[CLINICAL COMMENTARY]

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Rehabilitative Ultrasound Imaging of the Posterior Paraspinal Muscles

The role of muscles in joint protection and stabilization has been of increasing interest to researchers and clinicians involved in spinal pain and rehabilitation. Evidence for the importance of deep posterior muscles of the spine in the management of people with low back pain (LBP) has been provided by biomechanical[7,60,80,82] and neurophysiological[46,48] investigations. Imaging studies have further allowed definition of both normal morphology and impairments in paraspinal muscles.[22,27,32,33] Rehabilitative ultrasound imaging (RUSI) is a potentially useful tool in physical therapy for the assessment and treatment of these muscles. The advantages of RUSI over other imaging techniques have been discussed in a recently published related manuscript.[79]

The primary purpose of this clinical commentary is to review the current scientific literature on RUSI related to the posterior paraspinal muscles and to increase the understanding of how RUSI of the posterior paraspinal muscles can be incorporated into neuromusculoskeletal rehabilitation. The main applications of RUSI for measurement of morphological characteristics (morphometry) and visualization of muscle contraction for biofeedback are discussed. The lumbar multifidus is the most widely studied paraspinal muscle, in both healthy populations[68] and people with spinal pain and injury.[22,26,27] Studies of different cervical muscles are also emerging.[37,39,61-63] In the thoracic region, the lower trapezius is the first muscle to be measured with ultrasound imaging.[53] Quantitative evaluation of the posterior paraspinal musculature using static and dynamic imaging has been used to study muscle morphology and behavior during contraction.[34,39,64,74,76] In this context, behavior relates to level of contraction (change in thickness), changes in size over time and with respect to other muscles, as well as observation of contraction as a biofeedback tool for the patient or therapist. In this commentary we review what is known about RUSI as applied to the paraspinal musculature, propose guidelines for standardizing the imaging and measurement techniques in clinical and research applications, and propose future directions for research.

• **SYNOPSIS:** Interest in rehabilitative ultrasound imaging (RUSI) of the posterior paraspinal muscles is growing, along with the body of literature to support integration of this technique into routine physical therapy practice. This clinical commentary reviews how RUSI can be used as an evaluative and treatment tool and proposes guidelines for its use for the posterior muscles of the lumbar and cervical regions. Both quantitative and qualitative applications are described, as well as measurement reliability and validity. Measurement of morphological characteristics of the muscles (morphometry) in healthy populations and people with spinal pathology are described. Preliminary normal reference data exist for measurements of cross-sectional area (CSA), linear dimensions (muscle depth/thickness and width), and shape ratios. Compared to individuals without low back pain, changes in muscles' size at rest and during the contracted state have been observed using RUSI in people with spinal pathology. Visual observation of the image during contraction indicates that RUSI may be a valuable biofeedback tool. Further investigation of many of these observations is required using controlled studies to provide conclusive evidence that RUSI enhances clinical practice. *J Orthop Sports Phys Ther 2007;37(10):581-595. doi:10.2519/jospt.2007.2599*

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ANATOMY OF THE PARASPINAL MUSCULATURE

Interpretation of RUSI is dependent on an understanding of the anatomical features and function of the musculoskeletal structures of the spine. This section presents an overview of the anatomical and biomechanical properties of the paraspinal musculature, focusing on the lumbar and cervical muscles in relation to RUSI. The reader is referred to the following manuscripts for further more specific details of anatomy and function.[2-4,6,8,52,55,60]

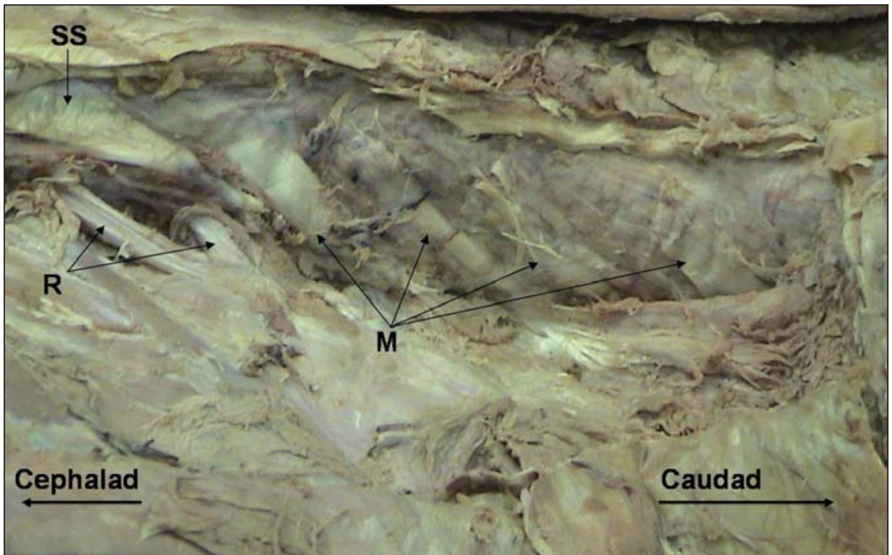

FIGURE 1. Cadaver dissection of lumbar multifidus (M), rotatores (R), and the semispinalis (SS) musculature, showing fascicles passing down in a caudal direction over the lumbar spine.

Posterior Lumbar Spine Musculature

The lumbar paraspinal muscles, lying behind the transverse processes, have been divided into 3 groups by Bogduk.[3] The first and deepest group includes the deep intersegmental muscles, interspinales, and intertransversarii mediales. These muscles are short and too small to provide sufficient clarity of their borders for adequate visualization by ultrasound imaging (USI). The second group comprises the polysegmental muscles, which attach directly to the lumbar vertebrae and include the multifidus and lumbar portions of the erector spinae (ES), longissimus, and iliocostalis muscles (**TABLE 1**). The third and most superficial group of muscles consists of long, polysegmental muscles, which traverse the lumbar region from the thoracic levels. These muscles attach to the ilium and sacrum, and include the thoracic portions of the ES muscles.

Lumbar Multifidus This is the most medial of the lumbar muscles and Macintosh et al[44] have described it as a large, multifascicular muscle composed of 5 overlapping layers, with its size increasing in a caudal direction (**FIGURE 1, TABLE 1**). The morphometry of the lumbar multifidus muscle can be assessed with RUSI

TABLE 1 Anatomy of Selected Lumbar and Cervical Posterior Paraspinal Muscles

Muscle	Origin	Insertion
Lumbar multifidus[44]	• Laminae and spinous processes of each lumbar vertebra	• Descend in a caudal direction to cross 3 to 5 vertebrae
	• Deep laminar fibers: inferior edge of a lamina	• Mamillary bodies and zygapophyseal joint capsule of the vertebra 2 levels caudal
	• Superficial fibers: along the spinous process	• Cross up to 5 levels: attach to the mamillary processes of the caudal vertebra, sacrum, and posterior superior iliac spine
Erector spinae[43]		
Longissimus	• Lumbar transverse and accessory processes	• Ventral surface of posterior superior iliac spine
Iliocostalis	• Tips of lumbar transverse processes and adjacent middle layer of the thoracolumbar fascia	• Ventral edge of iliac crest
Cervical multifidus[2]	• Laminae and spinous processes of cervical vertebrae	• Capsules of cervical facet joints[81]
Semispinalis cervicis[2]	• Transverse processes of the upper 5 or 6 thoracic vertebrae	• Cervical spinous processes of C2 to C5
Splenius capitis[2]	• Spinous processes of C7 and T3 or T4	• Just deep to sternocleidomastoid into the mastoid process and occipital bone just below lateral third of superior nuchal line
Semispinalis capitis[2]	• Tips of transverse processes of T6 and T7, and C1-C3 articular processes	• Mastoid process

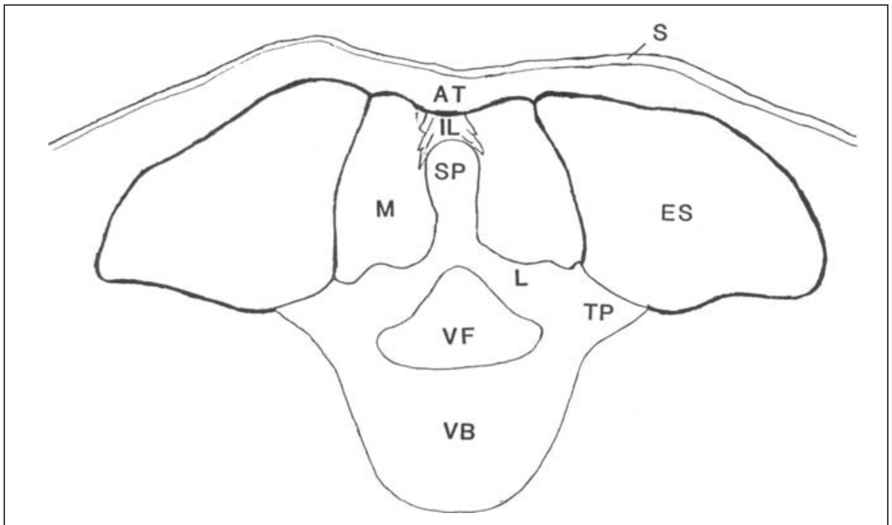

FIGURE 2. Schematic diagram of a cross section at the level of the fourth lumbar vertebra (L4). The lumbar multifidus muscle (M) lies lateral to the spinous process, superior to the lamina (L), and medial to erector spinae (ES). Abbreviations: AT, adipose tissue; IL, iliocostal ligament; S, skin; SP, spinous process; TP, transverse process; VB, vertebral body.

