# Role of ultrasound in Low Back Pain – A Review

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# Abstract

Low back pain is one of most common musculoskeletal disorders around the world. One major problem clinicians are faced with is the lack of objective assessment modalities. Computerized Tomography and Magnetic Resonance Imaging are commonly utilized but are unable to clearly distinguish abnormalities found in patients with low back pain from healthy subjects. The reason behind may be due to the anisotropic nature of muscles which is altered in function and those scans only provide structural assessment. In view of this, ultrasound may be helpful in understanding the disease as it is real-time and consists of different modes which measure thickness, blood flow and stiffness. Using ultrasound, patients with low back pain are found to be different from healthy subjects via thickness and stiffness of the transversus abdominis, thoracolumbar fascia and multifidus. The study results are currently still not conclusive and further study is necessary to validate. Future direction should focus on quantitative assessment of these tissues to provide textural, structural, hemodynamics and mechanical study of low back pain. This review highlights the current understanding of how medical ultrasound has been used for diagnosis and study of low back pain and discuss potential new applications.

Key Words: Low back pain; ultrasound; muscle; transversus abdominis; thoracolumbar fascia; multifidus

# Introduction

Low back pain (LBP) is one of the major musculoskeletal disorders around the world (Hoy, et al. 2012). According to the Global Burden of Disease 2010 Study which outlines the mortality and disability from major diseases, injuries and risk factors, LBP ranked first in terms of disability and sixth in terms of overall burden presented as disability-adjusted life years (Hoy, et al. 2014). As reported by the World Health Organization, it is one of the dominant factors which restrict motion and work ability, thus resulting in an economic and social burden (Kaplan, et al. 2013).

LBP is classified as acute and chronic according to the duration and pathology. Acute LBP refers to pain that lasts less than six weeks, whereas chronic LBP is when the pain persists for more than three months (Koes, et al. 2006). If the causative pathology is not conclusive, this type of LBP is referred to as non-specific LBP. Unfortunately, non-specific LBP is common with prevalence rate of 23% and accounts for about 90% of all LBP patients (Airaksinen, et al. 2006, Koes, et al. 2006, Mills 2015).

The following is a review regarding the role of ultrasound in diagnosis and treatment of LBP. All studies included have obtained informed consent from study participants and protocol approval by an institutional review board.

## LBP

Diagnosis is made through history-taking, physical examination and targeted investigations. After case history and identification of symptoms, physical examination like segmental motion tests, examination of the sacroiliac joint, facet joints, and paraspinal musculature aid in diagnosis of the pathology (Airaksinen, et al. 2006, Rubinstein and Van Tulder 2008). If the pain is severe or persists despite conservative treatment, further investigations are required, such as Computer Tomography (CT) and Magnetic Resonance Imaging (MRI) (Airaksinen, et al. 2006). However, they are often found ineffective in identifying the underlying cause because image abnormalities observed in patients with LBP may also be found in healthy individuals (Boden, et al. 1990). Hence, imaging features alone cannot differentiate symptomatic subjects from asymptomatic subjects (Koes, et al. 2006). Other studies also indicated that the use of imaging does not improve the clinical outcomes but increased the financial burden (Gilbert, et al. 2004, Chou, et al. 2009). Therefore, it is suggested that imaging should be used only when the pain is severe and persistent despite conservative treatment or for patients considering surgery (Jarvik and Deyo 2002, Chou, et al. 2007). Hence, symptomatology is most important, and imaging features are only tools for confirmation of diagnosis (Mills 2015).

Treatment is categorized into conservative, pharmacological and invasive means (Koes, et al. 2006). Conservative treatment includes exercise, physical therapy, behavior therapy and manual therapy. Pharmacological treatment includes non-steroidal anti-inflammatory drugs (NSAIDs), muscle relaxants and weak opioids. Invasive therapy includes acupuncture, steroid injections and surgery (Airaksinen, et al. 2006, Koes, et al. 2006, Mills 2015). Due to the wide disease spectrum, often no single treatment is effective and combination therapy may provide the best results. Indications are unclear and may be due variable pain generators and perception between acute and chronic LBP, lack of detailed disease severity and characteristics, and insufficient outcome measures (Flor and Turk 1984, Airaksinen, et al. 2006, Koes, et al. 2006).

# Tissues studied in understanding LBP

Lumbar muscle has been extensively investigated in LBP studies because it is one of the common causes of LBP (Rosomoff, et al. 1989), and it contributes to spinal stability (Roy, et al. 1989). It can be classified into two groups—local muscles and global muscles. Local muscles refer to those directly linked to the lumbar vertebrae and involved in segmental stability and position control (Roy, et al. 1989). These include multifidi (MF), psoas major, transversus abdominis (TrA), quadratus lumborum, diaphragm, posterior fibers of internal oblique (IO) and the lumbar portions of iliocostalis and longissimus (Stuge, et al. 2004). Global muscles refer to those connecting pelvis to the thoracic cage and contributing to torque production and trunk stabilisation (Roy, et al. 1989). They include rectus abdominis (RA), external oblique (EO), anterior fibers of internal oblique (IO) and the thoracic portion of iliocostalis (Stuge, et al. 2004).

Among those muscles, TrA and MF are studied most because TrA is controlled independently (Hodges and Richardson 1997, 1997, 1999) and MF is a dominant factor in providing spinal stiffness (Hodges and Richardson 1997). Compared with control subjects, patients with LBP have altered trunk muscle recruitment (Wilder, et al. 1996, Ng, et al. 2002, Van Dieen, et al. 2003, Silfies, et al. 2005), reduced size (Cooper, et al. 1992), weaker muscle (Mcneill, et al. 1980, Biering-Sorensen 1984, Hultman, et al. 1993), reduced flexibility/elasticity of the muscle (Biering-Sorensen 1984), shorter isometric endurance time (Nicolaisen and Jorgensen 1985, Hultman, et al. 1993) and fatty replacement (Alaranta, et al. 1993) in the lumbar muscle.

Other than muscle, fascia is also important in understanding LBP as it regulates human posture and movement by force transmission (Schleip, et al. 2005). Thoracolumbar fascia (TLF) is a connective tissue in the thoracic and cervical regions and contributes to spinal stability through stiffening (Tesh, et al. 1987). Due to its function, studies have focused on TLF.

### *TrA*

TrA is focused on in this paper because it is responsible for spinal stability. From Figure 1, the EO, IO, and TrA are abdominal muscles which form a wall to protect the organs and maintain spine posture (Ellis 1989). Several studies showed that patients with LBP and asymptomatic individuals differed in abdominal muscle property and function. For example, one study showed that there was a significant difference in terms of pressure change between people with and without LBP when performing abdominal drawing-in manoeuvre (ADIM)(Cairns, et al. 2000) which is one of the strengthening exercises for EO, IO and TrA (Park and Yu 2013). Previous studies have shown that TrA is controlled independently from others during limb movement, suggesting that TrA may play a special role in stability (Hodges and Richardson 1997, 1997, 1999). Later studies found that TrA improved stability through stiffening the spine by increasing intra-abdominal pressure (IAP) or stiffening TLF (Tesh, et al. 1987, Cresswell, et al. 1992, Cresswell, et al. 1994, Richardson and Jull 1995, Hodges, et al. 2003).

