinae (LES) and multifidus (MULT) in a lordotic (A) and maximally flexed lumbar posture (B). The arrows (posterior or anterior) indicate the direction of the muscle force. Dotted line shows the compressive axis of the lumbar spine.**

their ability to resist anterior shear forces at most vertebral levels.[5,6,9] The influence of lumbar flexion on multifidus fascicle arrangement is less clear because of its relative vertical alignment to the spine. However, when combined with the lower erector spinae, the change in fascicle angle of the multifidus from an anterior angulation in an upright posture to posterior angulation in the flexed lumbar spine enables this muscle to exert a posterior shear force at the level of L5.[5]

While a change in muscle architecture would suggest a reduction in the ability to generate an EM, the contrary has been shown to occur.[47–49] For example, Roy *et al.* found an approximate fourfold increase in the EM when moving from 20° extension (upright standing) to near full lumbar flexion.[48] This may well stem from an increase in muscle length and the storage of elastic energy.[5,50] It has also been suggested that as the lumbar spine flexes the erector spinae increases in length leading to optimal overlap of the actin and myosin filaments of the sarcomeres and enables greater forces to be generated.[7,38] Fig. 3 illustrates the length–force (tension) relationship of the erector spinae and multifidus muscles for different lumbar postures.

The length–tension relationship of the erector spinae has implications for the forces acting on the

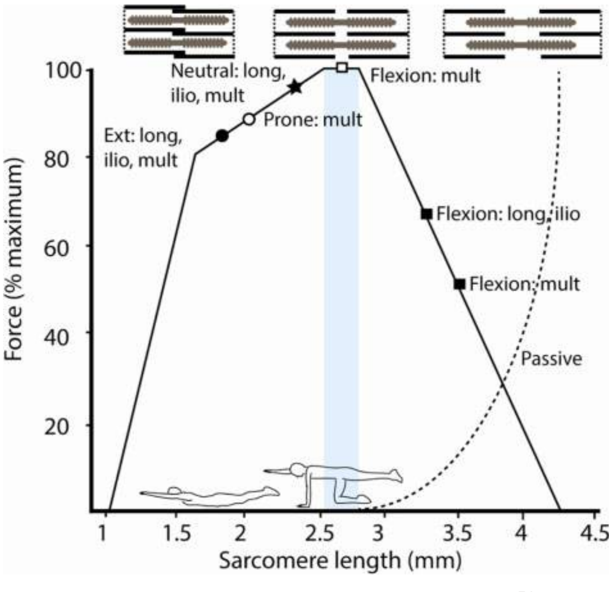

**Figure 3 Data adapted from Zwambag *et al.*[51] (filled symbols) and Ward *et al.*[38] (non-filled symbols) showing the length−force (tension) relationship of the erector spinae (long = longissimus, ilio = iliocostalis) and multifidus (mult) muscles in different lumbar postures [extension (•), prone (○), neutral (★), and full flexion (■)]. The position of the two figures represents the approximate length of the sarcomere for the 'superman' (left) and 'bird dog' (middle) exercises. The shaded area identifies the optimal overlap of actin and myosin filaments. The dotted curve represents the passive muscle contribution to force.**

lumbar spine during the performance of different trunk exercises. During those exercises that involve marked lumbar extension (e.g. the 'superman exercise'), the erector spinae and multifidus sarcomeres are potentially shortened and there is a high degree of overlap of the actin and myosin filaments (see Fig. 3). Consequently, in order to counteract the moment about the lower back, the erector spinae and multifidus muscles generate relatively high forces (activation). Such high levels of muscle activity can result in compressive forces of between 4000 and 6000 N in the lumbar spine.[16] Furthermore, due to the high levels of muscle activity in the lower fibres of the multifidus, this adds to anterior shear forces at the level of L5-S1.[4]

In contrast to the superman exercise, the 'bird dog' exercise requires an initial hip flexion of approximately 90°,[52] which leads to lumbar spine flexion[53] and this may place the erector spinae and multifidus sarcomeres at a more optimal overlap for generating force (see Fig. 3). Consequently, less muscle activation is required, which may account for the lower compressive forces (2000–2700 N) when compared to the superman exercise.[54]

