SPINE Volume 34, Number 6, pp E208–E214
©2009, Lippincott Williams & Wilkins

Different Ways to Balance the Spine

Subtle Changes in Sagittal Spinal Curves Affect Regional Muscle Activity

Andrew P. Claus, MPhty,* Julie A. Hides, PhD,* G. Lorimer Moseley, PhD,†‡ and Paul W. Hodges, PhD*

Study Design. Exploratory study of regional muscle activity in different postures.

Objective. To detail the relationship between spinal curves and regional muscle activity.

Summary of Background Data. Sagittal balanced spinal posture (C7 above S1 in the sagittal plane) is a goal for spinal surgery and conservative ergonomics. Three combinations of thoracolumbar and lumbar spinal curves can be considered sagittal balanced postures: (i) flat—at both regions, (ii) long lordosis—lordotic at both regions, and (iii) short lordosis—thoracic kyphosis and lumbar lordosis. This study compares regional muscle activity between these 3 sagittal balanced postures in sitting, as well as a slump posture.

Methods. Fine-wire electromyography (EMG) electrodes were inserted into the lumbar multifidus (deep and superficial), iliocostalis (lateral and medial), longissimus thoracis, and transversus abdominis in 14 healthy male volunteers. Fine-wire or surface EMG electrodes were also used to record activity of the obliquus internus, obliquus externus, and rectus abdominis muscles. Root mean square EMG amplitude in the flat, long lordosis, short lordosis, and slump sitting postures were normalized to maximal voluntary contraction, and also to the peak activity across the sitting postures. Muscle activity was compared between postures with a linear mixed model analysis.

Results. Of the extensor muscles, it was most notable that activity of the deep and superficial fibers of lumbar multifidus increased incrementally in the 3 sagittal balanced postures; flat, long lordosis, and short lordosis ($P < 0.05$). Of the abdominal muscles, obliquus internus was more active in short lordosis than the other postures ($P < 0.05$). Comparing the sagittal balanced postures, the flat posture showed the least muscle activity (similar to the slump posture at most muscles examined).

Conclusion. Discrete combinations of muscle activity supported the 3 different sagittal balanced postures in sitting, providing new detail for surgeons, researchers, and therapists to distinguish between different sagittal balanced postures.

Key words: lumbar spine, sitting, multifidus, extensor muscles, fine-wire electromyography. **Spine 2009;34: E208–E214**

"Neutral upright sagittal spinal alignment" (sagittal balance) is a postural goal for surgical interventions and conservative ergonomic training, but the definition of "neutral upright sagittal spinal alignment" is vague. A wide variety of thoracic and lumbar spinal curves satisfy a sagittal balance criterion of C7–S1 sagittal deviation <50 mm (asymptomatic adults in standing),[1,2] making it difficult for surgeons, researchers, therapists, and patients to know if they are examining or achieving the same postural goal. In neutral upright spinal alignment, the spine's propensity to bend, twist, and shear is managed by neuromuscular control.[3–6] Despite the importance of neuromuscular control to coordinate and protect the spine, little is known of how thoracic and lumbar curves in sagittally balanced postures influence regional muscle activity.

Electromyography (EMG) studies have shown that upright spinal postures in sitting require more extensor muscle activity than kyphotic postures (slumped).[7,8] A study of upright spinal posture in standing with surface electrodes over paraspinal muscles from C4–S2 showed large intersubject variation in activity between regions of the spinal extensor muscles,[9] but unfortunately the spinal curves that subjects used were not reported. A description of spinal curves that people commonly adopt in standing has been provided by a recent radiographic study of 160 asymptomatic adults in standing.[10] The authors suggested that balanced sagittal spinal curves could be grouped into 4 different postures: (1) a kyphotic thoracolumbar region with only the lower lumbar segments in a lordotic curve, (2) hypokyphotic thoracic and hypolordotic lumbar regions (flat), (3) Inflection of curves at the thoracolumbar region with a lordotic lumbar curve (short lordosis), and (4) lordotic curves at thoracolumbar and lumbar regions (long lordosis).[10] Few studies have compared muscle activity between these postures, but a recent surface EMG study[11] examined 2 of the spinal curve combinations. One posture sought to

From the *Centre of Clinical Research Excellence in Spinal Pain, Injury and Health, The University of Queensland, School of Health and Rehabilitation Sciences, Brisbane, Australia; †Department of Physiology, Anatomy, and Genetics, University of Oxford, Oxford, United Kingdom; and ‡Prince of Wales Medical Research Institute and School of Medical Sciences, The University of New South Wales, Sydney, Australia.
Acknowledgment date: June 9, 2008. Revision date: August 26, 2008. Acceptance date: September 8, 2008.
The manuscript submitted does not contain information about medical device(s)/drug(s).
Federal, institutional, and foundation funds were received in support of this work. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.
Supported by the National Health and Medical Research Council of Australia (to P.H.); The Nuffield Medical Research Fellowship from the University of Oxford (to G.L.M.). Reimbursement of study participants was funded by the The Dorothy Hopkins Award.
All procedures were approved by the University of Queensland Medical Research Ethics Committee, and written informed consent was obtained from all research subjects.
Address correspondence and reprint requests to Andrew Claus, MPhty, Division of Physiotherapy, School of Health and Rehabilitation Sciences, The University of Queensland, St. Lucia, Queensland 4072, Australia; E-mail: a.claus1@uq.edu.au

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

achieve lordotic curves at thoracolumbar and lumbar regions (long lordosis), and for the other posture only the lumbar region was in a lordotic curve (short lordosis). The results showed differential muscle activity at electrodes adjacent to T9 and L5, as well as obliquus internus and externus.[11] Unfortunately, surface EMG has limited ability to distinguish between sources of the electrical signal recorded, so the contribution of adjacent but distinct muscles could not be determined. Given the complexity of spinal extensor muscle anatomy[12,13] and the potential for the abdominal muscles to contribute to spinal support,[14–16] more detailed examination of regional muscle activity associated with different spinal curves in sagittally balanced postures is warranted.