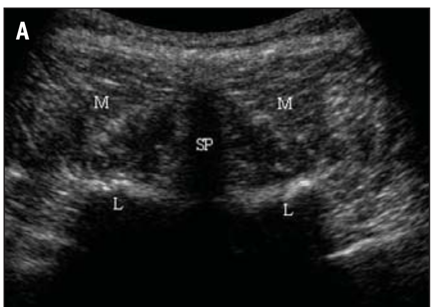

FIGURE 3. Bilateral transverse ultrasound image at L4, using a 5-MHz curvilinear transducer, showing the spinous process (SP) in the center of the image and the echogenic laminae (L) appearing as bright white horizontal landmarks, either side of the base of the SP and beneath the lumbar multifidus (M) muscle. The lateral borders are not clear enough to enable measurement of area and require the transducer to be angled more appropriately for each side separately.

FIGURE 4. Parasagittal ultrasound image of the lumbar multifidus muscle, taken lateral to the spinous process using a 5-MHz curvilinear transducer. The facet joints (F) can be used as landmarks for the lower border of the muscle.

using either a transverse or parasagittal image. On the transverse section, lumbar multifidus can be identified as a single region of muscle and separate fascicles are not often visible (**FIGURES 2** and **3**). The advantage of imaging using a transverse section is that the cross-sectional area (CSA) of the muscle can be measured.[21,68] Conversely, in a parasagittal (longitudinal) image, muscle fascicles can be identified from the connective tissue between muscle fibers (**FIGURE 4**). Parasagittal views are easier to interpret than transverse views, both for measuring muscle thickness[34] and for providing biofeedback of changes in the muscle during contraction.[24,74]

Researchers using biomechanical models based on anatomical data have suggested that the superficial fibers of lumbar multifidus create a posterior sagittal rotation (extension) of the lumbar spine, in addition to intervertebral compression,[43,4] while the deeper fibers primarily generate compressive forces, with minimal associated torque.[4,47] It has been proposed that the intersegmental nature of the deep lumbar multifidus provides an advantage to the neuromuscular system for controlling the stability of the motion segment.[55] For this reason, clinicians aim to include voluntary contraction of the deep fibers in their exercise (or rehabilitative) programs.[24] Electromyographic (EMG) studies of arm movement suggest differential activation of the deep (earlier onset) and superficial fibers.[51] This finding suggests that different exercises may be necessary for selectively re-educating the deep versus the superficial fibers, but this requires investigation.

There is consistent evidence that the lumbar multifidus muscle controls spinal motion, contributing to intervertebral stiffness.[31,55,80] Lumbar multifidus RUSI studies have identified reduced CSA in people with acute LBP,[26,27] and EMG evidence suggests that changes in motor control may be more localized to the deep fibers.[42] However, it is important to consider that all lumbar muscles contribute to stability of the lumbar spine.[7,8,12,18,47,48,80]

Lumbar ES The lumbar ES lie lateral to multifidus and consist of longissimus thoracis pars lumborum and iliocostalis lumborum pars lumborum (**TABLE 1**).[43] In the upper lumbar region, researchers have demonstrated that the longissimus muscle overlaps the fibers of the multifidus muscle.[43] Various studies have shown that the ES muscles contribute to lateral flexion, extension, and rotation of the lumbar spine, as well as stability.[7,8,12,18,47,48,80] Regarding imaging, the ES muscles are too large to allow CSA measurements using RUSI. However, Watanabe et al[78] have measured thickness successfully in the sagittal plane by placing the transducer longitudinally. Their technique illustrates the use of the echogenic (reflective, white) transverse processes and subcutaneous tissue-muscle border as landmarks to assess thickness of the ES muscles.

Posterior Cervical Spine Musculature

The posterior musculature of the cervical spine is commonly divided into 4 layers (**FIGURE 5**). The most superficial layer

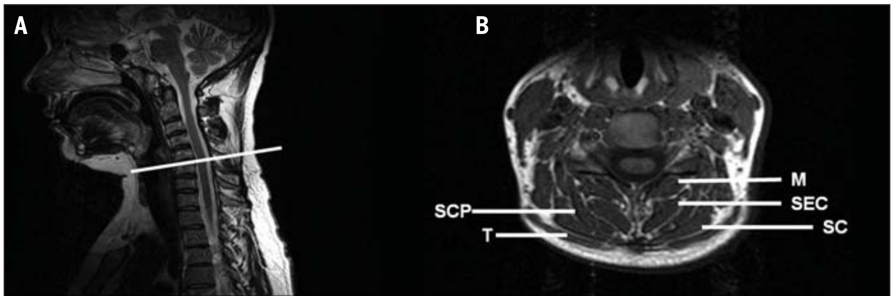

FIGURE 5. Magnetic resonance images: (A) sagittal cross section of the C6 vertebral level; (B) the corresponding axial scan at the C6 level showing the cervical multifidus (M), semispinalis cervicis (SEC), semispinalis capitis (SCP), splenius capitis (SC), and trapezius (T) muscles.

consists of the upper trapezius muscles, the second layer consists of the splenius capitis muscle,[62] the third layer consists of the semispinalis capitis[63] and semispinalis cervicis muscles,[71] while the deepest layer contains the multifidus and rotatores muscles. Some studies place semispinalis cervicis in this deepest layer,[61] while others also include the suboccipital muscles of rectus capitis posterior minor (RCPmin) and major (RCPmaj).[71] We have limited the description of anatomical features of cervical muscles to those described by researchers using RUSI.[37,39,61-63]

Cervical Multifidus and Semispinalis Cervicis Winkelstein et al[81] have suggested that the ability of the multifidus muscle to control cervical segmental motion could be compromised by its insertion directly into the capsules of the facet joints (**TABLE 1**), which have been widely implicated in neck pain and injury.[41,56,65,82] Degenerative changes in the deep cervical paraspinal musculature have been found in studies using RUSI and magnetic resonance imaging (MRI) in patients with persistent neck pain following trauma.[15,19,37,73] The semispinalis cervicis muscle (along with the capitii musculature) is considered a primary cervical spine extensor.[52]

Splenius Capitis and Semispinalis Capitis These muscles have been described as broad and flat, extending upward and lateral to their attachment on the mastoid process (**TABLE 1**).[62,63] The main function of these muscles is neck extension,[46,71] and they are more active during large, fast movements of the neck[11] than during sustained postural activity.

QUANTITATIVE EVALUATION

The procedures described are based on developmental studies by Hides et al,[21,26,27] Kiesel et al,[34] and a relatively large population study by Stokes et al,[68] and reflect the suggestions of the team of authors of this commentary. Both static and dynamic techniques for quantitative evaluation of muscles are described.

Imaging Procedure for Lumbar Multifidus

Images of lumbar multifidus have either been obtained from transverse (**FIGURE 3**)[21,22,26,27,68] or parasagittal (**FIGURE 4**)[34] orientations.

Positioning As originally suggested by Hides et al,[21] the subject is usually relaxed in a prone lying position. But this is not always possible, as Coldron et al[10] realized when attempting to scan lumbar multifidus in women who had recently given birth. Researchers have shown that the side-lying position can be used to obtain images without affecting muscle size at rest.[10] But this is not the case when imaging with the subject in a standing posture.[40] Lee et al[40] found that in healthy control subjects, lumbar multifidus CSA increased from prone lying to upright standing, then gradually decreased during forward flexion. In patients with LBP, CSA also increased from prone to upright standing, but forward flexion produced a further increase in CSA, suggesting altered function of lumbar multifidus.[40] As suggested by Hides et al,[21] we recommend that, in prone lying, 1 to 2 pillows be placed under the hips to minimize the lumbar lordosis, so that the muscles lie as horizontally as possible along the spine. Inclinometers were used by Hides et al[25] and Kiesel et al[34] to ensure the lumbar spine was within 10° of horizontal.

Positioning of the operator relative to the subject is important for standardization of the technique to achieve correct image interpretation. So, with the subject prone, we recommend that the scanner and operator be situated to the left of the prone subject (the opposite to imaging anterior structures in the supine subject), in keeping with standardized protocols in radiology.[9,79]

The lumbar spinous processes are palpated and their position located on the skin with an indelible marker, such as an eye liner pencil, which is water insoluble but easily removed with an alcohol swab.[54] In most individuals, the spinous process of L5 is a deep, small, blunted bony point lying at the center of the lumbosacral depression and can be found by palpating cranially from the sacrum.[5] On progression in a cranial direction is the comparatively large spinous process of L4. The remaining lumbar spinous processes are then identified by continuing palpation cranially. These locations can be verified with USI by including the sacral base in the image and counting the spinous processes cranially.

Transducers Various transducers have been used for imaging the lumbar multifidus muscle, but we suggest the use of a curved transducer with a frequency of 5 MHz, which is used for transverse imaging in the majority of studies (**TABLE 2**). This is because more of the sound waves emitted by a curved transducer are likely to be perpendicular to the rounded border of multifidus than those from a linear transducer. For parasagittal imaging, we consider transducer shape less important, so curvilinear[34] or linear[25] arrays can be used. Regarding transducer frequency, the depth of lumbar multifidus is more suited to 5 MHz[21,68] for image clarity than lower or higher frequencies, such as 3 MHz or 7 to 10 MHz, respectively.[79] The

Muscles	Transducer	Researchers	Footprint Size (cm)
Lumbar			
Multifidus			
Transverse image	5.0 MHz curvilinear	Van et al[74]	5.5†
		Stokes et al[68]	5.0
Parasagittal image	5.0 MHz curvilinear	Kiesel et al[34]	7.0
	7.5 MHz linear	Hides et al[25]	7.5†
Cervical (Transverse)			
Semispinalis capitis	7.5 MHz linear	Rankin et al[61]	8.0
Deep posterior group‡	5.0 MHz curvilinear	Rankin et al[61]	5.0
Multifidus	10.0 MHz linear	Lee et al[39]	3.8†
	7.5 MHz linear	Kristjansson[37]	7.0†

TABLE 2 Transducers for Ultrasound Imaging of the Posterior Lumbar and Cervical Paraspinal Muscles*

** Transducers with a large footprint (>5 cm) are preferable for sufficient contact with the skin to enable a wide field of view. Transducer size and frequency depend on availability with a particular scanner. The preferable transducer for transverse imaging of lumbar multifidus is 5 MHz curvilinear.*
† Not reported in paper cited (detail gained from authors).
‡ The deep posterior cervical group comprises the semispinalis cervicis, multifidus, and rotatores.

size of the transducer varies with different ultrasound machines (**TABLE 2**), but we suggest using as large a footprint (length of array surface) as possible, with a minimum of 5 cm, to ensure sufficient contact with the skin to enable a wide field of view on the scan. For further details on selecting transducers, see a related publication by Whittaker et al,[79] which discusses the relationships between muscle shape, depth, and transducer specifications.