The degree of lumbar flexion for optimal actin and myosin filament overlap is still unclear. Ward *et al.* suggest that the optimal length–tension of the multifidus occurs near full lumbar flexion,[38] whereas Zambag *et al.* found reduced overlap of actin and myosin filaments and force output at end range of lumbar flexion (see Fig. 3).[51]

Although elongation of the erector spinae in flexed lumbar postures may improve the ability to generate force and neuromuscular efficiency (ratio of EM output to muscle activation), a potential downside of the muscle lengthening is a significant reduction in inter-compartmental muscle volume at all lumbar levels.[55] This is of concern when the lumbar spine remains in flexion for prolonged periods of time, as human and animal studies have shown an increase in intramuscular pressure and a reduction in intramuscular blood flow and elevated levels of neuropeptides when lumbar muscle volume reduces.[56,57]

In addition to reduced muscle volume, biomechanical studies indicate that beyond 80% of lumbar flexion there is a reduction in active muscle contribution to the EM and an exponential increase in the contribution from the passive structures of the spine, e.g. ligaments and discs.[18,19] This concept is best illustrated by comparing the muscle activation patterns and the estimated bending moment[19] on the passive tissues of the lumbar spine of a subject with a lordotic lumbar posture (40% of maximum flexion) at the initiation of a lift with that of an individual who adopts full (100%) lumbar flexion (see Fig. 4A and B). The subject who adopts a more lordotic posture exhibits peak levels of upper and lower erector spinae muscle activation during the initiation of the lift, with minimal change in lumbar curvature.[58] Throughout the first half of the lift, the erector spinae performs isometrically (no change in lumbar angular motion) with minimal contribution from the passive spinal tissues to the EM (see Fig. 4A). In contrast, when lifting with the spine in full lumbar flexion (see Fig. 4B), lower erector spinae muscle activity is significantly lower at the start of the lift (flexion–relaxation phenomenon)[59] and according to Dolan *et al.*, the passive tissues of lumbar spine contribute up to 40% of the EM (see Fig. 4B).[19] While contribution of the passive tissues in more flexed postures has been shown to reduce the metabolic cost of work,[60] recruitment of the posterior ligamentous complex increases anterior shear force on the lumbar spine. As mentioned earlier, shear forces have the potential to damage the spine at much lower forces than the spine can withstand in compression.[1]

Differences in lower erector spinae muscle activation are also noted in those individuals adopting different lumbar postures during the mid-to-late stage of a lift (see Fig. 4A and B). Following the peak moment, both individuals show a progressive decrease in the bending moment and activity of the upper erector spinae. This is due to the object and trunk's centre of gravity moving closer to the body and the lumbar spine extending.[61] However, the lower erector spinae exhibits a different functional role in the subject using full lumbar flexion (see Fig. 4B) with activation levels peaking during the middle of the lift[58,62–64] when the moment is low and the rate of change in lumbar curvature (velocity) is at its maximum.[58]

The ability to maintain a lumbar posture that avoids end range of lumbar flexion is important during activities that involve repetitive forward flexion of the trunk. For example, in a 90-minute rowing session, a rower may perform up to 1800 flexion cycles.[3] Cadaver segments that have been repetitively loaded to end range of *in vivo* lumbar flexion have shown vertebral endplate damage in as little as 263 flexion cycles compared to over 8200 cycles if the spine is only flexed to mid-range.[24] Fig. 5 shows the percentage of maximal lumbar flexion adopted by young, inexperienced (2 km time trial) and elite male rowers (5 km time trial) throughout the drive phase of the rowing stroke, both at the beginning and end of a time trial.[65] Both groups had similar lumbar motion at the start of the trail and lumbar flexion is below 80% of their maximum, with minimal recruitment of the posterior ligamentous system.[19] By the end of the trial, elite rowers still maintained peak lumbar flexion within what