Fine-wire intramuscular electrodes are required to differentiate EMG signals between muscles and between superficial and deep fascicles within muscles. Fine-wire EMG data obtained during trunk rotation in asymptomatic subjects have shown discrete muscle activity in regions of the longissimus thoracis and thoracic multifidus,[17] as well as iliocostalis and lumbar multifidus muscles.[18] Among the spinal extensor muscles, the lumbar multifidus show unique deterioration with back pain,[49] spinal trauma[48] and surgical retraction,[19] and deep fibers of multifidus are uniquely coordinated in preparation for movement.[20,21] Furthermore, rehabilitation of multifidus function plays a role in preventing recurrence of low back pain after an initial episode,[22] and may have significance for postsurgical recovery.[23,24] Fine-wire electrodes are also the only tool to record activity of deep abdominal muscles such as transversus abdominis. Among the abdominal muscles, the transversus abdominis is uniquely coordinated in preparation for movement,[25,26] and this function deteriorates with back pain.[27–29] The objective of this study was to examine activity at 9 regions of the paraspinal and abdominal muscles using fine-wire and surface EMG, comparing activity between 3 sagittally balanced postures (flat, long lordosis, short lordosis) and a slump posture in sitting.

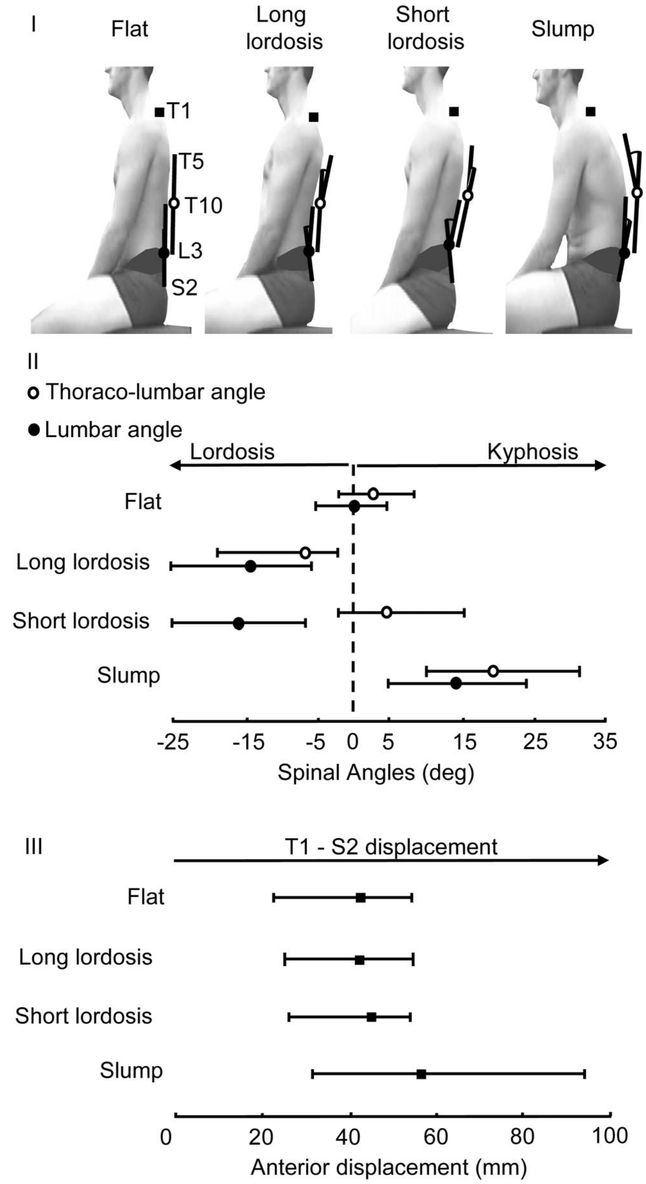

Figure 1. I, Thoracolumbar (T5–T10-L3) and lumbar angle (T10-L3-S2) curve directions are shown for the sitting postures examined: flat—flat at both regions, long lordosis—lordotic at both regions, short lordosis—kyphotic/flat thoracolumbar and lordotic lumbar regions, slump—kyphotic at both regions. II, Thoracolumbar and lumbar spinal angles means (range) for each posture. III, Anterior displacement of T1-S2 means (range) for each posture.

■ Materials and Methods

Subjects

Fourteen healthy men with a mean (SD) age of 22 (8) years, height of 178 (8) cm, and weight of 71 (10) kg participated in this study. Subjects were excluded if they had ever experienced thoracic or lumbar spinal pain that required treatment, or rest from normal activities for more than 2 days, or if they had a history of respiratory or neurologic conditions. An experienced musculoskeletal physiotherapist undertook a physical examination to determine that participants had no abnormal restriction of hip mobility, spinal mobility, or evidence of a scoliosis that would limit symmetrical performance of sitting postures. Written informed consent was obtained and all procedures were approved by the institutional Medical Research Ethics Committee.