TrA is the innermost muscle in the abdominal wall, runs horizontally around the abdomen via the TLF to the transverse aspect of the vertebrae, and links the ribs to the inguinal ligament (Ellis 1989, Critchley and Coutts 2002). It is the only muscle that is consistently linked to the TLF, which facilitates the support of the vertebrae (Tesh, et al. 1987, Springer, et al. 2006).

Patients with LBP are found to have a functional loss, delayed or absence of activity and a smaller change in thickness and cross-sectional area (CSA) in TrA muscle using electromyography (EMG), MRI and CT (Hodges and Richardson 1996, 1998, Hodges 1999).

### *TLF*

Fascia is also crucial for regulating human posture and movement by force transmission (Schleip, et al. 2005). The reason why TLF is also studied because it is stiffened by TrA to improve spinal stability (Tesh, et al. 1987).

It is a diamond-shaped connective tissue that covers intrinsic back muscles in the thoracic and cervical regions. It consists of several aponeurotic and fascial layers, and all layers fuse together at the base into a thick composite. This composite is attached to the posterior superior iliac spine and the sacrotuberous ligament. The posterior layer is dominated by the aponeurosis of the latissimus dorsi and the serratus posterior inferior. The middle layer is the intermuscular septum. The deep lamina encapsulates paraspinal retinacular sheath. It is responsible for posture, respiration, load bearing and load transfer among trunk muscles and the spine (Willard, et al. 2012). From figure 1, posterior, anterior and middle layers of TLF are observed.

TLF is less studied than the other two muscles that more investigation is needed to find out the differences between patients with LBP and healthy human subjects.

### *MF*

Wilke et al (Wilke, et al. 1995) found that MF contributed more than a two-thirds increase of the stiffness at the L4-5 segment. Since the stiffening process is a way to provide stability

(Solomonow, et al. 1998), MF is important in maintaining spine stability (Hodges and Richardson 1997).

MF forms the middle part of paraspinal muscle that is attached directly to the lumbar vertebrae, as shown in figure 1 (Stokes, et al. 2007). It has short muscle fibers and large cross-sectional area. Many muscle fibers are packed and results in large forces that stabilize the lumbar spine. It consists of five fascicles that arise from lumbar vertebrae and each of the fascicles can split into two parts, superficial and deep (Moseley, et al. 2002). Deep fibers span two vertebral segments and function tonically, while superficial fibers span three to five segments and function phasically (Freeman, et al. 2010). As MF is near the center of lumbar joint rotation, the superficial part is suitable for the orientation of the spine, while the deep part controls movement (Moseley, et al. 2002). MF is innervated by only one nerve root, while other paraspinal muscles consist of polysegmental innervation (Campbell, et al. 1998).

Patients with LBP demonstrated reduced endurance (Biedermann, et al. 1991), lower EMG activity during a high load exercise (Danneels, et al. 2002), reduced CSA (Danneels, et al. 2000, Barker, et al. 2004, Lee, et al. 2006), an increase in fat content (Parkkola, et al. 1993, Kjaer, et al. 2007), weaker strength (Parkkola, et al. 1993) and higher signal intensity in MF muscle (Yanik, et al. 2013). For other imaging modalities, only MRI has been used to study MF muscle signal intensity. To study the muscle recruitment patterns, one study calculated the signal intensity of lumbar muscle at rest and with lumbar extension exercise. The result showed that there were significant differences in signal between MF and longissimus/iliocostalis signal intensity in patients with LBP with and without surgery during exercises and in all groups at rest.(Flicker, et al. 1993) It has been found that MRI signal intensity was correlated to fat fraction and fat-signal fractions could represent lumbar muscle fat content in LBP subjects.(Fischer, et al. 2013) Another study focused on fatty degeneration signal intensity in MF and found out that the signal values were higher in LBP patients than controls.(Yanik, et al. 2013) Given that the CSA of MF was reduced in the painful side of patients with LBP compared to their non-painful side, there was no significant differences in terms of signal intensity between two sides.(Wan, et al. 2015)

# Diagnostic Ultrasound

Ultrasound is a sound wave with a frequency greater than the upper limit (20kHz) of the audible range of the human ears. Medical ultrasound not only is a diagnostic tool but also may exert a therapeutic effect. Compared with other imaging modalities, ultrasound imaging is non-invasive, real-time, portable and cost effective. It has been applied widely, for instance, in abdominal, cardiac, maternity, gynecological, urological, cerebrovascular, musculoskeletal and breast examinations (Kollmann 2015).

*Ultrasound B-mode imaging and TrA*

Commonly-used ultrasound probes include 5 to 7 MHz linear, 5 MHz curved and 2-5 MHz curvilinear arrays. The probe is mostly placed in the midway between the inferior angle of the rib cage and the iliac crest. TrA thickness measurements are usually taken at the end of expiration. Figure 2 shows a B-mode image of abdominal muscle in a healthy human subject reconstructed by coherent plane wave compounding with three steered (-2°, 0, 2°) plane waves (Montaldo, et al. 2009). This coherent plane wave compounding technique is a requisite in shear wave imaging (see Shear Wave Imaging section and figures 4-5). The intra-rater reliability for B-mode was good (Mcmeeken, et al. 2004, Koppenhaver, et al. 2009, Mangum, et al. 2016, Wilson, et al. 2016, Cuellar, et al. 2017, Gibbon, et al. 2017, Aboufazeli and Afshar-Mohajer 2018, Naghdi, et al. 2018), and an average of three consecutive measurements was suggested to obtain optimized intra-examiner measurement precision (Koppenhaver, et al. 2009, Linek, et al. 2014, 2015). Ultrasound thickness measurement was found to correlate with MRI (Hides, et al. 2006).

Studies using ultrasound and EMG had shown that TrA was recruited before the superficial abdominal muscle during various body movement. The differences in muscle activation between TrA and other abdominal muscles suggest that TrA is controlled independently (De Troyer, et al. 1990, Cresswell, et al. 1992, Hodges and Richardson 1997).

Since muscle thickness is related to the contraction level, B-mode has been used to measure the thickness of TrA (Mcmeeken, et al. 2004). The results showed that TrA was the major muscle involved in IAP generation and was the thickest at the end of expiration (Misuri, et al. 1997, Ainscough-Potts, et al. 2006). Its thickness was affected by the postural change, gender and Body Mass Index (BMI) (Ainscough-Potts, et al. 2006, Rankin, et al. 2006, Springer, et al. 2006, Manshadi, et al. 2011, Rho, et al. 2013, Eriksson Crommert, et al. 2017, Linek 2017). Linek et al. (Linek, et al. 2015) suggested body mass constituted 30% to 50% of the change in thickness. They also found positive correlation between body mass and muscle thickness in 321 adolescents (Linek, et al. 2017), but Nuzzo and Mayer (Nuzzo and Mayer 2013) did not in 62 male career firefighters. Since the subjects of the two studies are different, it is difficult to compare the results of the two studies and draw a conclusion about the relationship between those factors and muscle thickness. Thus, more studies are needed to establish the relationship.