Imaging Technique We endorse the technique used by a number of researchers,[21,25,27,68] in which the transducer was first placed longitudinally and centrally over the lower lumbar spine to orient and confirm the marks on the skin. The indicator mark on the side of the transducer (either a line or light) was directed cranially, producing a scan showing the spinous processes, as seen in **FIGURE 6**. For parasagittal imaging, researchers have described moving the transducer laterally to image lumbar multifidus,[34,74] using the facet joints inferiorly as a landmark (**FIGURE 4**). For transverse imaging, the transducer was rotated from the central longitudinal orientation through 90°, to lie transversely in the midline with its indicator mark towards the operator,[21,68] so that the right side of the anatomy would appear on the right side of the screen. This produced an image in which the spinous process and laminae could be seen, with lumbar multifidus muscles visible on both sides of the spine (**FIGURE 3**). If the muscles were too large for bilateral imaging, they were scanned individually by moving the transducer laterally, to the left and right (**FIGURES 7** and **8**). As in these previously cited studies, we recommend that the echogenic (bright) vertebral laminae be used as landmarks to identify the muscle's deep border, which is important when measuring CSA, as there is a large difference in CSA over the span of 1 vertebral level if a consistent landmark is not used.

The lateral border of the lumbar multifidus muscle is often difficult to distinguish from the lumbar longissimus muscle, and strategies to produce muscle contraction can help to identify the border during real-time imaging (**TABLE 3**). However, if a test movement is used, it is important that the subject relaxes before measurements are taken. Off-line measurements on stored images do not have the advantage of dynamic (real-time) imaging for locating muscle borders and it may me more of a matter of extrapolating between identifiable areas of a border.

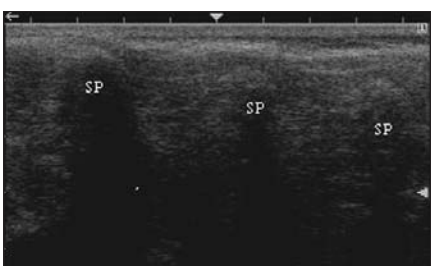

FIGURE 6. Ultrasound image showing a sagittal view of the lumbar spine. The 5-MHz linear transducer was placed centrally over the spinous processes (SP).

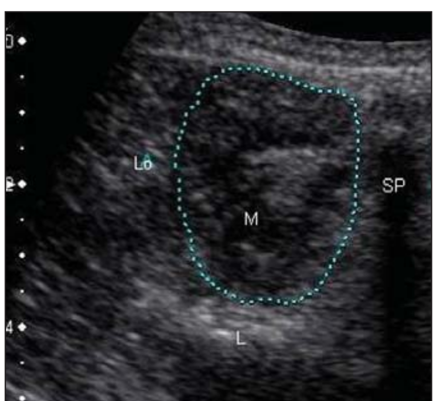

FIGURE 7. Transverse ultrasound image of a left lumbar multifidus (M) muscle at L4, using a 5-MHz curvilinear transducer. The oval shape of the muscle is evident and is bordered inferiorly by the lamina (L), medially by the spinous process (SP), and laterally by longissimus (Lo).

FIGURE 8. Transverse ultrasound image of the right lumbar multifidus muscle at L5, using a 5-MHz curvilinear transducer. The spinous process (SP) is shorter and the lateral edge less steep than at L4 (Figure 7). (Reproduced from Stokes et al,[68] with permission).

TABLE 3 Strategies for Identifying the Lateral Border of Lumbar Multifidus During Transverse Imaging

Maneuver by the Subject
• Raise (extend) the ipsilateral lower limb slightly[24]
• Shorten ipsilateral limb gently
• Raise the contralateral upper limb[34]
• Imagine the muscles are sausages on either side of the spine and try to shorten and fatten the sausages
• Note: ensure that movements are minimal to maintain the test position and avoid movement of the transducer from the scanning site
Observe on Transverse Image
• Movement of multifidus and adjacent erector spinae muscle (longissimus) in relation to each other. Fascicles of multifidus move in a swirling motion, sliding round against each other, which differs from the movements of longissimus
• Although a lateral border may not be visible, the relative motions of the muscles will indicate the boundary

Static Measurement of Lumbar Multifidus

The CSA (cm^2) of multifidus is measured by tracing around the muscle border with the on-screen cursor or off-line using an image-processing package such as ImageJ (http://rsb.info.nih.gov/ij/docs/index.html). For consistency, the precise part of the border needs to be traced each time and the inner edge of the border is often used.[68] Two linear dimensions are often measured, defined as the greatest depth (anteroposterior [AP]) and the greatest width (lateral dimension [Lat]), lying perpendicular to the AP dimension.[21] Hides et al[21] described the shape of the lumbar multifidus muscle as a ratio of the linear measurements, with the AP divided by the lateral dimension (AP/Lat). Stokes et al[68] made anthropometric measurements on ultrasound images to examine their relationships with CSA, including the length (cm) of the spinous process (SPL) and the horizontal distance (cm) between the lateral edge of each lamina (bilateral lamina width). Researchers have also used whole-body measurements and characteristics to assess their predictive value for estimating lumbar multifidus size, including height, age, body mass, and body mass index (BMI).[21,27,68] Relationships alluded to here, particularly between muscle dimensions, will be discussed later in the commentary.

Dynamic Measurement of Lumbar Multifidus

Real-time RUSI can be used to assess muscle during active movements. Dynamic measures are described for the posterior cervical[39] and the lumbar multifidus,[34,74,75] as well as muscular fatigue.[64] The most common RUSI measurement of the paraspinal muscles to represent muscle contraction is change in muscle thickness. Watanabe et al[78] measured thickness change of the lumbar ES muscles in the sagittal plane. Significant differences were found in measures obtained in neutral, flexed, and extended static postures. Kiesel et al[34] used graded resistance of contralateral upper extremity lifts, performed in prone, to produce incremental activation of lumbar multifidus and demonstrated a positive relationship between increases in muscle thickness and fine-wire EMG signals (see validity section below). Vasseljen et al[75] used high-speed motion mode (M-mode) ultrasound, compared with fine-wire EMG, to identify movement of the deep fibers of the lumbar multifidus muscle during rapid arm lifting. Lee et al[39] found significant increases in thickness of cervical multifidus during contractions, which were similar at 3 levels from C4 to C6.

It is clear that RUSI can be used to measure thickness of the posterior trunk musculature.[34] Preliminary studies of asymptomatic subjects comparing RUSI to the gold standard of intramuscular EMG are encouraging and suggest that RUSI may be used to measure both magnitude[34,39] and timing[75] of activation in the paraspinal muscles.

Morphometry of the Lumbar Multifidus

The lumbar multifidus muscle, in the absence of pathology, has been described as generally round or oval in shape, and its size varies among the vertebral levels.[25] Studies with similar methodology and subject groups provide consistent data, as summarized in **TABLE 4**.

Cross-sectional Area At the level of the fourth lumbar vertebra (L4), the mean CSA of multifidus has been reported to be approximately 8 cm^2 in males and approximately 6 cm^2 in females (**TABLE 4**). The muscle becomes larger at L5 (approximately 9 cm^2 in males and approximately 7 cm^2 in females). The CSAs at L4 and L5 are highly correlated ($r = 0.82$ for males, 0.80 for females), so one could be reasonably well estimated from the other using predictive equations.[68] A multilevel analysis of the entire lumbar spine indicated that multifidus CSA increases from L2 to L5 and then decreases at S1.[25] Mean data from a group of 10 young females were approximately 2.0 cm^2 at L2, 3.3 cm^2 at L3, 4.9 cm^2 at L4, 7.1 cm^2 at L5, and 6.4 cm^2 at S1.

Linear Dimensions The thickness or AP dimension of lumbar multifidus is approximately 2.6 cm and the lateral dimension is approximately 2.8 cm in healthy males (**TABLE 4**). In females, the mean values are approximately 2.2 cm for the AP dimension and 3.0 cm for the lateral dimension.

Muscle Shape The linear dimensions indicate that the muscle is almost round in males but more oval in a horizontal direction in females (ie, flatter).[21,68] A study of 120 healthy subjects reported round, oval, and triangular lumbar multifidus muscle shapes.[68] Gender, age, vertebral level, and physical activity accounted for these different shapes.

The shape of the lumbar multifidus

muscle is not always regular, particularly in subjects with relatively large muscles, where it can appear more triangular[68] (**FIGURE 9**). The medial and inferior (deep) borders of the multifidus are confined by the spinous process and lamina, so the multifidus can only hypertrophy in a lateral or superior (superficial) direction, which may explain the more triangular shape of hypertrophied muscles.[68] In such cases, the shape ratio is misleading as it would tend to suggest a round shape. Stokes et al[68] suggested that it may be more appropriate to describe a triangular-shaped muscle using 3 measurements (the superior, medial, and lateral borders), but this requires investigation. The clinical relevance of lumbar multifidus shape and whether or not it reflects muscle tone have yet to be explored.

FIGURE 9. Transverse ultrasound image of a triangular shaped left lumbar multifidus muscle at L4, taken using a 5-MHz curvilinear transducer. (Reproduced from Stokes et al,[68] with permission.)