Postures and Measurement

Sitting postures were examined in preference to standing because sitting allowed greater control of pelvis position and postural sway through repeated trials in lumbar postures ranging from lordosis to kyphosis. Four spinal postures were examined: flat—minimal curve at thoracolumbar and lumbar regions; long lordosis—lordotic curve at thoracolumbar and lumbar regions; short lordosis—flat/kyphotic thoracolumbar with a lordotic lumbar curve; and slump— kyphotic at thoracolumbar and lumbar regions (Figure 1).

To quantify thoracolumbar and lumbar spinal curves in the sagittal plane, 3-dimensional surface tracking was used. Position data for 11 subjects were recorded with an electromagnetic tracking system (Ascension, sensor static position absolute error was 1.8 mm, position data recorded before 15 seconds EMG) and Motion Monitor software (Innovative Sports Training); and data for 3 subjects were recorded with an optical

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

Table 1. Electrode Placement

Muscle	Origin—insertion of relevant fibres	Fine-wire electrodes placement	Surface electrodes placement
Deep multifidus at L4	Laminae, mamillary processes and facet joint capsules—2 vertebral segments inferiorly	~30 mm lateral to spinous process, and directed medially to contact the L4 lamina[21] n = 12	
Superficial multifidus at L4	Upper lumbar segments spinous processes—sacrum and ilia	~30 mm lateral to the spinous process; ~10 mm below the skin surface[21] n = 13	
Iliocostalis L2 (lateral)	Ribs 11 and 12—iliac crest/lumbo-dorsal fascia	~80 mm lateral to L2 spinous process (previously examined with sEMG[54]) n = 13	
Iliocostalis T11 (medial)	Ribs 6–9—iliac crest/lumbo-dorsal fascia	~60 mm lateral to T11 spinous process, and lateral to the transverse process[18] n = 14	
Longissimus thoracis	Transverse processes of mid-thoracic vertebral segments—lumbo-dorsal fascia	~40 mm lateral to T11 spinous process; directed toward the dorsal aspect of the transverse process[17] n = 14	
Transversus abdominis	Lumbodorsal fascia—linea alba	Between the anterior superior iliac spine and the ribcage[55] n = 13	
Obliquus internus	Iliac crest—aponeurosis to linea alba	Between the anterior superior iliac spine and the ribcage[55] n = 7	Transverse arrangement ~30 mm medial to the anterior superior iliac spine n = 7
Obliquus externus	Ribs 9–12—iliac crest and inguinal ligament	Between the anterior superior iliac spine and the ribcage[55] n = 7	Lateral electrode proximal to medial ~45 deg to transverse plane between the iliac crest and the ribcage n = 7
Rectus abdominis	Pubis—costal cartilage of ribs 5–7 and xiphoid process	~20 mm infero-lateral to the umbilicus n = 5	Sagittal arrangement ~20 mm infero-lateral to the umbilicus n = 9

tracking system with (Vicon, reflector position absolute error was 0.1 mm, position data and EMG recorded simultaneously) using Nexus software (Vicon). Relative positions of surface markers have been validated with radiography for relative positions of vertebrae, with a standard error of 4 mm at the thoracolumbar region and 2 mm at the lumbar region.[30] Lumbar surface markers have also been shown to accurately represent radiographic measures for change in vertebral flexion/extension.[31] The boundary between thoracic and lumbar curves was defined as being located at the T10 vertebral segment for 2 reasons. Facet joint orientation[32] and spinal curves in standing[10] can transition as proximally as T10. Sagittal angles representing surface spinal curves at thoracolumbar and lumbar regions of the spine were measured between segments connecting T5–T10 and T10-L3 (thoracolumbar angle), T10-L3 and L3-S2 (lumbar angle) (Figure 1),[33] with kyphotic angles described as positive, and lordotic angles as negative. Global sagittal balance was also measured with anterior displacement of T1 relative to S2, which was similar for the 3 upright sitting postures (Figure 1).

Measures of spinal curve are continuous variables, but to differentiate postures and categorize angles as lordotic, flat, or kyphotic it was necessary to impose discreet limits for these angles. The flat posture was used as a reference. When the 14 subjects performed 3 trials of the flat posture, the mean (range) thoracolumbar angle was 2.3° (−4.9 to 5.5), and the mean lumbar angle mean was −0.2° (−5.5 to 4.4). On this basis, spinal angles for the flat posture were defined as thoracolumbar angles −3.0° to 7.0°, and lumbar angles −5.0° to 5.0°. Greater angles were categorized as kyphotic spinal curves, and lesser angles as lordotic spinal curves. Figure 1 shows angle data in each posture for all trials included in the study.

Electromyography

EMG activity of 9 regions of the spinal extensor and abdominal muscles was recorded with bipolar fine-wire electrodes fabricated from Teflon-coated stainless steel wire (75-μm diameter) or surface electrodes (Table 1). The fine-wire electrodes had 1 mm of Teflon removed from the cut ends, were bent back to form hooks at ~1 and 2.5 mm from the ends, threaded into a hypodermic needle, and sterilized. With the subjects positioned lying on the left side, the morphology of spinal extensor and the abdominal muscles was imaged sonographically (8–12 MHz transducer, GE Logic 9), and hypodermic needles (0.50 × 70 mm or 0.50 × 32 mm) with fine-wire electrodes were inserted into the extensor and abdominal muscles on the subject's right side (Figure 2; Table 1). For the superficial abdominal muscles, subjects were offered either fine-wire or surface electrodes. Pairs of surface electrodes (Ag/AgCl discs, 10 mm in diameter; either Cleartrace, Conmed, NY, or Red Dot, 3 M Health Care Products, London, Canada were used) were placed in parallel with fibers of the superficial abdominal muscles (20 mm inter-electrode distance). A ground electrode was placed over the right iliac crest.