In healthy subjects, performing low-abdominal hollowing and a weight-bearing task could lead to an increase in TrA thickness (Critchley 2002, Hides, et al. 2007). For patients with LBP, many studies found that they had a smaller increase in thickness compared to control when performing tasks or in standing or sitting positions (Critchley and Coutts 2002, Ferreira, et al. 2004, Rasouli, et al. 2011, Rostami, et al. 2015, Chen, et al. 2016, Ehsani, et al. 2016, Gray, et al. 2016, Shadani, et al. 2018, Shahali S Pt, et al. 2019). Contraction ratio calculated based on the TrA thickness at rest and at contracted state also indicated a significant difference between patients with LBP and controls (Pulkovski, et al. 2012). However, some studies found no significant differences in the thickness change of TrA between patients with LBP and controls (Pinto, et al. 2011, Rostami, et al. 2015, Sutherlin, et al. 2018). Another study also found that there is no correlation between abdominal muscle thickness and LBP (Noormohammadpour, et al. 2016).

Although some previous studies found there was a delayed onset of feedforward action in patients with LBP (Hodges and Richardson 1996, 1998, Hodges 1999), a study (Gubler, et al. 2010) conversely found that earlier activation occurred on the right side in patients. Since the results did not show a relationship between the onset of activation and pain, further studies are needed to find out the clinical significance of the activation.

As the majority of studies found differences between patients with LBP and controls in terms of thickness, some of the rehabilitation exercises for the patients have focused on strengthening the TrA to increase its thickness. Studies had shown that abdominal draw-in maneuver, motor control exercise and long-term pilates exercises increased the muscle thickness in patients with LBP (Kermode 2004, Teyhen, et al. 2005, Hides, et al. 2006, Yang, et al. 2016, Gala-Alarcón, et al. 2018). However, one study found that patients had positive clinical improvements (pain and disability) after an 8-week lumbar stabilization exercise program but showed minimal systematic changes in muscle thickness. (Lariviere, et al. 2018). A study (Pishnamaz, et al. 2018) also proposed that muscle function was not highly correlated to pain. The complex nature of LBP may explain the contradiction of the results. Future study in investigating the outcomes of using rehabilitation exercises have to consider the nature of the LBP patients. For example, the subjects should be single sex and have similar BMI.

*Ultrasound B-mode imaging and TLF*

Generally, a linear array probe is used and it is mostly positioned longitudinally 2 cm lateral to the midline at the level of the L2-3 interspace. The thickness measurement is usually taken at the end of expiration. Figure 3 shows a B-mode image of TLF in a healthy human subject reconstructed by coherent plane wave compounding with three steered (-2°, 0, 2°) plane waves (Montaldo, et al. 2009). High intra-class correlation and modest Krippendorff's Alpha were obtained (De Coninck, et al. 2015). This shows that US is a valid method to measure thickness of TLF.

A study used ultrasound-guided bolus injection on TLF and suggested TLF is sensitive to chemical stimulation (Schilder, et al. 2014). The other study found that transmitting electrical high-frequency pulses in fascia would increase pain intensity. This suggested fascia is one of the tissues attributing to LBP. (Schilder, et al. 2016).

TLF was found to be abnormal in patients with LBP with greater thickness and echogenicity (Langevin, et al. 2009). Two studies performed by the same group of researchers found that the echogenicity of TLF is greater in LBP than healthy subjects for both sexes. The echogenicity was found to be positively correlated to BMI (Langevin, et al. 2009, Langevin, et al. 2011). Those may be due to genetic factors, abnormal movement and connective tissue pathology (Langevin, et al. 2009, Langevin, et al. 2011). One study which focused on one patient found a potential space within the TLF, and the condition could be improved by platelet-rich plasma (Panagos 2018). The abnormal structure may affect the stiffening process of TLF and thus affect its contribution to stability.

*Ultrasound B-mode image and MF*

A 7.5MHz linear array probe is used generally and mostly placed at 4cm laterally to the right of L3 over the longissimus muscle group. The measurement is usually taken at the end of expiration. Figure 3 shows a B-mode image of back muscle in a healthy human subject reconstructed by coherent plane wave compounding with three steered (-2°, 0, 2°) plane waves (Montaldo, et al. 2009). Moderate between day inter-rater reliability was obtained with the measurement made by ultrasound (Pressler, et al. 2006, Koppenhaver, et al. 2009, Belavy, et al. 2015, Cuellar, et al. 2015, Hosseinifar, et al. 2015, Sions, et al. 2015, Wilson, et al. 2016, Cuellar, et al. 2017, Mahdavi and Rezasoltani 2017, Sarafraz, et al. 2018) and an average of 3 measurements was recommended to have a high inter-rater score (Hides, et al. 2006, Wallwork, et al. 2007). However, reliability was affected by the position taken during scanning that tabletop position was found to have the highest reliability in MF thickness measurement (Mangum, et al. 2016). Ultrasound thickness measurement was reported to be highly correlated with the EMG signal but the correlation with MRI is not confirmed for both thickness and CSA (Hides, et al. 1995, Vasseljen, et al. 2006, Kiesel, et al. 2007, Belavy, et al. 2015, Sions, et al. 2017, Naghdi, et al. 2018)

In healthy subjects, the muscle size of MF was the largest at L5 than at L4 (Stokes, et al. 2005) and in male than females (Stokes, et al. 2005, Hides, et al. 2008). A study also found a positive correlation between body mass and MF thickness (Nuzzo and Mayer 2013). MF thickness is affected by the postures and exercises taken (Kang and Shim 2015, Choi, et al. 2016). The CSA was not affected under a posture change from prone to side lying but affected from prone to upright and then 25 degrees and 45 degrees stooping (Coldron, et al. 2003, Chan, et al. 2012). Age was found to be related to the muscle quality as fatty tissue infiltration increased with age, leading to high echogenicity in ultrasound (Stokes, et al. 2005).

For most patients, MF muscle was asymmetric (Hides, et al. 1994, Hides, et al. 2008, Fortin, et al. 2019), smaller than that of the control group at L4-L5 level (Hides, et al. 1994, Hides, et al. 2008, Wallwork, et al. 2009, Chan, et al. 2012, Rostami, et al. 2015, Fortin, et al. 2019), altered in contractile activity (Flicker, et al. 1993, Zhang, et al. 2018), and had more fat area (Chan, et al. 2012) and sciatic nerve enlargement (Sarafraz, et al. 2019). The percentage change in thickness from rest to contracted was also different between patients and controls (Kiesel, et al. 2007, Wallwork, et al. 2009). The degree of asymmetry was not related to severity (Hides, et al. 1994) and the asymmetry might indicate imbalance to stabilize the spine. Reduced size and change in thickness may suggest that the stabilizing force generated by MF is altered because the force applied is related to the size and thickness is related to muscle contraction. Patients with LBP could not obtain maximum contraction as the control group when performing the same position, such as prone lying and upright standing (Lee, et al. 2006). It showed the role in stabilization in patients is altered. However, one study showed that LBP and control groups did not differ in MF thickness (Sutherlin, et al. 2018).