Prediction of CSA From Linear Measurements Researchers have shown that linear measurements can reflect CSA accurately.[21,27,68] Linear measurements can be made more quickly and easily than tracing the muscle border to measure area (an option not available on all ultrasound apparatus). Linear measurements are therefore more applicable for clinical use than CSA, provided they predict CSA accurately. The combined linear measurements (AP × Lat) were highly correlated with CSA at L4 and L5 (range in males, r = 0.95 to 0.98; range in females, r = 0.93 to 0.95) in 3 studies (**TABLE 4**).[21,27,68] However, it is known that this correlation for resting muscle weakens when muscle becomes atrophied (r = 0.75 and 0.85 in males and females, respectively[27]) and cannot be assumed in all situations. Thus the clinical utility of the prediction of CSA from resting linear measures may

TABLE 4 Lumbar Multifidus Morphometry From Images in Prone Lying in Healthy Populations

Population	Age (y)*	Researchers	CSA (cm²)*	Shape Ratio*	AP Dimension Thickness (cm)*	Lateral Dimension (cm)*	CSA Versus Linear Dimensions Multiplied (r)
Fourth Lumbar Vertebra							
Males							
n = 21	18-35	Hides et al[21]	6.15 ± 0.93 (4.35-8.5)	0.91 ± 0.12 (0.68-1.19)	2.55 ± 0.3 (2.03-3.35)	2.82 ± 0.23 (2.50-3.31)	0.98
n = 52	40 ± 13 (20-69)	Stokes et al[68]	7.78 ± 1.85 (4.24-11.5 [95%])	1.02 ± 0.15 (0.72-1.33)	NR	NR	0.96
n = 19	41.7 (35-47)	Lee et al[40]	R, 7.68 ± 1.29; L, 7.62 ± 1.38	NR	NR	NR	NR
Females							
n = 27	18-35	Hides et al[21]	5.6 ± 0.8 (4.18-7.23)	0.75 ± 0.13 (0.42-0.98)	2.24 ± 2.98 (1.63-2.75)	3.05 ± 3.25 (2.35-3.96)	0.93
n = 10	25.5 (21-31)	Hides et al[27]	4.87 ± 1.22	NR	NR	NR	NR
n = 68	34 ± 13 (20-64)	Stokes et al[68]	5.55 ± 1.28 (3.03-8.06 [95%])	1.05 ± 0.21 (0.64-1.47)	NR	NR	0.95
Fifth Lumbar Vertebra							
Males							
n = 45	39 ± 13 (20-69)	Stokes et al[68]	8.91 ± 1.68 (5.62-12.30 [95%])	1.03 ± 0.17 (0.70-1.36)	NR	NR	0.95
n = 19	41.7 (35-47)	Lee et al[40]	R, 7.25 ± 2.11; L, 7.14 ± 1.55	NR	NR	NR	NR
Females							
n = 10	25.5 (21-31)	Hides et al[27]	7.12 ± 0.68	NR	NR	NR	NR
n = 46	32 ± 12 (20-64)	Stokes et al[68]	6.65 ± 1.0 (4.69-8.60 [95%])	0.95 ± 0.17 (0.62-1.28)	NR	NR	0.94
L4/5							
Males and females, n = 5	28 ± 5.6	Kiesel et al[34]	NR	NR	2.48 ± 0.19	NR	NR

Abbreviations: AP, anteroposterior; CSA, cross-sectional area; L, left; NR, not reported; R, right.
** Mean ± 1 SD, range.*

be limited, as in most cases comparison of atrophied and nonatrophied muscles is the objective of the assessment. During contraction, however, Kiesel et al[33] found that the AP linear measurement of lumbar multifidus was consistently decreased by induced pain, indicating that this simple, time-efficient measure may be clinically useful for assessment of contraction capability. Correlations were found to be poor between muscle size and body anthropometry.[68]

Muscle thickness (AP dimension) was also highly correlated with CSA at L4 (males, $r = 0.8$; females, $r = 0.7$). However, at L5, although statistically significant ($P<.001$), the relationship was not strong enough to be of clinical value (males, $r = 0.66$; females, $r = 0.54$), assuming that correlation coefficients above 0.70 are required to be clinically significant.[36] We suggest that multiplication of the linear dimensions, although not representative of a round or oval shape, is preferable to a single measurement when area cannot be measured, based on evidence of its high correlation with lumbar multifidus CSA.[21,27,68]

Symmetry Mean between-side difference in lumbar multifidus muscle size in healthy individuals without pain or pathology has been found to be below 10% (mean ± SD, 3 ± 4%[27]; 9.6% ± 8% in males,[68] 8.1% ± 6% in females[68]). Marked asymmetry can occur with acute LBP[27] and be a useful clinical indicator of abnormality.

Effect of Age Researchers have not found differences in lumbar multifidus muscle size among different age groups.[68] However, the quality of the muscle may become altered, as changes in water and fat content that occur with age produce changes in signal intensity on MRI scans.[72] Infiltration with fatty or fibrous tissue increases the echogenicity of muscle, making it appear whiter than usual, as observed in some of the older subjects (up to age 69 years) studied by Stokes et al.[68] But a reliable method for quantification of these changes in ultrasound images has yet to be developed.

Imaging Procedure for the Posterior Cervical Muscles

There are limited published data on RUSI of the cervical muscles. Those studied include splenius capitis,[62] semispinalis capitis,[61,63] multifidus,[37,39] and the deep posterior cervical muscle group comprising semispinalis cervicis, multifidus, and rotators.[61]

Positioning Imaging of the cervical muscles has been described with the subject sitting[39,63] or prone lying,[37,61,62,63] with the neck in a neutral position. Rezasoltani et al[63] used an inclinometer to help ensure that the thoracic and cervical postures were horizontal during the ultrasound measurements. Locating the vertebral levels to be imaged has been achieved by palpation of the cervical spinous processes between C2 (the first bony landmark caudal to the occiput) and C7 (the most prominent spinous process), as detailed by Lee et al.[39]

Transducers Examples of transducers used for the different muscles are listed in **TABLE 2**. For example, a 7.5-MHz linear transducer was used for imaging semispinalis capitis[61,63] and splenius capitis,[62] which are relatively superficial flat muscles, while a 5-MHz curvilinear transducer was used for the deep muscle group, which has a more oval shape.[61] Conversely, for imaging cervical multifidus, a deep oval muscle, Lee et al[39] used a 10-MHz linear transducer and Kristjansson[37] used a 7.5-MHz linear transducer, possibly determined by availability of transducers rather than suitability. Most researchers have held the transducer in place manually, but custom-made devices to hold the transducer have also been described.[39] The devices can enable a more consistent technique than manual application but need to allow the transducer to be tilted or angled to sharpen the image if necessary. Devices obviously have cost implications.

Imaging Technique Procedures have been described for splenius capitis at C3,[62] semispinalis capitis at C3,[61,63] the deep muscles as a group at C3,[61] and multifidus at C4[37] and C4 to C6.[39] In all cases,

FIGURE 10. Transverse ultrasound image of the left semispinalis capitis muscle, a long strap-like muscle, using a 7.5-MHz linear transducer. The cross-sectional area and aponeurosis (A) dividing the muscle into medial and lateral parts are indicated. (Reproduced from Rankin et al,[61] with permission).

the transducer was placed transversely in the midline over the spinous process at the level of interest and then moved laterally to image the left or right muscles. Identification of the echogenic (bright, reflective) laminae is then useful, whichever muscles are imaged.

The splenius capitis lies deep to the trapezius and is a broad, flat muscle. The semispinalis capitis is easily recognized as a long, strap-like muscle divided into 2 sections by an aponeurotic intersection (**FIGURE 10**). The deep neck muscle group has a distinctive teardrop shape, but the fascia between the 3 constituent muscles (semispinalis cervicis, multifidus, and rotatores) are not always easy to distinguish in symptomatic or asymptomatic subjects with RUSI (**FIGURE 11**). The cervical multifidus muscle lies ventral to the semispinalis cervicis and the fascia between them is more consistently defined using 7.5- to 10.0-MHz linear transducers than a 5.0-MHz curvilinear transducer (**FIGURE 11**).

Morphometry of the Posterior Cervical Muscles

Researchers have reported data for CSA, linear dimensions, and shape ratios in healthy populations and some examples are shown in **TABLE 5**. The muscles of the neck are relatively small (mean CSA between 1 and 3 cm^2) compared with the lumbar muscles. Atrophy of the cervical multifidus muscle was demonstrated in women with chronic whiplash-associated disorder (mean ± SD multifidus CSA at C4: right, 0.96 ± 0.19 cm^2; left,

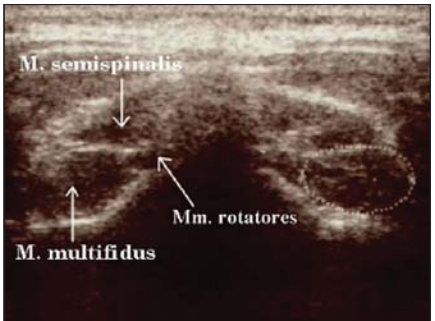

FIGURE 11. Bilateral transverse ultrasound image of the deep posterior cervical muscle group, using a 7.5-MHz linear transducer, showing the teardrop shape, consisting of multifidus, rotatores, and semispinalis. The cross-sectional area of cervical multifidus is indicated on the right side of the image. (Reproduced from Kristjansson[37] with permission.)

1.06 ± 0.19 cm^2) compared with healthy females (right, 1.23 ± 0.09 cm^2; left, 1.25 ± 0.10 cm^2) ($P<.05$).[37] Studies of multifidus at C4 showed slight differences in CSA between the groups studied but marked differences in shape ratio,[37,39] as evident in **TABLE 5**. These differences for cervical multifidus could have been due to the different postures used for imaging, as in 1 study the subjects were lying prone[37] and in the other they were sitting,[39] which could have affected the tonic activity of the resting muscle. There were no differences in measurements of the semispinalis capitis muscle made in prone and sitting,[63] and the 2 studies of the semispinalis capitis were in agreement.[61,63] The shape ratio value indicates the shape well, for example, the 2 flat superficial muscles, splenius capitis and semispinalis capitis, were approximately 7 to 8 times wider than they were thick. The multiplied linear dimensions were correlated with CSA in all muscles (r = 0.77-0.96).