EMG data were amplified 2000 × (Neurolog Digitimer, UK) and data from 9 subjects were sampled at 2000 Hz (Spike2.6, CED, Cambridge, UK). Due to error in data collection, data for 5 subjects were sampled at 100 Hz. Although part of the EMG spectrum lies above 100 Hz, careful evaluation of the EMG amplitude showed that between postures the 100 Hz data changed in a similar manner to the 2000 Hz data, so the 100 Hz data were retained in the analysis.

Procedure

To achieve the required spinal curves, subjects sat on a stool adjusted to the height of their popliteal crease. They were then shown pictures of each posture (similar to Figure 1) with verbal description of the spinal curves required. For the flat, long lordosis and short lordosis postures, manual guidance and feedback pertaining to the pelvis position and spinal curves were provided. For the long and short lordosis postures, participants were taught to tilt the upper aspect of the sacrum

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

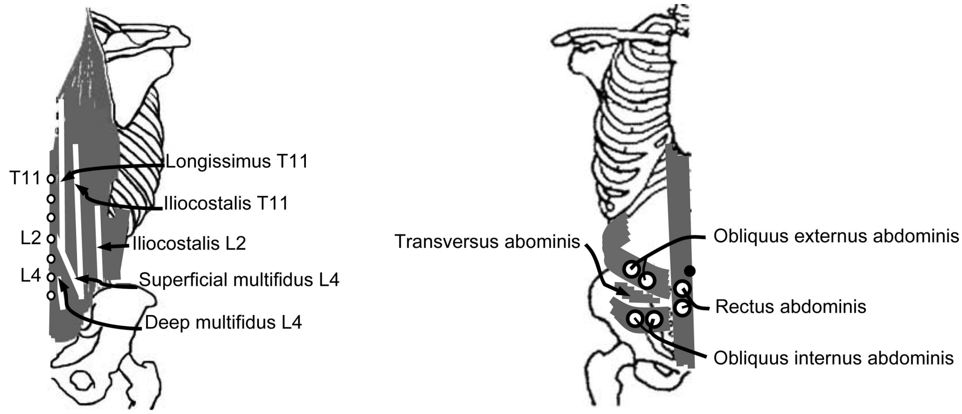

Figure 2. Intramuscular EMG electrodes were inserted into deep and superficial muscle fibers of multifidus at L4, iliocostalis adjacent to L2 and T11, longissimus at T11, and transversus abdominis on the right side. Obliquus internus, obliquus externus, and rectus abdominis muscle activity were measured with either surface EMG or intramuscular electrodes.

forward, sitting toward the front of their ischia and perineum, similar to the pelvis position on a bicycle saddle.[33] Sitting postures were performed in random order for three 45-second trials. Subjects were advised to breathe naturally, avoid talking, and generally face forward during trials. Between trials, subjects stood briefly to minimize the effects of fatigue or task sequence.

A series of 3 maximal voluntary contractions (MVC) for 3 seconds against manual resistance were recorded.[34] In supine lying, subjects flexed the trunk to recruit the rectus abdominis muscle, and rotated the trunk to the left for the obliquus externus muscle. In sitting, subjects performed a maximal forced expiratory maneuver for the obliquus internus and transversus abdominis muscles. In prone lying, subjects extended the trunk to recruit the 5 spinal extensor muscles that were recorded. Activities at rest, in supine and in prone, were also recorded to determine the amplitude of baseline activity/noise.

Data Processing

Spinal curve measures from 3-dimensional tracking data were exported and analyzed (Matlab 6, Mathworks) for the 3 trials in each posture. Trials in which spinal angles failed to achieve the required curve directions (Figure 1) were excluded, leaving data for 12 subjects for the flat and long lordosis postures, 13 subjects for short lordosis, and 10 subjects in the slump posture (slump data were excluded from 4 subjects who achieved a kyphotic curve at the thoracolumbar but not the lumbar angle).

EMG data were exported, a 5-second sample was selected from each trial to avoid artifact in the EMG traces (assessor blinded to posture), and root mean square amplitude was calculated (Matlab 6, Mathworks) for each trial. Baseline root mean square EMG amplitude at rest was subtracted from all trials (sitting posture and the MVC trials), and 2 separate normalization procedures were used. To indicate the absolute amplitude of EMG activity in the sitting postures and data were expressed as a percentage of MVC. However, normalization of EMG activity to MVC has been shown to increase variability of data in comparison with normalization to a submaximal task.[35] Hence, data were also expressed as a percentage of the peak activity recorded in sitting.

Statistical Analysis

EMG amplitude of data normalized to peak activity recorded in sitting for each muscle were compared between postures with a linear mixed model analysis (SPSS version 15, IL). Test of fixed effects for the interaction of posture by EMG amplitude was significant ($P < 0.001$), so for each of the 9 muscles, pairwise comparisons of EMG amplitude between postures were undertaken with Bonferroni adjustment for multiple comparisons. The level of significance was set at $\alpha < 0.05$.

Results

Data normalized to MVC for each muscle and posture (mean and 95% CI) are shown in Table 2. In general, the deep and superficial fibers of multifidus and the longissimus thoracis muscle were the most active, with >10% MVC in one of the postures. The Iliocostalis at T11 and at L2, transversus abdominis, obliquus internus, and obliquus externus muscles showed activity levels up to 3% to 4% MVC, and rectus abdominis was active at ~1% MVC in the sitting postures.