Ultrasound could be used as a bio-feedback for specific stabilization exercise in patients with LBP to enhance accurate contraction (Yang 2015). MF was improved after a core stabilization exercise program, swiss ball, or dry-needling (Kliziene, et al. 2015, Koppenhaver, et al. 2015, Scott, et al. 2015, Hides, et al. 2017). However, some observed that there was no correlation either between muscle size and LBP or muscle function and clinical outcomes such as pain and quality of life (Noormohammadpour, et al. 2016, Pishnamaz, et al. 2018).

Although B-mode imaging can rule out structural abnormalities between patients with LBP and controls in the three tissues, those abnormalities are not able to differentiate the patients from controls as they did not occur in all patients. Scanning beyond anatomical information may be useful, so the use of Doppler imaging and shear wave elastography (SWE) have emerged to facilitate an understanding of LBP.

*Doppler Ultrasound*

Doppler imaging has been applied to study the blood flow in the case of LBP. Table 1 summarized the studies using Doppler Ultrasound. To investigate the relationship among TrA, sacroiliac joint and low back pain, B-mode ultrasound and EMG were used to record muscle patterns, and Doppler imaging was employed to record the sacroiliac joint laxity values which refers to instability of the joint. Vibration of the ilium and sacrum caused by an external vibrator was recorded by Doppler imaging. Laxity value refers to the differences in the two threshold values which were observed in Doppler color image of ilium and sacrum (Damen, et al. 2002, Richardson, et al. 2002). They found that TrA could significantly decrease the laxity of the sacroiliac joint through the contraction.

Espahbodi et al (Espahbodi, et al. 2013) investigated the blood flow in the lumbar artery using Doppler imaging and showed that both patients with LBP and controls had a similar increase in angle-corrected peak systolic blood flow velocity (PSV), but patients had a higher normalized lumbar artery blood flow PSV ratio at all levels than controls. This may indicate that patients with LBP require more blood flow, which may be associated with the pathology of LBP or compensation mechanism.

Tissue Doppler imaging (TDI) is reliable and validated in measuring the onset of feedforward activity (Mannion, et al. 2008). However, one study applied TDI on patients with LBP and found that they did not show a delayed onset of feedforward activity but only earlier activation on one right side. This result contradicts with other studies (Gubler, et al. 2010). Thus, the relationship between time of onset of the muscle activity and pain requires more investigation.

To conclude, patients with LBP needed a higher blood flow in the lumbar artery which may associate with the pathology of LBP.

*Shear Wave Elastography (SWE)*

SWE produces images of elasticity which is elastogram and quantifies the stiffness of the tissue. It captures the propagation of shear wave inside the tissue using ultrafast imaging and the calculated the velocity which is further computed to obtain shear modulus (Lee, et al. 2012).

The propagation wave can be induced by an internal source or an external force. Internal source refer to tissues which produce shear wave through vibration (Lee, et al. 2012), for example, pulse waves of heart tissue was used to measure myocardial viscoelasticity (Kanai 2005). Based on the vibration type, external production of the shear wave can be classified into two groups, quaistatic compression and dynamic which include transient elastography, acoustic radiation force imaging, supersonic imaging and others.

Studies which investigated SWE and TrA in patients with LBP are listed in table 2. Figure 4 shows the shear wave velocity map of TrA in a healthy subject using our in-house shear wave imaging realization (Lee, et al. 2012). In normal subjects, the stiffness is activity-dependent and was found to be higher in certain activities, such as Valsalva maneuver and abdominal bracing (Tran, et al. 2016, Hirayama, et al. 2017). Patients with LBP had significantly higher ratio of right external abdominal oblique shear wave velocity-to-muscle thickness in patients than healthy subjects (Gabrielsen, et al. 2018). Since both external abdominal oblique and TrA are abdominal muscles, TrA stiffness is suspected to be different in patients with LBP than healthy subjects given the external oblique was different between two groups.

Stiffness values estimated by shear wave elastography had moderate to high intra-session and inter-rater reliabilities (Hirayama, et al. 2015, Macdonald, et al. 2016) but were affected by the thick superficial layer that one study found SWE of participants with thick fat layer had many imaging artifacts (Macdonald, et al. 2016).

Table 3 listed studies investigating TLF on patients with LBP. Shear wave velocity map of TLF in a healthy subject is shown in figure 5. Patients had stiffer TLF than controls at rest (Langevin, et al. 2011). However, one study found no significant differences in stiffness in lateral raphe which is part of the TLF between two groups. They also showed that the stiffness was symmetrical on both sides and did not change during rest and ADIM in the asymptomatic group. For patients with LBP, the stiffness increased for both painful and non-painful sides during ADIM (Wei-Ju 2016). Although former study had a larger sample size then the latter one, the differences in terms of sample size could not explain the contradiction. This suggests that more investigation is needed to confirm the relationship between stiffness and LBP.

To investigate the motion of TLF between patients and controls, RF data was acquired when subjects carrying passive flexion or extension of the back and then calculated the displacement to obtain elastography. Patients with LBP had on average less tissue motion, greater left/right variability and greater variable motion in more superficial shear planes than controls. These findings propose that morphology change in LBP is related to the motion of TLF (Fox, et al. 2009).

Studies using SWE on MF on patients with LBP are listed in table 4. Shear wave velocity map of MF of a healthy subject is shown in figure 5. In normal subjects, the shear modulus of MF was around 5.4± 1.6kPa to 6kPa (Creze, et al. 2017, Koppenhaver, et al. 2019) and was affected by position, sex, BMI, self-reported activity level (Chan, et al. 2012, Koppenhaver, et al. 2019, Masaki, et al. 2019, Sadeghi, et al. 2019). Tensioning of TLF was found not related to change in stiffness of paraspinal muscle (Blain, et al. 2019). Although the TLF encloses the lumbar paraspinal muscles and is involved in spinal stability through tensioning, there may not be a direction relationship between TLF and paraspinal muscle (Blain, et al. 2019) . When comparing patients with LBP to controls, there was a significant increase in MF stiffness between patients and controls (Chan, et al. 2012, Masaki, et al. 2017). The increase in stiffness may suggest the change in MF muscle in response to loading. Thunder-fire moxibustion therapy can be used to treat LBP as it can reduce pain and MF tension (Xu, et al. 2018). MF stiffness value was found to be negatively correlated with the disease duration and severity of the nerve compression (Alis, et al. 2018). Further study on the relationship between nerve and MF stiffness may provide more understanding for its role in LBP.