Reliability of Measurement of Paraspinal Muscles

Various factors influence the robustness of measurements and have been discussed elsewhere in a related commentary.[79] Consistently recognizable bony features can be useful internal landmarks, such as the echogenic vertebral laminae, when imaging the paraspinal muscles.[68] To our knowledge, 8 studies have reported the reliability of using RUSI to measure paraspinal musculature. Differences in study design, statistical tests, and reporting method make direct comparisons somewhat difficult, but those values considered key when interpreting reliability have been included in **TABLE 6**. The majority of researchers measured muscle girth (CSA),[59,61,63,68] while others measured thickness utilizing the parasagittal view.[34,74,76] Intraclass correlation coefficient (ICC) values range from 0.72 to 0.98.

In addition to the ICCs, the standard error of measurement (SEM) or 95% limits of agreement, both of which are considered measures of response stability,

TABLE 5 Cervical Paraspinal Muscle Morphometry in Healthy Populations*

Muscle/Position	Level	Population	Age (y)	CSA (cm^2)	Shape Ratio Lat/AP	AP Dimension (Thickness) (cm)	Lat Dimension (cm)	CSA Versus Linear Dimensions Multiplied (r)
Splenius capitis								
Prone lying[62]	C3	Females, n = 10	19-29	R, 1.90 ± 0.23	R, 8.83 ± 1.05	NR	NR	0.77
				L, 1.76 ± 0.25	L, 8.54 ± 1.08			
Semispinalis capitis								
Sitting[63]	C3	Males, n = 18	19-34	R, 1.99 ± 0.37	R, 6.82 ± 0.93	R, 0.58 ± 0.08	R, 3.85 ± 0.39	0.85
				L, 1.93 ± 0.38	L, 6.58 ± 1.04	L, 0.59 ± 0.08	L, 3.76 ± 0.36	
		Females, n = 28	19-34	R, 1.57 ± 0.35	R, 7.00 ± 1.07	R, 0.51 ± 0.08	R, 3.55 ± 0.42	
				L, 1.56 ± 0.34	L, 6.86 ± 1.10	L, 0.52 ± 0.07	L, 3.53 ± 0.41	
Prone lying[61]	C3	Males, n = 46	20-72	1.77 ± 0.40	7.20 ± 1.14	0.53 ± 0.08	3.73 ± 0.39	0.86
		Females, n = 53	18-70	1.34 ± 0.42	7.10 ± 1.34	0.48 ± 0.11	3.27 ± 0.48	0.84
Deep neck muscles								
Prone lying[61]	C3	Males, n = 46	20-72	3.15 ± 0.67	0.57 ± 0.06	2.76 ± 0.36	1.57 ± 0.17	0.96
		Females, n = 53	18-70	2.60 ± 0.05	0.57 ± 0.10	2.49 ± 0.28	1.40 ± 0.19	0.84
Cervical multifidus								
Sitting[39]	C4-C6	Males and	26.8 ± 3.8	C4, 0.92 ± 0.16	C4, 2.40 ± 0.47	C4, 0.72 ± 0.10	C4, 1.70 ± 0.20	NR
		females, n = 17		C5, 0.96 ± 0.16	C5, 2.67 ± 0.52	C5, 0.68 ± 0.08	C5, 1.80 ± 0.25	NR
				C6, 1.20 ± 0.29	C6, 2.54 ± 0.63	C6, 0.77 ± 0.09	C6, 1.90 ± 0.38	NR
Prone lying[37]	C4	Females n = 10	31.5 ± 11.4	R, 1.23 ± 0.09	R, 1.68 ± 0.19	NR	NR	NR
				L, 1.25 ± 0.10	L, 1.58 ± 0.14	NR	NR	NR

Abbreviations: AP, anteroposterior; CSA, cross-sectional area; Lat, lateral; L, left; NR, not reported; R, right.
** Subject positioning is indicated for each study. Data are mean ± 1 SD, except for age ranges, with 2 exceptions.*

TABLE 6 Reliability of Rehabilitative Ultrasound Imaging of the Paraspinal Muscles

		Intrarater Reliability		Interrater Reliability	
Researchers	**Population and Muscles**	**ICC**	**Response Stability**	**ICC**	**Response Stability**
Stokes et al[68]	10 healthy subjects (5 male). Lumbar multifidus CSA at L4	Within session and between days, 0.98-1.0	95% limits of agreement within session, −0.25 to 0.5 cm^2; between days, −0.62 to 0.67 cm^2	NR	NR
Pressler et al[59]	15 healthy females. Multifidus CSA at S1	Between-days $ICC_{3,1}$; R, 0.80; L, 0.72	SEM: R, 0.32 cm^2; L, 0.37 cm^2	NR	NR
Kiesel et al[34]	8 healthy subjects. Lumbar multifidus thickness measured on parasagittal images	$ICC_{3,1}$ = 0.85	NR	Measurements made by both raters on same scans. $ICC_{3,1}$ = 0.95	NR
Van et al[74]	25 healthy subjects. Lumbar multifidus thickness at L4/5	Within-day $ICC_{1,1}$, 0.98 and 0.97	SEM: rater 1, 0.31 cm; rater 2, 0.32 cm	$ICC_{2,3}$ = 0.98	SEM, 0.31 cm
Wallwork et al[77]	Lumbar multifidus thickness at L4/5	$ICC_{1,3}$ = 0.92, both raters	NR	$ICC_{3,2}$ = 0.97	NR
Rankin et al[61]	Semispinalis capitis CSA	Within session and between days, 0.99	95% limits of agreement within session, −0.09 to 0.16 cm^2; between days, −0.16 to 0.16 cm^2	NR	NR
Rankin et al[61]	Deep cervical muscles CSA	0.98-0.99	95% limits of agreement within session, −0.27 to 0.28 cm^2; between days −0.04 to 0.41 cm^2	NR	NR
Rezasoltani et al[63]	Semispinalis capitis CSA	0.98	NR	0.98	NR

Abbreviations: CSA, cross-sectional area; ICC, intraclass correlation coefficient; L, left; NR, not reported; R, right; SEM, standard error of measurement.

may be reported (**TABLE 6**). The purpose of the measurement must also be taken into consideration. For example, it has been shown that by taking an average of 3 measures of the transversus abdominis muscle with RUSI, the SEM is reduced by approximately 50%.[67] Reducing the SEM may be helpful in detecting group difference, but may be more important when the purpose of the measure is to assess change postintervention. To be 95% confident that true change (greater than measurement error) has occurred from preintervention to postintervention, the change score must exceed the minimal detectable change (MDC) for that measure. The MDC_{95} is SEM $\times \sqrt{2} \times$ 1.96, where 1.96 represents the value of the t distribution for a 95% confidence interval (CI) and is in the units of the measure. For example, Van et al[74] used RUSI to measure lumbar multifidus muscle thickness during contraction. The ICC was reported to be 0.98 and the SEM was 0.31 cm. If this measurement were used to assess change in muscle thickness following an intervention period, the MDC_{95} could be calculated. To be 95% confident that true change occurred, the thickness measured would have had to change by at least the value of the MDC_{95}, which is 0.86 cm, based on $0.31 \times \sqrt{2} \times 1.96 = 0.86$. In general, the reliability of using RUSI to measure paraspinal musculature can be considered to be fair to excellent (ICC = 0.72-0.98) and acceptable for clinical use, as defined by Portney and Watkins.[58]

Validity of Measurements of Paraspinal Muscles

Hides et al[25] conducted a study to determine the validity of RUSI measures of lumbar multifidus compared with MRI. Bilateral measurements of CSA were made at vertebral levels from L2 to S1 in healthy females. No significant differences were demonstrated between RUSI and MRI, despite the inherent differences in position for imaging (prone lying for RUSI and supine lying for MRI), when researchers adhered to a strict measurement protocol.[25]

To validate the use of RUSI for measuring muscle contraction, changes in muscle thickness have been compared to EMG activity of various muscles, including the transversus abdominis[49,29] and lumbar multifidus muscles.[34] The relationship varies between muscles and the experimental protocol (eg, contraction type), but, in general, it is considered to be curvilinear.

In the parasagittal view of the lumbar multifidus muscles, Kiesel et al[34] studied the relationship between thickness change (percent change from rest) and fine-wire EMG activity (percent of maximum) during a contralateral prone arm-lifting task with increasing resistance, which automatically recruited the ipsilateral multifidus muscle. This task produced contractions from 19% to 43% of maximum effort, with a strong correlation (r = 0.79, P<.001) between thickness change and EMG activity. But, there was no significant difference in multifidus thickness change between the last 2 levels of activation, indicating that the EMG signal continued to increase with load but thickness change was nearing its maximum. Muscles are considered to reach their maximum thickness at relatively low EMG values (approximately 20% of maximal contraction).[29] In isometric contractions this relates to the point at which tendon stiffness precludes further tendon stretch and the muscle continues to form cross-bridges and increase electrical activity, but with minimal further change in length and, therefore, thickness. Many functional daily activities involve contractions at relatively low forces, which would fall within the linear part of the relationship, where change in EMG reflects change in muscle thickness. With respect to joint stabilization, mathematical models have predicted that only low-level contractions of the lumbar multifidus muscle are required to stiffen the spine.[6] Clinicians have therefore advocated low-level voluntary contractions to train the multifidus muscle for this role, which can be aided by observing changes in thickness on RUSI images.[24]

Vasseljen et al[75] used high-speed M-mode ultrasound to identify deformation of the deep fibers of the lumbar multifidus muscle with concurrent EMG signal to test the validity of using the ultrasound to measure the timing of activation. Subjects performed rapid arm lifting, which is known to activate the deep and superficial lumbar multifidus muscle,[51] the onset of which may be delayed in patients with LBP. Visual determination of the muscle onset using ultrasound was comparable to EMG, but with a small systematic delay. Although preliminary, these results suggest that ultrasound may be used in the future to measure deep muscle onsets clinically.