Comparisons between postures are shown in Figure 3 for extensor muscles and Figure 4 for abdominal muscles, with EMG amplitude normalized to peak activity in sitting. For the deep and superficial fibers of the multifidus muscle, activity in the flat and slump postures were similar ($P = 1.00$), but activity was greater in the long lordosis and greatest in the short lordosis posture (all comparisons $P < 0.05$). For iliocostalis at L2, activity in the short lordosis posture was greater than flat and slump postures ($P < 0.05$), but other comparisons were not different. The longissimus thoracis muscle was least active in the slump posture ($P < 0.05$), but other comparisons were not different. For the obliquus internus muscle, the flat and long lordosis postures were similar ($P = 1.00$), activity was least in slump, and activity was greatest for the short lordosis posture (all comparisons $P <$

Table 2. EMG Results Normalized to MVC

	Mean % MVC (95% CI) in Each Posture			
Muscle	Flat	Long Lordosis	Short Lordosis	Slump
Deep multifidus	2.8 (2.4)	10.7 (6.5)	16.8 (7.9)	3.3 (6.0)
Superficial multifidus	2.1 (1.6)	7.4 (5.4)	10.9 (5.2)	0.9 (1.0)
Iliocostalis L2 (lateral)	1.5 (1.1)	2.8 (2.4)	3.5 (2.3)	0.6 (0.5)
Iliocostalis T11 (medial)	1.4 (1.2)	2.4 (2.2)	3.0 (3.1)	0.5 (0.4)
Longissimus thoracis	10.3 (5.0)	12.5 (9.1)	8.7 (4.6)	1.8 (1.5)
Transversus abdominis	2.4 (1.5)	2.7 (1.4)	4.3 (3.3)	1.4 (1.5)
Obliquus internus	3.0 (1.4)	2.8 (1.5)	4.0 (1.9)	1.6 (1.4)
Obliquus externus	2.1 (1.4)	3.4 (2.2)	1.7 (1.2)	1.6 (1.4)
Rectus abdominis	0.6 (0.4)	0.8 (0.5)	0.9 (0.8)	0.9 (1.0)

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

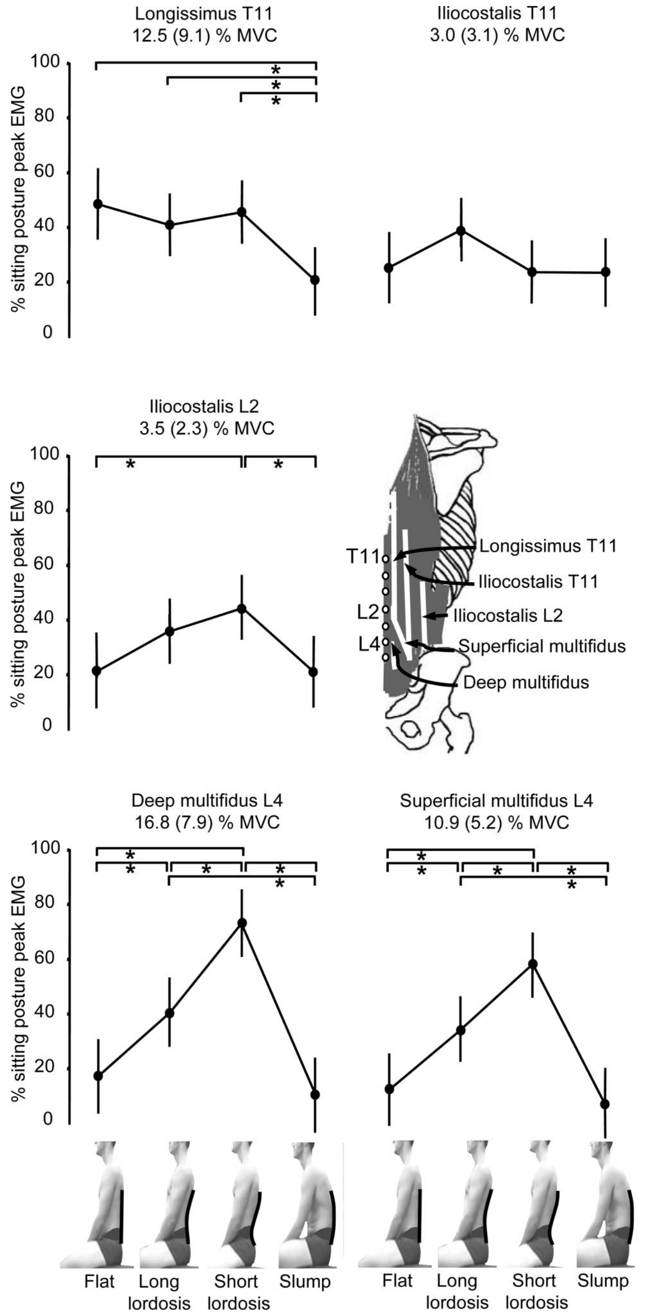

Figure 3. Extensor muscle EMG normalized to peak activity in sitting. $^{*}P < 0.05$; error bars—95% confidence intervals. Highest maximal voluntary contractions normalization results from Table 1 are shown to indicate magnitude of peak activity.