The stiffness of all three muscles changes according to the activity. In TrA, significant stiffness differences were observed between LBP and control groups. For TLF, patients with LBP had less relative tissue motion, greater left and right variability and greater motion than controls. More study is needed to prove there is a difference in stiffness between patients and controls. In MF, patients with LBP had a significantly higher stiffness value than controls.

# Discussion

*Current state of art*

LBP is complex in nature and involves different muscle and tissue groups. Since muscle is anisotropic, ultrasound is expected to examine the structural information and mechanical properties more thoroughly than other imaging modalities as it is real-time and have various imaging modes. Therefore, the use of different modes of ultrasound can provide a comprehensive study of targeted tissue in understanding the nature of LBP and also act as a therapy evaluation tool.

Ultrasound can provide multiplane quantitative analysis of muscle, i.e. texture, thickness, Doppler flow velocity, and stiffness. B-mode is applied to calculate the percentage change in thickness of the tissue from rest to contracted state. The change in percentage can correlate to the muscle activation and show whether the muscle contractile ability altered in patients when performing different tasks. Echogenicity can also be calculated from B-mode and refers to the textural property of the tissue. For Doppler mode, studying the blood flow can provide information of the diameter and flow velocity of the vertebral artery which are related to the pain transmission through the nerve since the spinal cord is near the artery. Stiffer muscle on SWE means it is more difficult to activate the muscle, and thus results in altered muscle function.

If stiffness of the tissues could be obtained in different tasks and motions, the altered muscle function could be examined and categorized to enhance the understanding to LBP. Those modes provide a more objective assessment than conventional methods. Quantitative assessment can also be correlated with the clinical outcomes, such as pain index.

*Future direction*

Current studies have focused on the causality which means that they tried to rule out differences between patients with LBP and healthy subjects but not finding out the cause-and-effect relationship. One of the future works may be trying to rule out the consequences of alternation in muscle. If the correlation exists between different ultrasound parameters (thickness, stiffness and blood flow velocity) and clinical outcomes, such as pain, the patients with LBP can be classified based on the parameters into different groups. Those parameters can also be used to assess the effect of therapy as currently there is lack of evaluation tool. As LBP is complex in nature, one parameter may not be enough to quantify the LBP. Thus, multiple parameters should be considered in understanding and classification of LBP. Another aspect will be protocol standardization in both scanning and data procession to eliminate interpersonal interpretation and allow comparison of the result between different studies. Since knowing the 3D structure, such as muscle fiber orientation, fascicle location, will be helpful in understanding the structure and do diagnosis, techniques of turning 2D images to 3D structure is necessary. Deep learning can also be applied in differentiating patients with LBP from healthy subjects and help to produce more visible images. A program combining automatic real-time measurement into scanning system will reduce time cost in data processing and facilitate diagnosis. Lastly, ultrasound scanning can be taken in a wider range of motion with the help of a fixation device. This enables a more comprehensive study of LBP. Its treatment capabilities should also be addressed in future study.

# Conclusions

LBP is complex in nature as most cases do not have an obvious cause. Muscles are an important component of LBP. They are dynamic and affected by many factors including fatty infiltration. There are limitations to Computerized Tomography and Magnetic Resonance Imaging due to lack of clinical correlation in many patients with LBP. In view of this, ultrasound is useful as it is real-time and consists of three modes (B-mode, Doppler and Shear Wave Elastography). Patients with LBP generally have structural abnormalities, higher blood flow and stiffer muscles. Future work should focus on quantitative assessment of the tissue to provide an objective diagnosis and treatment evaluation tool of LBP.

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**Figure Legends**

Figure 1. Cross-section of lumbar muscle.

Figure 2. shows a B-mode image of abdominal muscle in a healthy human subject reconstructed by coherent plane wave compounding with three steered (-2°, 0, 2°) plane waves.

Figure 3. shows a B-mode image of TLF and back muscle in a healthy human subject reconstructed by coherent plane wave compounding with three steered (-2°, 0, 2°) plane waves.

Figure 4. shows the shear wave velocity map of TrA in a healthy subject using our in-house shear wave imaging realization.

Figure 5. shows the shear wave velocity map of back muscle in a healthy subject using our in-house shear wave imaging realization.