Validity of RUSI against MRI was examined for the cervical multifidus muscle in 10 healthy subjects at 3 cervical levels from C4 to C6.[39] Lee et al[39] considered that validity was acceptable for muscle thickness measurements (R^2 = 0.42-0.64), but not for CSA (R^2 = 0.11-0.39) and width (R^2 = 0.16-0.69). The small CSA of the muscle (approximately 1 cm^2 compared with 7 cm^2 for lumbar multifidus) may amplify errors, thus influence the variability of measurements.

CLINICAL STUDIES OF STATIC PARAMETERS

The paraspinal muscles have been studied using RUSI to assess the effects of acute and chronic LBP, as well as the effects of interventions, such as exercise and spinal surgery.

Acute LBP

Hides et al[27] found marked side-to-side asymmetry of the lumbar multifidus muscle CSA in 26 patients with first-episode acute unilateral LBP. The smaller muscle was found at the symptomatic segment (identified by manual palpation), was on the side ipsilateral to symptoms, and was confined predominantly to 1 vertebral level. In the 26 subjects with LBP, average (±SD) between-side difference was 31% ± 8%, compared with 3% ± 4% in 51 asymptomatic subjects. It was not possible to determine whether the reduction in CSA was pre-existing in these subjects. However, data from a study using a porcine model have confirmed that the CSA of the lumbar multifidus muscle reduces rapidly (as early as 3 days) after injury to an intervertebral disc, is isolated to a single segment (the level below the injured disc), and is associated with histochemical changes in the muscle.[28]

Kiesel et al[33] demonstrated the effect of pain on lumbar multifidus muscle function experimentally in humans. Increases in multifidus thickness during arm-lifting tasks were significantly reduced by pain in response to injection of saline into the erector spinae muscles. This investigative application of RUSI not only contributed to knowledge about the effects of pain on muscle activation but added to the validity of RUSI as a clinical measurement of muscle dysfunction.

Chronic LBP

Significant atrophy of CSA was found by Hides et al[22] in patients with chronic LBP compared with healthy controls at the lowest 2 lumbar vertebral levels. Greatest asymmetry was seen at L5 in those with unilateral pain. These results were in agreement with previous computed tomography studies indicating that the pattern of lumbar multifidus muscle atrophy in patients with chronic LBP was localized to the lower region of the spine rather than generalized[13] and that asymmetry occurred in those with unilateral pain.[1] In an MRI study of patients with LBP, Barker et al[1] also reported this selective, localized atrophy. Conversely, another study using computed tomography to measure patients with chronic LBP found generalized atrophy in the lumbar spine but also relatively greater CSA of multifidus on the symptomatic side.[70] This finding was consistent with histological evidence of type I fiber hypertrophy and type II fiber atrophy in individuals with chronic LBP,[17] possibly indicating an adaptive response to muscle wasting. We speculate that this pseudohypertrophy could also be related to fatty infiltration.[35]

Prelumbar Surgery and Postlumbar Surgery

Imaging techniques have proved useful for investigating the effects of spinal surgery on the lumbar multifidus muscle.[32,38,66] In cases of unilateral LBP, researchers using computed tomography found that paraspinal muscles were 10% to 30% smaller on the affected side compared to the unaffected side and fatty degeneration was also evident.[38] Reduced muscle CSA was seen using RUSI in patients prior to surgery with atrophy being more severe in those with greater LBP.[32] Postoperative images showed no further decrease in CSA. However, it was not possible to confirm that muscle atrophy had not occurred, as size changes could have been masked by intramuscular inflammation, seen as hypoechoic areas. Long-term follow-up at 1 year indicated that multifidus muscle atrophy was long lasting.

QUALITATIVE ASSESSMENT AND FEEDBACK

Both static and dynamic parameters can be assessed qualitatively using RUSI. Static assessment generally involves evaluating the ultrasound image focusing on tissue quality. The assessment of dynamic parameters includes using USI to evaluate the ability of the muscle to contract and teaching muscle activation using the image as a source of biofeedback.

Assessment of Static Parameters

Impairments of the lumbar muscles in subjects with LBP have been demonstrated in terms of both decreased muscle size and density.[27,50] Decreased muscle density can be caused by fatty infiltration (increased fat-muscle fiber ratio) or actual fatty replacement of fibers.[35,45] While changes in density have been predominantly reported in computed tomography and MRI studies, changes in consistency of the lumbar multifidus muscles have been observed using USI.[27,32] The ultrasound appearance of healthy muscle is usually dark, due to its excellent perfusion and resultant high fluid content. The presence of fatty infiltration, fibrous changes, or scar tissue (noncontractile tissue) leads to a change in its sonographic appearance, as noncontractile tissue is hyperechoic, making muscle appear more white (**FIGURE 12**).[27] On computerized tomographic scans, normal healthy muscle

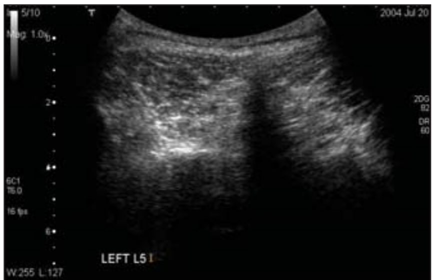

FIGURE 12. Hyperechoic lumbar multifidus muscle at L5 in a patient with chronic low back pain, using a 5-MHz curvilinear transducer. The muscle tissue appears whiter compared with that in the scans of normal subjects in Figures 3, 7, 8, and 9.

appears grey and uniform. Consistency changes will present as dark areas. In contrast, on specific MRI sequencing, fatty infiltration and fibrous changes appear white. Consistency changes have most commonly been reported in subjects with chronic LBP.[30]

The fat content of the lumbar multifidus and longissimus muscles was measured in 25 patients with chronic LBP and 25 matched asymptomatic volunteers using MR spectroscopy.[50] There was a significantly higher mean percentage of fat content in subjects with chronic LBP (23.6%; 95% CI: 17.5%, 29.7%) than in asymptomatic subjects (14.5%; 95% CI: 10.8%, 18.3%). Values for the longissimus muscle did not differ between patients and control subjects. Further work is required to validate the interpretation of muscle density on RUSI and to determine reliability. This is likely to be a complex task because image brightness is influenced by the individualized gain settings used by the operator.

Lumbar multifidus muscle atrophy appears to be a common finding in patients with chronic LBP. In a recent MRI study of 78 patients with LBP (with and without lower extremity pain), changes in multifidus muscle consistency were graded as mild (fatty or fibrous tissue replacement less than 10%), moderate (replacement less than 50%), and severe (greater than 50%).[30] Degeneration of multifidus was present in 80% of the subjects with LBP, and most commonly occurred at the L4-L5 and L5-SI levels. Sixty-six of the 78 patients with LBP (85%) had degenerated lumbar discs on MRI.

Assessment of Dynamic Parameters

Clinical assessment of paraspinal muscle performance involves palpation of the lumbar multifidus muscles at each vertebral level as the patient preferentially activates the muscle. Muscle thickness changes can be seen using real-time RUSI (**FIGURE 13**) as the patient performs the test maneuver and have been demonstrated reliably in the lumbar[24,26] and cervical muscles.[39]

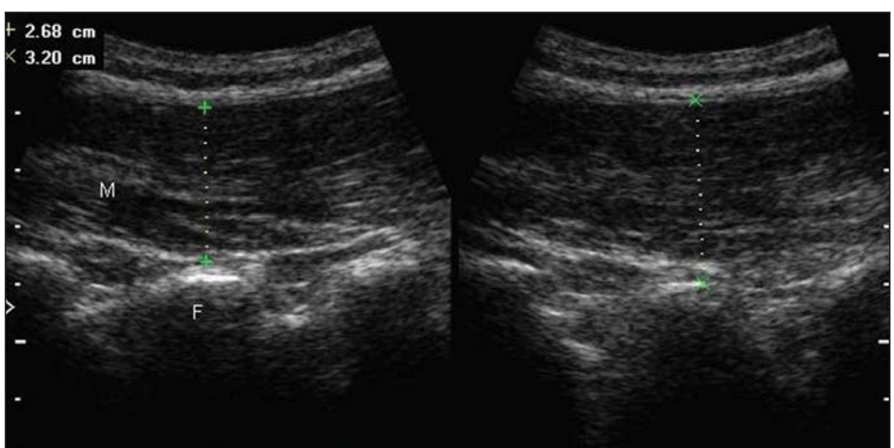

FIGURE 13. Biofeedback of lumbar multifidus: parasagittal view using split-screen function and 5-MHz curvilinear transducer. The facet joints (F) were used as landmarks for the lower borders of the multifidus (M) muscle. During contraction (right panel), the muscle becomes thicker and the angle of the fibers becomes steeper, providing feedback. The left panel shows the muscle at rest.

The ability of patients with chronic LBP to activate the lumbar multifidus muscle has been found to be reduced, as evidenced by smaller increases in thickness on RUSI images during contraction than in asymptomatic controls.[77] A randomized controlled trial of healthy subjects by Van et al[74] examined whether visual biofeedback using RUSI enhanced the ability to activate the lumbar multifidus muscle. All subjects received clinical instruction on how to activate the multifidus muscle isometrically and verbal feedback on performance (acquisition phase). The intervention group received visual biofeedback with RUSI in parasagittal section.[24,26,34] Both subject groups improved voluntary contraction (increases from resting thickness) in the acquisition phase, but the RUSI biofeedback group achieved greater improvements. On reassessment a week later (retention phase), the RUSI group maintained the improvements, whereas performance in the control group decreased.