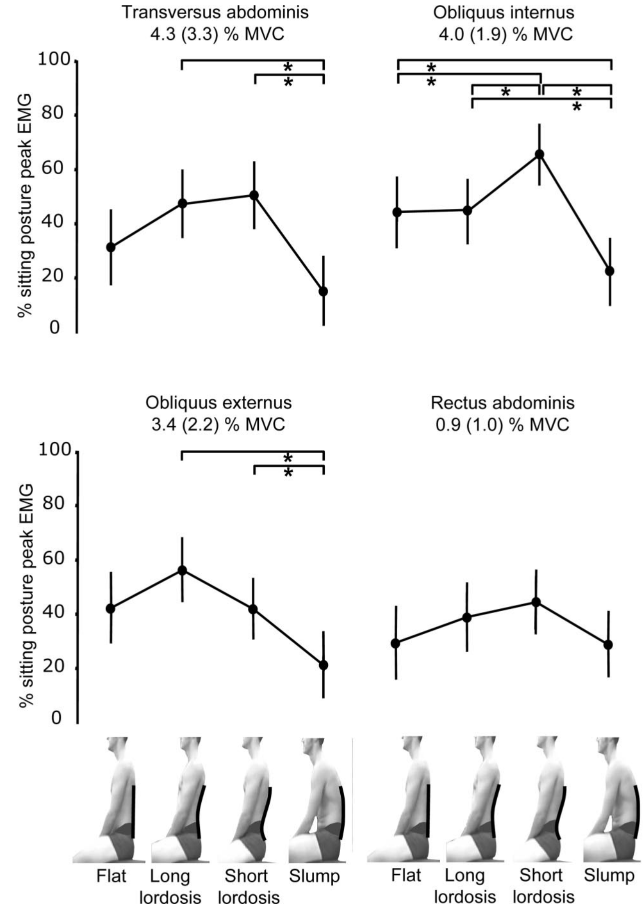

Figure 4. Abdominal muscle EMG normalized to peak activity in sitting. *Significant difference at $P < 0.05$; error bars—95% confidence intervals. Highest maximal voluntary contractions normalization results from Table 1 are shown to indicate magnitude of peak activity.

0.05). The transversus abdominis and obliquus externus muscles were less active in the slump than the long lordosis and short lordosis postures ($P < 0.05$), but other comparisons were not different. The EMG amplitude of iliocostalis adjacent to T11 and rectus abdominis muscles did not differ between postures.

■ Discussion

This study provides the most specific measurement of surface spinal curves and associated regional muscle activity to date. The results show that thoracolumbar and lumbar spinal curves in sagittally balanced postures are determinants of regional extensor and abdominal muscle activity. Notably, activity of the deep and the superficial fibers of lumbar multifidus increased incrementally in the 3 sagittally balanced postures; flat, long lordosis, and short lordosis. The activity of the iliocostalis muscle adjacent to L2 was greater in the short lordosis than in the flat posture, but activity of the iliocostalis adjacent to T11 and of the longissimus thoracis muscles did not differ between the sagittally balanced postures. Consistent with the anatomy of the lumbar multifidus muscle (fascicles crossing 2–5 motion segments[12]), the results demonstrate that the lumbar multifidus has a unique role among the spinal extensor muscles, for subtle adjustment and/or support of a lumbar lordosis.

To speculate on the role of lumbar multifidus (and other intrinsic muscles) to mediate spinal curves, origins and insertions of the deep-medial and superficial-lateral fascicles[12] bear obvious resemblance to the attachment sites for screws and wires to secure posterior internal fixators. Intrinsic muscular support might act segmentally to mediate bending, twisting, and shearing of a motion segment,[36,37] or regionally to mediate distribution

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

of movement among a chain of mobile segments. The incremental change in multifidus activity shown to occur with change in thoracolumbar and lumbar curves may represent a combination of these segmental and regional functions of the multifidus muscles.

The most notable result concerning abdominal muscle EMG was that obliquus internus was more active in short lordosis than in the other postures. Surface electrodes were used in 7 subjects (activity from obliquus internus and transversus abdominis) and the lower region of abdominal wall is known to have greater postural activity of transversus abdominis.[34] Thus, the contribution of transversus abdominis cannot be excluded. Muscle activity <5% MVC at obliquus internus, obliquus externus, transversus abdominis, and iliocostalis adjacent to L2 suggests that these muscles play a modest role in supporting the long lordosis and short lordosis postures more than slump.

A key reason for maintaining C7 over S1 is to minimize muscular effort to support the spine.[38–40] Sagittal imbalance in standing, with anterior displacement of C7 relative to S2 >50 mm occurs in kyphotic patients,[2,38] scoliotic patients, and can occur in asymptomatic populations,[41] especially with increasing age.[42] If the objective of an efficient posture is to balance the spine with minimal stress to articular and ligamentous systems, then the flat posture was midway between the lumbar curves in lordotic and slump postures. Although surface tracking accurately represents changes in lumbar flexion and extension, there is evidence that radiographic measures show larger angles of lordosis.[31] Hence, flat surface measures may involve a small degree of lordosis at the vertebral bodies. Furthermore, the flat posture demonstrated the lowest muscle activity of the 3 upright postures, with only longissimus thoracis and obliquus internus muscles more active than in the slump posture. Provided that lumbar extension range is available for standing and gait, the flat posture may satisfy clinical descriptions of sagittal balance and provide the most efficient mechanical balance for the spine in sitting.