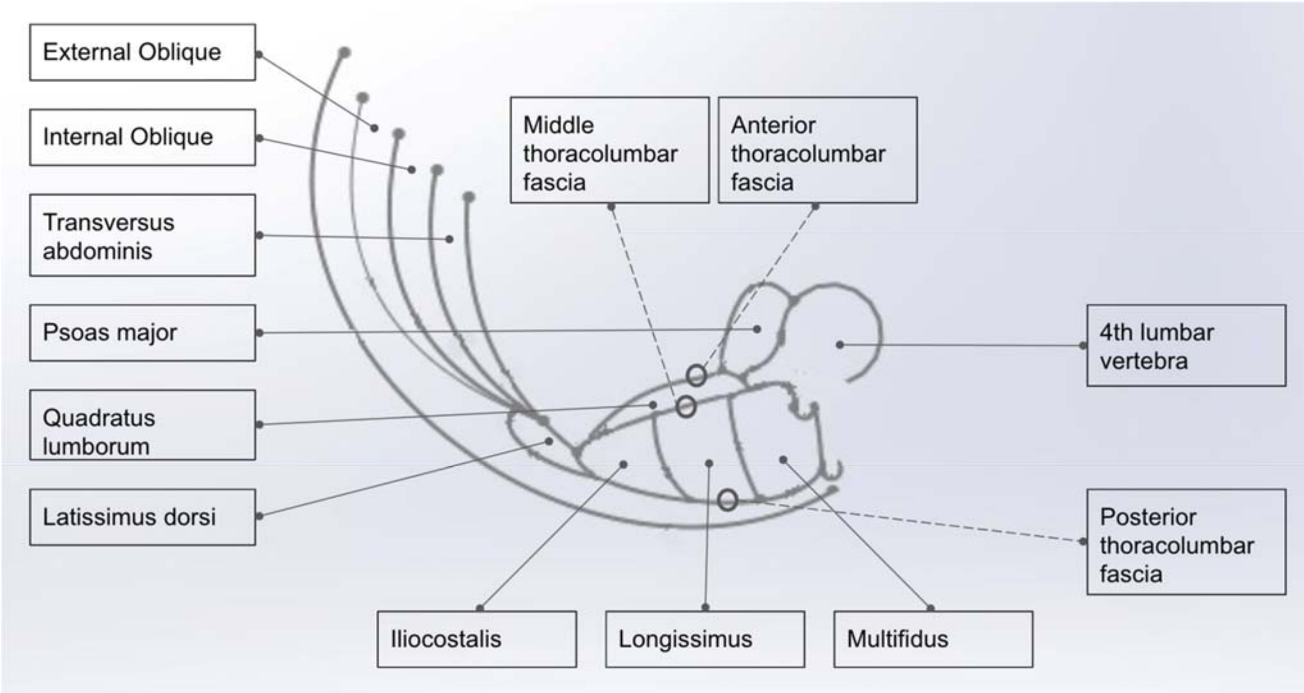


Figure 1. Cross section of abdomen at L4

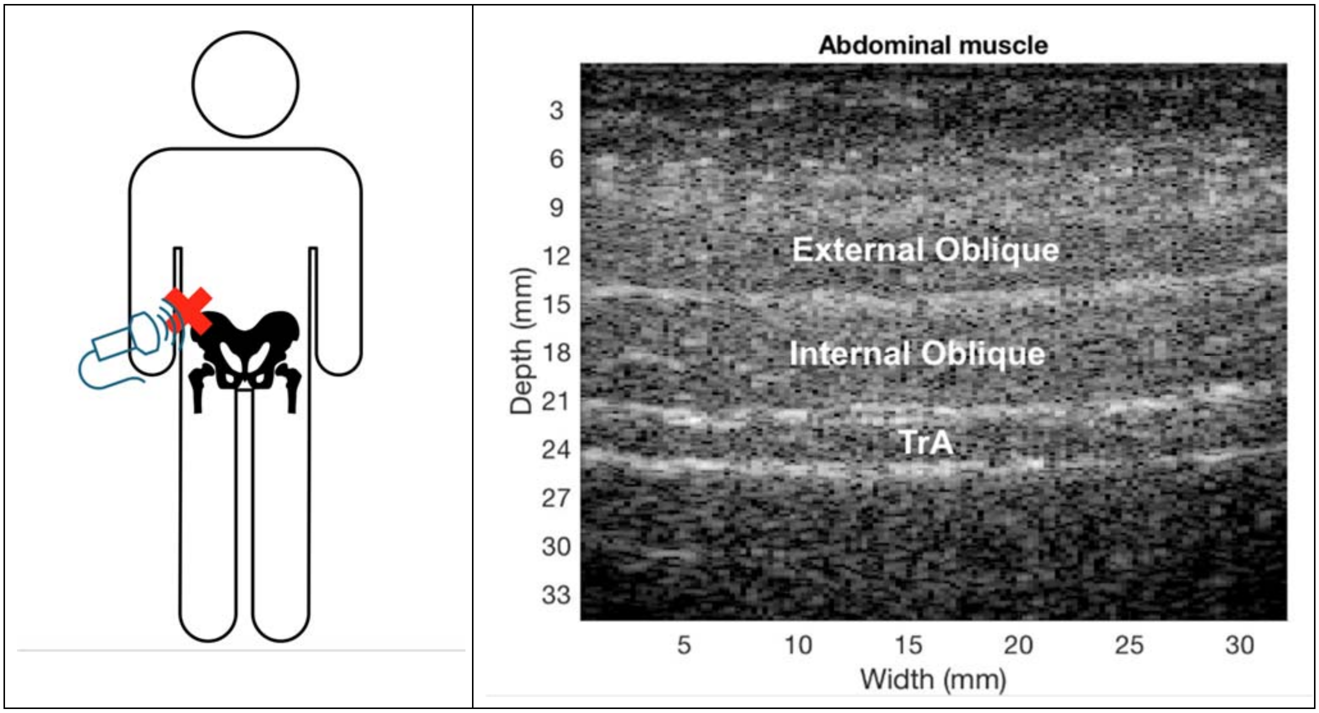


Figure 2. shows a B-mode image of abdominal muscle in a healthy human subject reconstructed by coherent plane wave compounding with three steered (-2°, 0, 2°) plane waves.

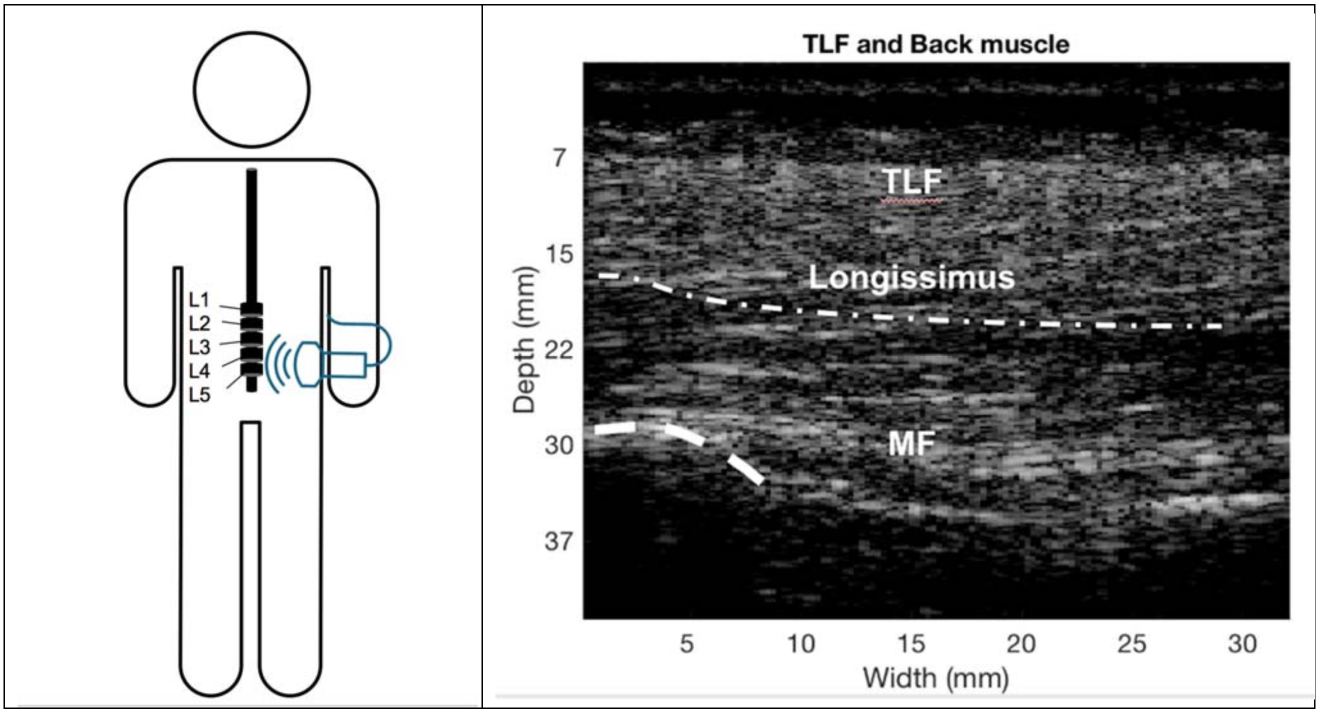

Figure 3. shows a B-mode image of TLF and back muscle in a healthy human subject reconstructed by coherent plane wave compounding with three steered (-2°, 0, 2°) plane waves.