A clinical randomized controlled trial of people with acute LBP used RUSI successfully for feedback of lumbar multifidus muscle activation.[26] Symmetry of multifidus CSA was restored in the exercise intervention group within 4 weeks. Despite pain relief and the general muscle use associated with return to normal activity levels, patients in the control group (conventional treatment) still displayed multifidus atrophy at a 10-week follow-up. Long-term results revealed that subjects from the specific-exercise group experienced fewer recurrences of LBP than the control group.[23] A limitation of this work is the lack of comparison with an exercise group focusing on multifidus rehabilitation without RUSI feedback. Nevertheless, other investigators have similarly advocated the benefits of RUSI for teaching muscle activation.[14,20,24,74]

The principles of motor learning[16] may explain why visual feedback is of benefit for subjects with LBP. In the initial stages of learning a new skill (cognitive stage), time is spent understanding the demands of the task, what to do, and what to feel. The clinical observation that people with LBP find it difficult to contract the lumbar multifidus muscle may be due to processes such as reflex inhibition,[69] which was thought to play a role in multifidus wasting in individuals with acute LBP.[27] Biofeedback may be beneficial as subjects with LBP have been shown to have decreased proprioception,[57] which affects their ability to provide and process internal feedback.

Clinical Implications

Prescription of therapeutic exercise for the patient with LBP is based on knowledge of normal function of the paraspinal muscles, and the presence and nature of impairment in terms of size or activation. Impairment of lumbar multifidus is often specific to the side and vertebral level of symptoms[22,24,26,27] and this has been found in subjects with acute and chronic LBP. Before the introduction of RUSI into clinical practice, physical therapists could only palpate for multifidus muscle atrophy. This may have previously led to an underestimation of atrophy. Via visualization of the paraspinal muscles using RUSI, impairments can be better assessed and documented. In addition to objective measurements of muscle size, changes in muscle consistency can also be observed. RUSI can be used to provide baseline measures of impairments, and also to document improvements over time and with intervention. Therapeutic exercise may need to be as specific as the impairments that occur in order to address them. RUSI can provide visual feedback to enhance motor learning for contracting a specific muscle or part of a muscle. From a clinical perspective, the use of imaging techniques has already provided a wealth of information in both research and clinical practice.

Evidence that feedback with RUSI enhances motor learning holds promise for the future but studies are needed on subjects with LBP, and therapeutic exercise interventions need to be compared with and without the use of RUSI for biofeedback, to ultimately determine the benefits of this rehabilitation tool.

DIRECTION OF FUTURE RESEARCH

Almost all lines of research on paraspinal muscles produce more questions or uncover areas of uncertainty. If RUSI is to become a routine aid to physical therapy practice and a robust research tool, standardized protocols are needed. Technical studies of the size of the transducer and whether linear and curvilinear arrays produce the same measurements are needed to provide guidance on appropriate methodology. The predictive value of linear measurements to provide an estimate of CSA needs to be established for different muscles in different states, such as resting, contracted, wasted, or hypertrophied. The validity of using linear measurements to predict the CSA of irregularly shaped muscles requires attention.

Comprehensive studies of healthy populations are needed to generate reference databases for assessing the effects of pathology and interventions. Factors to consider include age, gender, body type (physical characteristics including height and body mass), ethnicity, geographic distribution (due to lifestyle differences), and levels of habitual physical activity from sedentary to elite sporting groups. Data for interrelationships between different spinal levels would be useful for detecting abnormality at a specific level.

Substantial work remains to validate the dynamic techniques for measuring both magnitude and timing of changes in muscle for clinical use. Longitudinal epidemiological studies are needed to determine those at risk of developing LBP or neck conditions, whether wasting occurs before the onset of injury and/or pain, and to help elucidate the mechanisms of wasting.

The contribution of noncontractile tissue to CSA, affecting the density (or consistency) of muscle, needs to be quantified to determine true muscle size with pathology, particularly in subjects with chronic pain, and aging. The sonographic technique of elastography is potentially useful for distinguishing the biomechanical behavior of these tissues.[53,79] It would be of interest to know if the ratio of noncontractile tissue to contractile tissue can be altered with therapeutic exercise. Elastography may also help distinguish between activity of the deep and superficial parts of muscle to study their differing functions.

The effects of different pathologies on the paraspinal muscles need to be established in musculoskeletal and neurological disorders. Large randomized controlled trials are needed to demonstrate that RUSI is a reliable outcome measure for assessing the effects of interventions. We recommend that future studies present data consistently and use the same statistical methods, as outlined by Whittaker et al[79] to enable valid comparison between studies and to enhance accumulation of large reference databases as a common resource for evaluation of abnormality.

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REFERENCES

1. Barker KL, Shamley DR, Jackson D. Changes in the cross-sectional area of multifidus and psoas in patients with unilateral back pain: the relationship to pain and disability. *Spine.* 2004;29:E515-519.
2. Bogduk N. The clinical anatomy of the cervical dorsal rami. *Spine.* 1982;7:319-330.
3. Bogduk N. Clinical *Anatomy of the Lumbar Spine and Sacrum.* Edinburgh, UK: Churchill Livingston; 2006.
4. Bogduk N, Macintosh JE, Pearcy MJ. A universal model of the lumbar back muscles in the upright position. *Spine.* 1992;17:897-913.
5. Burton A. Regional lumbar sagittal mobility: measurement by flexicurves. *Clin Biomech.* 1986;1:20-26.
6. 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.
7. Cholewicki J, Panjabi MM, Khachatryan A. Stabilizing function of trunk flexor-extensor muscles around a neutral spine posture. *Spine.* 1997;22:2207-2212.
8. Cholewicki J, VanVliet JJ. Relative contribution of trunk muscles to the stability of the lumbar spine during isometric exertions. *Clin Biomech (Bristol, Avon).* 2002;17:99-105.
9. Chudleigh T, Thilaganathan B. *Obstetric Ultrasound.* London, UK: Churchill Livingstone; 2004.
10. Coldron Y, Stokes M, Cook K. Lumbar multifidus muscle size does not differ whether ultrasound imaging is performed in prone or side lying. *Man Ther.* 2003;8:161-165.
11. Corneil BD, Olivier E, Richmond FJ, Loeb GE, Munoz DP. Neck muscles in the rhesus monkey. II. Electromyographic patterns of activation underlying postures and movements. *J Neurophysiol.* 2001;86:1729-1749.
12. Crisco JJ, third, Panjabi MM. The intersegmental and multisegmental muscles of the lumbar spine. A biomechanical model comparing lateral stabilizing potential. *Spine.* 1991;16:793-799.
13. Danneels LA, Vanderstraeten GG, Cambier DC, Witvrouw EE, De Cuyper HJ. CT imaging of trunk muscles in chronic low back pain patients and healthy control subjects. *Eur Spine J.* 2000;9:266-272.
14. Dietz HP, Wilson PD, Clarke B. The use of perineal ultrasound to quantify levator activity and teach pelvic floor muscle exercises. *Int Urogynecol J Pelvic Floor Dysfunct.* 2001;12:166-168; discussion 168-169.
15. Elliott J, Jull G, Noteboom JT, Darnell R, Galloway G, Gibbon WW. Fatty infiltration in the cervical extensor muscles in persistent whiplash-associated disorders: a magnetic resonance imaging analysis. *Spine.* 2006;31:E847-855.
16. Fitts PM, Posner MI. *Human Performance.* Belmont, CA: Brooks/Cole; 1967.
17. Fitzmaurice R, Cooper RG, Freemont AJ. A histomorphometric comparison of muscle biopsies from normal subjects and patients with ankylosing spondylitis and severe mechanical low back pain. *J Pathol.* 1992;163:182A.
18. Granata KP, Marras WS. Cost-benefit of muscle cocontraction in protecting against spinal instability. *Spine.* 2000;25:1398-1404.
19. Hayashi N, Masumoto T, Abe O, Aoki S, Ohtomo K, Tajiri Y. Accuracy of abnormal paraspinal muscle findings on contrast-enhanced MR images as indirect signs of unilateral cervical root-avulsion injury. *Radiology.* 2002;223:397-402.
20. Henry SM, Westervelt KC. The use of real-time ultrasound feedback in teaching abdominal hollowing exercises to healthy subjects. *J Orthop Sports Phys Ther.* 2005;35:338-345.
21. Hides J, Cooper DH, Stokes MJ. Diagnostic ultrasound imaging for measurement of the lumbar multifidus muscle in normal young adults. *Physiother Theor Pract.* 1992;8:19-26.
22. Hides J, Gilmore C, Stanton W, Bohlscheid E. Multifidus size and symmetry among chronic LBP and healthy asymptomatic subjects. *Man Ther.* 2006 Oct 26; [Epub ahead of print].
23. Hides JA, Jull GA, Richardson CA. Long-term effects of specific stabilizing exercises for first-episode low back pain. *Spine.* 2001;26:E243-248.
24. Hides JA, Richardson CA, Jull G. Use of real-time ultrasound imaging for feedback in rehabilitation. *Man Ther.* 1998;3:125-131.
25. Hides JA, Richardson CA, Jull GA. Magnetic resonance imaging and ultrasonography of the lumbar multifidus muscle. Comparison of two different modalities. *Spine.* 1995;20:54-58.
26. Hides JA, Richardson CA, Jull GA. Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. *Spine.* 1996;21:2763-2769.
27. Hides JA, Stokes MJ, Saide M, Jull GA, Cooper DH. Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute/subacute low back pain. *Spine.* 1994;19:165-172.
28. Hodges P, Holm AK, Hansson T, Holm S. Rapid atrophy of the lumbar multifidus follows experimental disc or nerve root injury. *Spine.* 2006;31:2926-2933.
29. Hodges PW, Pengel LH, Herbert RD, Gandevia SC. Measurement of muscle contraction with ultrasound imaging. *Muscle Nerve.* 2003;27:682-692.
30. Kader DF, Wardlaw D, Smith FW. Correlation between the MRI changes in the lumbar multifidus muscles and leg pain. *Clin Radiol.* 2000;55:145-149.
31. Kaigle AM, Holm SH, Hansson TH. Experimental instability in the lumbar spine. *Spine.* 1995;20:421-430.
32. Kelley SM. *The Effect of Two Exercise Programs Following Back Surgery* [thesis]. Queensland, Australia: University of Queensland; 2005.
33. Kiesel KB, Uhl T, Underwood FB, Nitz AJ. Rehabilitative ultrasound measurement of select trunk muscle activation during induced pain. *Man Ther.* 2006 Dec 30; [Epub ahead of print].
34. Kiesel KB, Uhl TL, Underwood FB, Rodd DW, Nitz AJ. Measurement of lumbar multifidus muscle contraction with rehabilitative ultrasound imaging. *Man Ther.* 2007;12:161-166.
35. Kjaer P, Bendix T, Sorensen JS, Korsholm L, Leboeuf-Yde C. Are MRI-defined fat infiltrations in the multifidus muscles associated with low back pain? *BMC Med.* 2007;5:2.
36. Kline P. *A Handbook of Test Construction.* London, UK: Methuen; 1986.
37. Kristjansson E. Reliability of ultrasonography for the cervical multifidus muscle in asymptomatic and symptomatic subjects. *Man Ther.* 2004;9:83-88.