In contrast with flat, the short lordosis posture demonstrated the highest levels of muscle activity, particularly at the lumbar multifidus, with 16.8% (7.9) MVC. This raises an important question, can people sustain the % MVC observed in the short lordosis sitting posture? Evidence to quantify endurance at specific extensor muscles could not be found, but 5% MVC of the spinal extensor muscles (surface EMG) can be sustained for 30 minutes or more.[43] At other regions of the body 10% MVC is sustainable for an hour at triceps surae[44] and elbow flexors.[45] Endurance at 20% MVC varies from 1 to 30 minutes at the elbow flexors[45,46] and craniocervical flexor muscles.[47] Based on those data, sustained lordosis in sitting postures may exceed the endurance capacity of the lumbar multifidus muscle. For people whose function of the lumbar multifidus is compromised after spinal pain, injury, or surgery,[19,48,49] the long lordosis and short lordosis postures could be even harder to sustain. To sustain lordotic spinal curves in sitting might be an unreasonable stress on the lumbar multifidus muscles, contributing to fatigue or pain. Alternatively, lordotic sitting postures might maintain or aid rehabilitation of the lumbar multifidus muscles. The advantages and disadvantages of specific sagittally balanced postures warrant investigation.

The current results should be considered in light of several factors. First, this was a study of a common, functional, and commonly problematic task, sitting without backrest support. It is uncertain whether the muscle activity results would be comparable in standing postures. Second, individuals with inherently kyphotic or lordotic lumbar curves (research participants were screened for ability to adopt all required spinal curves) may require greater or lesser activity than our participants showed in the lordotic postures. Third, this was a study of "global sagittal balance" of the spine, as opposed to "segmental sagittal balance," which would require radiographic measures of segmental positions.[50] Fourth, aspects beyond the scope of this study include the activity of other paraspinal muscles (such as quadratus lumborum and psoas major) and gender differences.[51] These limitations aside, the results of this study distinguish 3 sagittally balanced postures by spinal curves and associated muscle activity, provide new detail of multifidus muscle function, and a basis to examine whether particular "neutral upright sagittal spinal alignment" may be advantageous.

■ Conclusion

The results provide new detail to distinguish between sagittally balanced postures. Subtle changes in thoracolumbar and lumbar spinal curves in sitting are associated with varying magnitudes of muscle activity, particularly in the deep and superficial regions of lumbar multifidus. The highest activity levels at multifidus and obliquus internus abdominis muscles occurred in the short lordosis posture. The lowest activity levels were observed at most muscles in the flat posture.

■ Key Points

- EMG of 9 spinal extensor and abdominal muscles was used to compare activity in 3 different sagittal balanced sitting postures.
- Activity at the lumbar multifidus muscles adjusted with subtle changes of lumbar and thoracolumbar spinal curves.
- The results provide basis to distinguish between sagittal balanced spinal postures.

Acknowledgments

The authors thank Linda-Joy Lee, David MacDonald, Börje Rehn, and Ross Darnell for assistance in planning methods, data collection, and analysis for this study; and Dorothy Hopkins award for financial assistance with reimbursing research subjects.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