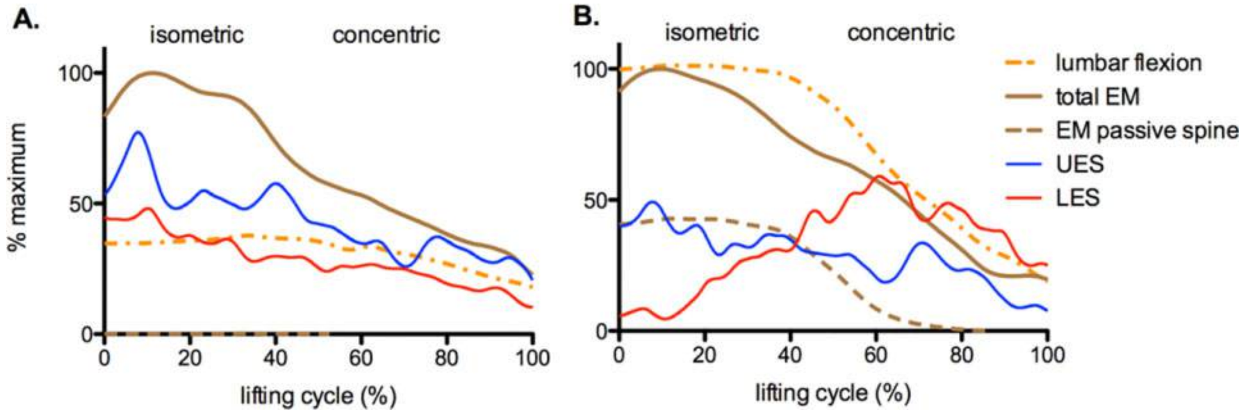

**Figure 4** Total and passive extensor moment (EM), lumbar curvature and muscle activation of the upper and lower erector spinae expressed as a percentage of maximum during a dynamic lift of a 13 kg box in subjects who initially adopt a lordotic (A) and fully flexed (B) lumbar posture.

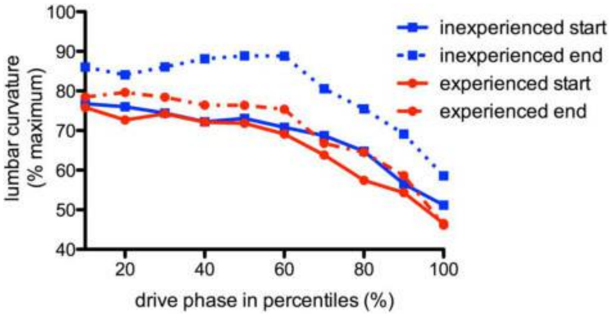

**Figure 5** Change in lumbar curvature of inexperienced (youth) and experienced (elite) male rowers at the beginning and end of 2000 m (youth) and 5000 m (elite) rowing ergometer time trial. Data reproduced with the permission of Caldwell.[65]

might be considered a 'safe zone'. In contrast, the younger rowers increased lumbar flexion beyond 80% of their maximum (see Fig. 5).

Similar patterns have been found during a 20-minute repetitive lifting task with young adults progressively increasing lumbar flexion to approximately 100% of full flexion by the end of the lifting task.[17] In contrast, middle-aged adults were able to maintain approximately 80% of maximal lumbar flexion.[17] The recruitment of passive tissues of the spine to resist bending moments during repetitive flexion cycles can lead to increased ligament and disc creep, and alters erector spinae and multifidus activity.[25]

## Clinical Implications

As discussed, end range of lumbar flexion should be avoided. Pain provocation in flexed postures (fear avoidance) does not seem to provide sufficient feedback for postural correction as patients with low back pain often habitually adopt a more flexed posture than their non-injured worker or sporting colleague.[66,67] Therefore, the therapist has an important role in developing interventions to correct posture to enable sufficient recruitment of the erector spinae and multifidus muscles without excessive loading of the lumbar spine. Case studies would indicate that cognitive functional therapy interventions that focus on hip flexion and minimise end range of lumbar flexion during rowing and cycling reduce pain in these athletes.[68,69] Interestingly, portable wireless biofeedback devices that provide reliable and valid feedback on lumbar posture are now being integrated into sports training.[70,71]