38. Laasonen EM. Atrophy of sacrospinal muscle groups in patients with chronic, diffusely radiating lumbar back pain. *Neuroradiology.* 1984;26:9-13.
39. Lee JP, Tseng WY, Shau YW, Wang CL, Wang HK, Wang SF. Measurement of segmental cervical multifidus contraction by ultrasonography in asymptomatic adults. *Man Ther.* 2007;12:286-294.
40. Lee SW, Chan CK, Lam TS, et al. Relationship between low back pain and lumbar multifidus size at different postures. *Spine.* 2006;31:2258-2262.
41. Lord SM, Barnsley L, Wallis BJ, Bogduk N. Chronic cervical zygapophysial joint pain after whiplash. A placebo-controlled prevalence study. *Spine.* 1996;21:1737-1744; discussion 1744-1745.
42. MacDonald D, Moseley GL, Hodges PW. The function of the lumbar multifidus in unilateral low back pain. *Proceedings of World Congress of Low Back and Pelvic Pain.* Melbourne, Australia; 2004:329.
43. Macintosh JE, Bogduk N. 1987 Volvo award in basic science. The morphology of the lumbar erector spinae. *Spine.* 1987;12:658-668.
44. Macintosh JE, Valencia F, Bogduk N, Munro RR. The morphology of the human lumbar multifidus. *Clin Biomech.* 1986;1:196-204.
45. Mayer TG, Vanharanta H, Gatchel RJ, et al. Comparison of CT scan muscle measurements and isokinetic trunk strength in postoperative patients. *Spine.* 1989;14:33-36.
46. Mayoux-Benhamou MA, Revel M, Vallee C. Selective electromyography of dorsal neck muscles in humans. *Exp Brain Res.* 1997;113:353-360.
47. McGill SM. Kinetic potential of the lumbar trunk musculature about three orthogonal orthopaedic axes in extreme postures. *Spine.* 1991;16:809-815.
48. McGill SM, Grenier S, Kavcic N, Cholewicki J. Coordination of muscle activity to assure stability of the lumbar spine. *J Electromyogr Kinesiol.* 2003;13:353-359.
49. McMeeken JM, Beith ID, Newham DJ, Milligan P, Critchley DJ. The relationship between EMG and change in thickness of transversus abdominis. *Clin Biomech (Bristol, Avon).* 2004;19:337-342.
50. Mengiardi B, Schmid MR, Boos N, et al. Fat content of lumbar paraspinal muscles in patients with chronic low back pain and in asymptomatic volunteers: quantification with MR spectroscopy. *Radiology.* 2006;240:786-792.
51. 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.
52. Nolan JP, Jr., Sherk HH. Biomechanical evaluation of the extensor musculature of the cervical spine. *Spine.* 1988;13:9-11.
53. Ophir J, Cespedes I, Ponnekanti H, Yazdi Y, Li X. Elastography: a quantitative method for imaging the elasticity of biological tissues. *Ultrason Imaging.* 1991;13:111-134.
54. O'Sullivan C, Bentman S, Bennett K, Stokes M. Rehabilitative ultrasound imaging of the lower trapezius muscle: technical description and reliability. *J Orthop Sports Phys Ther.* 2007;37(10):620-626.
55. Panjabi M, Abumi K, Duranceau J, Oxland T. Spinal stability and intersegmental muscle forces. A biomechanical model. *Spine.* 1989;14:194-200.
56. Panjabi MM, Cholewicki J, Nibu K, Grauer JN, Babat LB, Dvorak J. Mechanism of whiplash injury. *Clin Biomech (Bristol, Avon).* 1998;13:239-249.
57. Parkhurst TM, Burnett CN. Injury and proprioception in the lower back. *J Orthop Sports Phys Ther.* 1994;19:282-295.
58. Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice.* London, UK: Prentice-Hall Health; 2000.
59. Pressler JF, Heiss DG, Buford JA, Chidley JV. Between-day repeatability and symmetry of multifidus cross-sectional area measured using ultrasound imaging. *J Orthop Sports Phys Ther.* 2006;36:10-18.
60. Quint U, Wilke HJ, Shirazi-Adl A, Parnianpour M, Loer F, Claes LE. Importance of the intersegmental trunk muscles for the stability of the lumbar spine. A biomechanical study in vitro. *Spine.* 1998;23:1937-1945.
61. Rankin G, Stokes M, Newham DJ. Size and shape of the posterior neck muscles measured by ultrasound imaging: normal values in males and females of different ages. *Man Ther.* 2005;10:108-115.
62. RezaSoltani A, Kallinen M, Malkia E, Vihko V. Ultrasonography of the neck splenius capitis muscle. Investigation in a group of young healthy women. *Acta Radiol.* 1996;37:647-650.
63. RezaSoltani A, Kallinen M, Malkia E, Vihko V. Neck semispinalis capitis muscle size in sitting and prone positions measured by real-time ultrasonography. *Clin Rehabil.* 1998;12:36-44.
64. Shi J, Zheng YP, Chen X, Huang QH. Assessment of muscle fatigue using sonomyography: muscle thickness change detected from ultrasound images. *Med Eng Phys.* 2007;29:472-479.
65. Siegmund GP, Myers BS, Davis MB, Bohnet HF, Winkelstein BA. Mechanical evidence of cervical facet capsule injury during whiplash: a cadaveric study using combined shear, compression, and extension loading. *Spine.* 2001;26:2095-2101.
66. Sihvonen T, Herno A, Paljarvi L, Airaksinen O, Partanen J, Tapaninaho A. Local denervation atrophy of paraspinal muscles in postoperative failed back syndrome. *Spine.* 1993;18:575-581.
67. Springer BA, Mielcarek BJ, Nesfield TK, Teyhen DS. Relationships among lateral abdominal muscles, gender, body mass index, and hand dominance. *J Orthop Sports Phys Ther.* 2006;36:289-297.
68. Stokes M, Rankin G, Newham DJ. Ultrasound imaging of lumbar multifidus muscle: normal reference ranges for measurements and practical guidance on the technique. *Man Ther.* 2005;10:116-126.
69. Stokes M, Young A. The contribution of reflex inhibition to arthrogenous muscle weakness. *Clin Sci (Lond).* 1984;67:7-14.
70. Stokes MJ, Cooper RG, Jayson MIV. Selective changes in multifidus dimensions in patients with chronic low back pain. *Eur Spine J.* 1992;1:38-42.
71. Takebe K, Vitti M, Basmajian JV. The functions of semispinalis capitis and splenius capitis muscles: an electromyographic study. *Anat Rec.* 1974;179:477-480.
72. Tsubahara A, Chino N, Akaboshi K, Okajima Y, Takahashi H. Age-related changes of water and fat content in muscles estimated by magnetic resonance (MR) imaging. *Disabil Rehabil.* 1995;17:298-304.
73. Uetani M, Hayashi K, Hashmi R, Nakahara N, Aso N, Ito N. Traction injuries of the brachial plexus: signal intensity changes of the posterior cervical paraspinal muscles on MRI. *J Comput Assist Tomogr.* 1997;21:790-795.
74. Van K, Hides JA, Richardson CA. The use of real-time ultrasound imaging for biofeedback of lumbar multifidus muscle contraction in healthy subjects. *J Orthop Sports Phys Ther.* 2006;36:920-925.
75. Vasseljen O, Dahl HH, Mork PJ, Torp HG. Muscle activity onset in the lumbar multifidus muscle recorded simultaneously by ultrasound imaging and intramuscular electromyography. *Clin Biomech (Bristol, Avon).* 2006;21:905-913.
76. Wallwork T, Hides J, Stanton W, Belavy D. Intrarater and interrater reliability of assessment of lumbar multifidus muscle thickness using real-time ultrasound imaging. *J Orthop Sports Phys Ther.* 2007;37(10):608-612.
77. Wallwork TL. *The Effect of Chronic Low Back Pain on the Size and Activation of the Lumbar Multifidus Muscle* [thesis]. Queensland, Australia: University of Queensland; 2006.
78. Watanabe K, Miyamoto K, Masuda T, Shimizu K. Use of ultrasonography to evaluate thickness of the erector spinae muscle in maximum flexion and extension of the lumbar spine. *Spine.* 2004;29:1472-1477.
79. Whittaker JL, Teyhen DS, Elliott J, et al. Rehabilitative ultrasound imaging: understanding the technology and its applications. *J Orthop Sports Phys Ther.* 2007;37:434-449.
80. Wilke HJ, Wolf S, Claes LE, Arand M, Wiesend A. Stability increase of the lumbar spine with different muscle groups. A biomechanical in vitro study. *Spine.* 1995;20:192-198.
81. Winkelstein BA, McLendon RE, Barbir A, Myers BS. An anatomical investigation of the human cervical facet capsule, quantifying muscle insertion area. *J Anat.* 2001;198:455-461.
82. Winkelstein BA, Nightingale RW, Richardson WJ, Myers BS. The cervical facet capsule and its role in whiplash injury: a biomechanical investigation. *Spine.* 2000;25:1238-1246.