References

1. Kuntz Ct, Levin LS, Ondra SL, et al. Neutral upright sagittal spinal alignment from the occiput to the pelvis in asymptomatic adults: a review and resynthesis of the literature. *J Neurosurg Spine* 2007;6:104–12.
2. Booth KC, Bridwell KH, Lenke LG, et al. Complications and predictive factors for the successful treatment of flatback deformity (fixed sagittal imbalance). *Spine* 1999;24:1712–20.
3. Morris JM, Lucas DB, Bresler B. Role of the trunk in stability of the spine. *J Bone Joint Surg* 1961;43:327–51.
4. Crisco JJ, Panjabi MM. Euler stability of the human ligamentous lumbar spine. Part II: experiment. *Clin Biomech (Bristol, Avon)* 1992;7:27–32.
5. Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. *Clin Biomech (Bristol, Avon)* 1996;11:1–15.
6. Adams MA, Dolan P. Recent advances in lumbar spinal mechanics and their clinical significance. *Clin Biomech (Bristol, Avon)* 1995;10:3–19.
7. Floyd WF, Silver PHS. The function of the erector spinae muscle in certain movements and postures in man. *J Physiol* 1955;129:184–203.
8. O'Sullivan PB, Grahamslaw KM, Kendell M, et al. The effect of different standing and sitting postures on trunk muscle activity in a pain-free population. *Spine* 2002;27:1238–44.
9. Joseph J, McColl I. Electromyography of muscles of posture: posterior vertebral muscles in males. *J Physiol* 1961;157:33–7.
10. Roussouly P, Gollogly S, Berthonnaud E, et al. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. *Spine* 2005;30:346–53.
11. O'Sullivan PB, Dankaerts W, Burnett AF, et al. Effect of different upright sitting postures on spinal-pelvic curvature and trunk muscle activation in a pain-free population. *Spine* 2006;31:E707–12.
12. Bogduk N, Macintosh JE, Pearcy MJ. A universal model of the lumbar back muscles in the upright position. *Spine* 1992;17:897–913.
13. Kalimo H, Rantanen J, Viljanen T, et al. Lumbar muscles: structure and function. *Ann Med* 1989;21:353–9.
14. Hodges PW. Is there a role for transversus abdominis in lumbo-pelvic stability? *Man Ther* 1999;4:74–86.
15. Hodges PW, Gandevia SC. Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *J Appl Physiol* 2000;89:967–76.
16. Hodges PW, Eriksson AE, Shirley D, et al. Intra-abdominal pressure increases stiffness of the lumbar spine. *J Biomech* 2005;38:1873–80.
17. Lee LJ, Coppieters MW, Hodges PW. Differential activation of the thoracic multifidus and longissimus thoracis during trunk rotation. *Spine* 2005;30:870–6.
18. Morris JM, Benner G, Lucas DB. An electromyographic study of the intrinsic muscles of the back in man. *J Anat* 1962;96:509–20.
19. Taylor H, McGregor AH, Medhi-Zadeh S, et al. The impact of self-retaining retractors on the paraspinal muscles during posterior spinal surgery. *Spine* 2002;27:2758–62.
20. Moseley GL, Hodges PW, Gandevia SC. External perturbation of the trunk in standing humans differentially activates components of the medial back muscles. *J Physiol* 2003;547:581–7.
21. Moseley GL, Hodges PW, Gandevia SC. Deep and superficial fibers of the lumbar multifidus muscle are differentially active during voluntary arm movements. *Spine* 2002;27:E29–36.
22. Hides JA, Jull GA, Richardson CA. Long-term effects of specific stabilizing exercises for first-episode low back pain. *Spine* 2001;26:E243–8.
23. Datta G, Gnanalingham KK, Peterson D, et al. Back pain and disability after lumbar laminectomy: is there a relationship to muscle retraction? *Neurosurgery* 2004;54:1413–20; discussion 20.
24. Rantanen J, Hurme M, Falck B, et al. The lumbar multifidus muscle five years after surgery for a lumbar intervertebral disc herniation. *Spine* 1993;18:568–74.
25. Hodges PW, Richardson CA. Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. *Exp Brain Res* 1997;114:362–70.
26. Hodges PW, Richardson CA. Transversus abdominis and the superficial abdominal muscles are controlled independently in a postural task. *Neurosci Lett* 1999;265:91–4.
27. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. *Spine* 1996;21:2640–50.
28. Hodges PW, Moseley GL, Gabrielsson A, et al. Experimental muscle pain changes feedforward postural responses of the trunk muscles. *Exp Brain Res* 2003;151:262–71.
29. Hodges PW, Richardson CA. Delayed postural contraction of transversus abdominis in low back pain associated with movement of the lower limb. *J Spinal Disord* 1998;11:46–56.
30. Bryant JT, Reid JG, Smith BL, et al. Method for determining vertebral body positions in the sagittal plane using skin markers. *Spine* 1989;14:258–65.
31. Gracovetsky S, Kary M, Levy S, et al. Analysis of spinal and muscular activity during flexion/extension and free lifts. *Spine* 1990;15:1333–9.
32. Singer KP, Edmondston SJ, Day RE, et al. Computer-assisted curvature assessment and Cobb angle determination of the thoracic kyphosis. An in vivo and in vitro comparison. *Spine* 1994;19:1381–4.
33. Claus A, Hides J, Moseley GL, et al. Is ideal sitting posture real? Measurement of spinal curves in four sitting postures. *Man Ther*. In press.
34. Hodges P, Cresswell A, Thorstensson A. Preparatory trunk muscle motion accompanies rapid upper limb movement. *Exp Brain Res* 1999;124:69–79.
35. Allison GT, Godfrey P, Robinson G. EMG signal amplitude assessment during abdominal bracing and hollowing. *J Electromyogr Kinesiol* 1998;8:51–7.
36. Panjabi MM. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. *J Spinal Disord* 1992;5:383–9.
37. Panjabi MM. The stabilizing system of the spine. Part II. Neutral zone and instability hypothesis. *J Spinal Disord* 1992;5:390–6.
38. Farcy JP, Schwab FJ. Management of flatback and related kyphotic decompensation syndromes. *Spine* 1997;22:2452–7.
39. Kim YJ, Bridwell KH, Lenke LG, et al. An analysis of sagittal spinal alignment following long adult lumbar instrumentation and fusion to L5 or S1: can we predict ideal lumbar lordosis? *Spine* 2006;31:2343–52.
40. Saha D, Gard S, Fatone S, et al. The effect of trunk-flexed postures on balance and metabolic energy expenditure during standing. *Spine* 2007;32:1605–11.
41. El Fegoun AB, Schwab F, Gamez L, et al. Center of gravity and radiographic posture analysis: a preliminary review of adult volunteers and adult patients affected by scoliosis. *Spine* 2005;30:1535–40.
42. Schwab F, Lafage V, Boyce R, et al. Gravity line analysis in adult volunteers: age-related correlation with spinal parameters, pelvic parameters, and foot position. *Spine* 2006;31:E959–67.
43. van Dieen JH, Westebring-van der Putten EP, Kingma I, et al. Low-level activity of the trunk extensor muscles causes electromyographic manifestations of fatigue in absence of decreased oxygenation. *J Electromyogr Kinesiol*. In press.
44. McLean L, Goudy N. Neuromuscular response to sustained low-level muscle activation: within- and between-synergist substitution in the triceps surae muscles. *Eur J Appl Physiol* 2004;91:204–16.
45. Bjorksten M, Jonsson B. Endurance limit of force in long-term intermittent static contractions. *Scand J Work Environ Health* 1977;3:23–7.
46. Caldwell LS, Smith RP. Pain and endurance of isometric muscle contractions. *J Eng Psychol* 1966;5:25–32.
47. O'Leary S, Jull G, Kim M, et al. Cranio-cervical flexor muscle impairment at maximal, moderate, and low loads is a feature of neck pain. *Man Ther* 2007;12:34–9.
48. Hodges P, KaigleHolm A, Hansson T, et al. Rapid atrophy of the lumbar multifidus follows experimental disc or nerve root injury. *Spine* 2006;31:2926–33.
49. Hides JA, Richardson CA, Jull GA. Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. *Spine* 1996;21:2763–9.
50. Angevine PD, Bridwell KH. Sagittal imbalance. *Neurosurg Clin N Am* 2006;17:353–63, vii.
51. Vialle R, Levassor N, Rillardon L, et al. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. *J Bone Joint Surg Am* 2005;87:260–7.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.