Physiotherapists also need to consider lumbar posture when developing rehabilitation exercises for low back pain patients. Exercises that involve active hyperextension of the lumbar spine should be avoided, as the erector spinae and multifidus muscles are in a shortened position so greater levels of muscle activation are required to counteract the external moment. This may increase compression and anterior shear forces in the lumbar spine[4,38] and would be inappropriate for patients with lower lumbar instability or those with pain stemming from disc compression.[4] Exercises near end range flexion should also be avoided due to the increased loading on the passive tissues and reduce blood flow to the erector spinae.[1,12–14,56] Whilst exercises in end range postures should be avoided, biomechanical data would indicate that erector spinae and multifidus muscles are designed to control external forces over a range of lumbar postures. For example, during anterior loading in a more lordotic posture, such as standing, the larger lever arms and increased fascicle obliquity give the upper and lower erector spinae a mechanical advantage for resisting bending moments and anterior shear forces.[1,29] In moderately flexed postures, improved length–tension relationships of these muscles allow improved neuromuscular efficiency and the multifidus to resist shear forces.[5,7,38,48,51]

When designing low back exercises, erector spinae muscle endurance should be considered. Erector spinae and multifidus muscles have a high percentage of type I fibres, and following low back injury there is often an increase in the percentage of type II fibres.[72] Both clinical testing and electromyographical indices of fatigue indicate that low back pain populations have a reduction in erector spinae muscle endurance.[67,73] Therapeutic interventions that focus on improving endurance (high repetitions at low loads) of the erector spinae and multifidus muscles have been recommended for improved functional outcomes in patients with lumbar instability and muscle hypertrophy.[74–76] Whilst others have suggested that an exercise intensity of at least 65–70% of a single maximum exertion is necessary to recruit all muscle fibre types and develop erector spinae muscle hypertrophy.[77,78]

Erector spinae muscle endurance and lumbar posture should also be considered in combination when performing repetitive activities involving lumbar flexion. Work–rest intervals should be customised to match the level of experience and fitness of the individual to prevent individuals adopting postures that recruit the passive tissues of the spine.[17,27,79]

Therapeutic exercises should address deficits in all erector spinae muscle divisions in those ranges of lumbar motion commonly associated with activities of daily living or when involved in sports participation. Whilst there is evidence of wasting and increased intramuscular fat content of the multifidus in people with low back injury,[80,81] similar changes in muscle architecture are found in the lower erector spinae at higher lumbar levels following disuse and injury.[82–84] The influence of injury or disuse on upper erector spinae has not been clearly established. With ageing and disuse, there is also a reduction in lean muscle mass of the lower erector spinae and multifidus muscles, and a flattening of the lumbar lordosis and a decrease in obliquity of the lower erector spinae muscle fascicles relative to the longitudinal axis of the lumbar spine.[9,82,85] Activity and resistance training interventions have been shown to reverse some of these changes in paraspinal muscles, and strength training of the lower limbs has been shown to increase fascicle obliquity of the knee extensor muscles.[82,85–87]

To achieve optimum gains in lean muscle mass and EM production, training interventions should use exercises that develop sufficient muscle tension in targetted muscles, induce metabolic stress by performing exercises to volitional fatigue and include static and dynamic (concentric and eccentric) muscle actions throughout a range of lumbar postures.[77,78,88] However, when choosing exercises, the therapist should consider the implications of exercise selection on spinal posture and the forces acting on the spine.[4,54,89]

## Conclusions

The erector spinae and multifidus muscles comprise divisions that have distinct biomechanical roles in controlling forces and moments on the lumbar spine. Extreme end range of lumbar sagittal plane motion compromises the ability of these muscles to resist forces and may increase loading on the passive tissues of the spine. Therapists should develop low back interventions that accord with the functional biomechanics of the erector spinae and multifidus muscles. They should recognise the importance of lumbar posture and promote efficient recruitment of these muscles that minimise loading on the passive tissues of the spine.

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