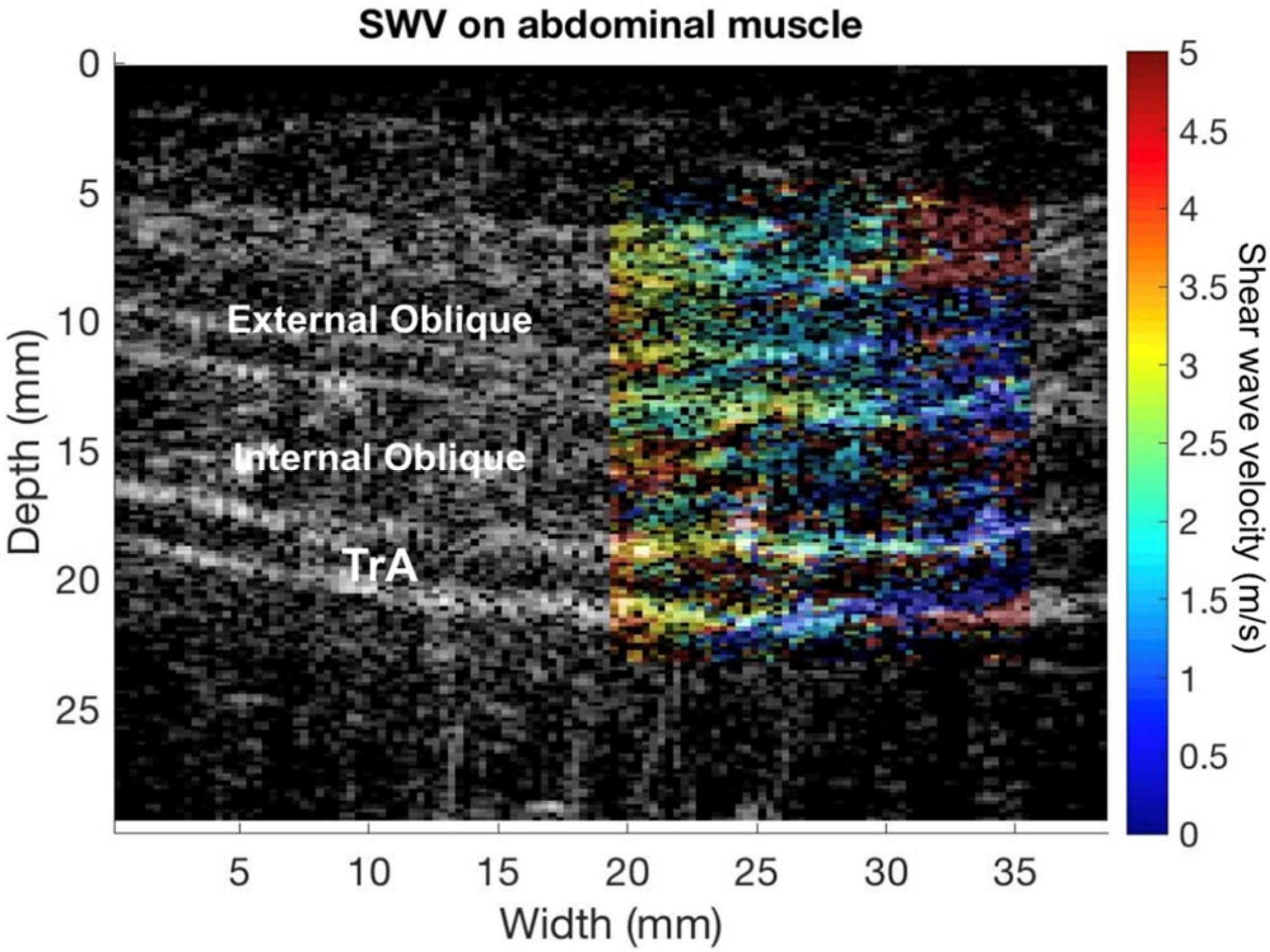


Figure 4. shows the shear wave velocity map of TrA in a healthy subject using our in-house shear wave imaging realization.

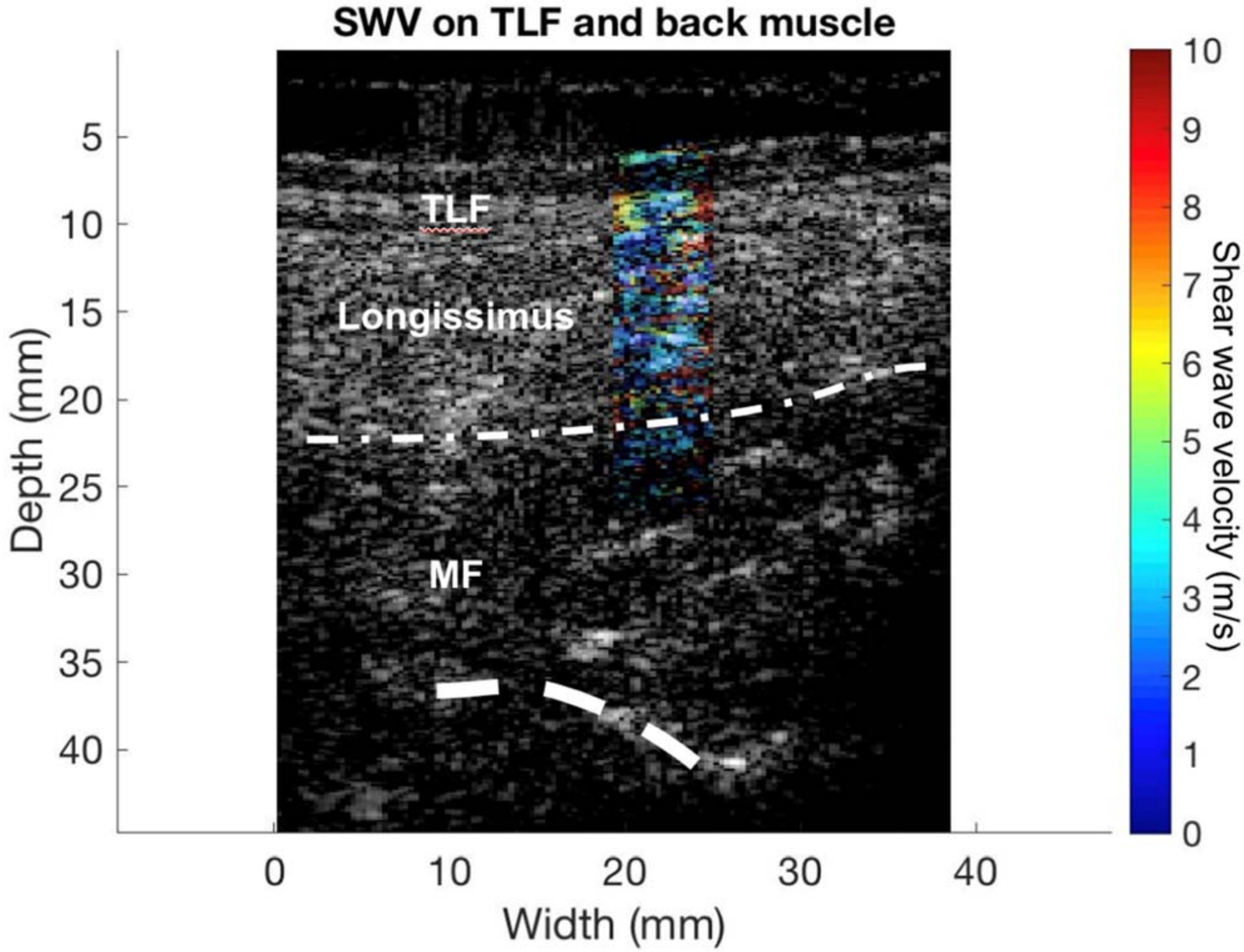


Figure 5. shows the shear wave velocity map of back muscle in a healthy subject using our in-house shear wave imaging realization.

Table 1: Studies using Ultrasound Color Doppler imaging

| Reference | Subjects (numbers) | Measuring items | Imaging mode | Key findings |
|---|---|---|---|---|
| Richardson et al [141] | 13 healthy | Sacroiliac joint laxity values | Prone lying, draw-in test, brace test | Using Doppler imaging to found the vibrations of the ilium and the adjacent sacrum |
| Klauser et al [145] | 103 inflammatory LBP<br>30 controls | Sensitivity, specificity, PPV, NPV of unenhanced and contrast-enhanced color Doppler ultrasound | Color Doppler | Microbubble contrast agents for color Doppler ultrasound is a sensitive technique to detect active sacroilitis |
| Mannion et al [140] | 14 CLBP<br>14 controls | Thickness | Abdominal hollowing exercise in supine hook-lying | There was no significant different in between-day thickness measurement. TrA preferential activation ratio is inaccurate to be used clinically |
| Mannion et al [144] | 14 healthy | EMG, tissue-velocity change | Rapid shoulder flexion, abduction, and extension | Tissue Doppler imaging is a reliable and valid method in measuring the earlier onset of feedforward activity |
| Gubler et al [87] | 48 CLBP<br>48 matched LBP-free controls | EMG, tissue velocity, pain, disability | Rapid shoulder flexion, abduction, and extension | LBP patients did not show a delayed onset of feed-forward activity but earlier activation for one body side. No relationship between time of onset of the muscle activity and pain |
| Espahbodi et al [143] | 64 LBP<br>30 controls | Blood flow velocity | Color Doppler | Blood flow velocity in lumbar arteries at all levels (L1-S1) was significantly higher in LBP group than control |

LBP: low back pain; PPV: positive predictive value; NPV: negative predictive value; EMG: electromyogram

Table 2: Studies using Shear Wave Elastography to evaluate Transversus abdominis

| Reference | Subjects (numbers) | Imaging mode | Conclusion |
|---|---|---|---|
| Hirayama et al [151] | 10 healthy | Supersonic Imaging | Moderate to high reliability of unskilled and skilled operators |
| MacDonald et al [152] | 30 healthy | Supersonic Imaging | Thick superficial fat layer affected the measurement. Moderate to high intra-session and inter-rater reliability |
| Tran et al [148] | 11 healthy | Supersonic Imaging | Abdomen stiffness was affected by the activity. Valsalva maneuver produced a statistically significant increase of shear modulus compared to other activities |
| Hirayama et al [149] | 10 healthy | Supersonic Imaging | Abdominal bracing produced a statistically significant higher elasticity value compared to other activities |
| Gabrielsen et al [150] | 10 actives<br>10 controls | ARFI-SWV | 8 features were significantly different between control and active group |

ARFI-SWV: acoustic radiation force impulse – shear wave velocity

Table 3: Studies using elastography methods to evaluate Thoracolumbar Fascia

| Reference | Subjects (numbers) | Imaging mode | Conclusion |
|---|---|---|---|
| Fox et al [154] | 51 LBP<br>36 non-LBP | Ultrasound strain imaging | LBP patients had on average less relative tissue motion, greater left/right variability and greater variable motion in more superficial shear planes than subjects without LBP |
| Langevin et al [107] | 71 LBP<br>50 non-LBP | Ultrasound strain imaging | LBP patients had stiffer TLF |
| Wei-Ju et al [153] | 22 unilateral LBP<br>20 asymptomatic | Supersonic Imaging | No difference in lateral raphe stiffness between LBP patients and asymptomatic. Stiffness of patients increased during ADIM |
| Roldán-Ruiz et al [155] | 4 women | / | Low-free sugars diet did not improve the thickness and elasticity of the TLF |

LBP: Low back pain; TLF: thoracolumbar fascia; ADIM: abdominal drawing-in manoeuvre

Table 4: Studies using Shear Wave Elastography to evaluate Lumbar Multifidus

| Researches | Subjects (numbers) | Imaging mode | Conclusion |
|---|---|---|---|
| Chan et al [115] | 12 LBP<br>12 asymptomatic | US palpation system | Position affected the MF stiffness. MF stiffness was differences between patients and controls in upright and forward stooping positions |
| Moreau et al [164] | 10 asymptotic | Supersonic Imaging | Excellent intra- and inter-observer reliability |
| Creze et al [156] | 16 healthy | Supersonic Imaging | MF is a multiceps and multipennate muscle with muscle fiber orientations due to random layering of millimetric fascicles, tendons and fatty spaces. The MF shear moduli is around $5.4 \pm 1.6$ kPa |
| Masaki et al [161] | 9 LBP<br>23 controls | Supersonic Imaging | MF stiffness was significantly higher in LBP group than controls group |
| Alis et al [163] | 33 unilateral subarticular patients | / | Lower stiffness value on the ipsilateral side. The MF stiffness value is negatively correlated with the disease duration and severity of the nerve compression |
| Koppenhaver et al [165] | 36 healthy | Supersonic Imaging | Fair to excellent overall reliability. Higher reliability in MF than ES |
| Xu et al [162] | 63 LBP | Supersonic Imaging | Thunder-fire moxibustion is effective in treating LBP due to primary osteoporosis |
| Blain et al [160] | 15 normal | Supersonic Imaging | Fair to excellent reliability. Higher reliability in ES than MF in seated position. Tensioning of the TLF via latissimus dorsi did not produce significant change in paraspinal muscle stiffness |
| Masaki et al [158] | 10 healthy | Supersonic imaging | Shear elastic modulus of MF was similar in the flexion, flexion-lateral flexion and flexion-rotation 2 positions but significantly lower in the rest position |
| Sadeghi et al [159] | / | / | MF shear modulus is affected by the posture and is lower in deeper MF than superficial layer. ICC is excellent |
| Koppenhaver et al [157] | 120 asymptomatic | Supersonic imaging | Shear modulus for MF was around 6kPa at rest and is affected by sex, BMI, self-reported activity level. It increases during contraction and is more in active individuals |

US: ultrasound; MF: multifidus; ES: erector spinae; LBP: low back pain; ICC: intraclass correlation; BMI: body mass index