Critical Reviews™ in Physical and Rehabilitation Medicine, 22(1–4), 279–300 (2010)

Real-Time Ultrasound Imaging in Physiotherapy Evaluation and Treatment of Transversus Abdominus and Multifidus Muscles in Individuals with Low-Back Pain

Clementine Cheng & Norma J. MacIntyre*

School of Rehabilitation Science, McMaster University, Hamilton, ON L8S 1C7, Canada

*Address correspondence to: Norma J. MacIntyre, Assistant Professor, macint@mcmaster.ca.

ABSTRACT: Clinical diagnosis and treatment of low back pain may be enhanced through the use of imaging modalities. This study investigates the use of rehabilitative ultrasound imaging in the physiotherapy management of low back pain associated with dysfunction of the transversus abdominis and multifidus muscles. Although encouraging, current evidence for integrating rehabilitative ultrasound imaging into clinical practice is weak and several knowledge gaps have been identified. In particular, the impact on clinical outcomes needs to be determined and well-designed randomized controlled trials investigating effectiveness for improving physical therapy assessment and treatment are required before endorsing translation of rehabilitative ultrasound imaging into clinical practice.

KEY WORDS: ultrasonography, assessment, biofeedback, reproducibility of results, validity, motor control

ABBREVIATIONS: ADIM: abdominal drawing in maneuver; **ASIS:** anterior superior iliac spine; **BMI:** body mass index; **CSA:** cross-sectional area; **CT:** computed tomography; **DMf:** deep fibers of the multifidus; **EMG:** electromyography; **ICC:** intra-class correlation coefficients; **KP:** knowledge of performance; **KR:** knowledge of results; **LBP:** low back pain; **Mf:** multifidus; **MRI:** magnetic resonance imaging; **MVC:** maximal voluntary contraction; **RCT:** randomized controlled trials; **TrA:** transversus abdominis; **RUSI:** rehabilitative ultrasound imaging; **SEM:** standard error of measurement; **SMf:** superficial fibers of multifidus; **TBC:** treatment-based classification

I. INTRODUCTION

The prevalence of low back pain (LBP) is rising. About 100 million workdays are lost annually in the United States due to LBP,[1] and 60%–80% of adults report experiencing recurrent LBP.[2] In those with LBP, activation of the transversus abdominis (TrA) muscle is delayed[3–5] and morphology of the deep paraspinal multifidus (Mf) muscles is altered.[6,7] In this population, a specific trunk stabilization exercise program has been shown to decrease Mf wasting and correct the patterns of muscle recruitment.[8–14]

Rehabilitative ultrasound imaging (RUSI) has enhanced our understanding of the importance of TrA and Mf muscles as trunk stabilizers in the rehabilitation of LBP. There are numerous advantages to RUSI. It offers a less expensive research tool for evaluating these muscles compared with more traditional methods such as magnetic resonance imaging (MRI). RUSI may also be more specific than surface electromyography (EMG) and is non-invasive in contrast with needle EMG for detecting morphological changes in deep muscle associated with muscle activation.[15]

Ultrasound imaging is generated by electrical impulses that vibrate crystalline structures called transducers,[16] which produce high-frequency sound waves. RUSI captures the sound waves (echoes) returning from the tissues to the ultrasound transducer and converts them into an electrical signal. The electrical signals are displayed for the operator/client to see. The typical mode, b-mode, "generates a cross-sectional image of an anatomical region using information gathered from the entire length of the transducer."[16] M-mode is used to "illustrate the motion of a structure by displaying its depth over time."[16] RUSI thus allows for the immediate visualization (real-time imaging) of muscle morphology, including length, depth, diameter, cross-sectional area (CSA) and volume, and muscle density.[17]

Over the past decade, the use of RUSI has shifted from a research tool to an emerging application in physiotherapy assessment, in detecting changes in muscle morphology, and in treatment, as a biofeedback tool. For deep muscles such as TrA and Mf, RUSI has been used to visualize muscle activity.[15] To establish the value of RUSI as a research tool, reliability[18–23] and validity have been determined.[15,21,24,25] A few studies of limited quality have used RUSI to assess TrA and Mf muscles during functional activity and compared the results with clinically relevant outcomes.[18,26,27] As yet, no literature has examined its responsiveness to clinically relevant changes.

The purpose of this paper is to critically evaluate the contribution RUSI may make in the management of LBP in physiotherapy practice. Many factors play a role in the dynamic stability of the spine and pelvis, such as the pelvic floor muscles and the diaphragm; however, these considerations are beyond the scope of this paper. The current use of RUSI in measuring TrA and Mf, the clinical application of this tool in relation to restoring physical function in clients with LBP through physiotherapy, and future directions for clinical use and research will be discussed.

II. CURRENT USE OF RUSI IN THE MANAGEMENT OF CLIENTS WITH LOW BACK PAIN

In this section, discussion will focus on an understanding of the anatomy of TrA and Mf, and a critical review of the literature describing the use of RUSI as an evaluative and feedback tool.

A. Imaging of Transversus Abdominis Muscles

1. Functional Anatomy of Transversus Abdominis Muscles and the Dysfunction Observed in Individuals with Low Back Pain

The TrA muscle originates from the inner surface of the lower six costal cartilages, the thoracolumbar fascia, the anterior two-thirds of the iliac crest, and the lateral third of the inguinal ligament, and inserts anteriorly into the linea alba and pelvis.[28] It acts as a stabilizer for the lumbar spine by two proposed mechanisms: (1) by raising intra-abdominal pressure[29] and (2) by resisting rotational and translatory forces.[3] TrA is activated in anticipation of a predictable force[5,29] in a tonic manner independent of the direction of the forces acting on the spine.[5,30,31] TrA activity increases where there is more demand for postural stabilization, such as in upper and lower limb movements[32–35] and walking.[36]

Clinically, the preferential voluntary activation of TrA has been observed by the abdominal drawing in maneuver (ADIM).[37–39] During ADIM, TrA has been observed to increase in thickness using RUSI[40,41] and MRI.[42] In individuals with LBP, a greater latency in TrA activation or an inability to perform the ADIM has been observed.[3–5] Kiesel et al. found that experimentally induced pain decreased TrA contraction during the ADIM in normal controls.[43] No published evidence indicates that altered performance on this task is directly related to altered motor control; however, the evidence that shows TrA activation in anticipation of a task[5,29] is suggestive of this relationship.[16]

2. Use of RUSI as an Evaluative Tool for Assessing Transversus Abdominis

a. Imaging Protocols

The standardized position for assessing TrA is supine with hips/knees flexed (crook lying) typically using 5–10 MHz.[12,16,25,44–47] A higher frequency curvilinear transducer allows for greater visualization of the TrA due to its diverging field of view.[48] Various placements for the transducer have been proposed, and agreement on a standardized location is pending given the wide anatomical distribution of the TrA.[49] Each location has its benefits and drawbacks in terms of visualizing a certain area of TrA; reliability needs to be established for the specific imaging protocol selected.

b. Reliability

Table 1 summarizes the intra-rater reliability characterized in terms of intra-class correlation coefficients (ICC) and the standard error of measurement (SEM) for RUSI-based measures of TrA muscle thickness. For b-mode, the ICC varies from 0.62 to 0.99 and the SEM varies from 0.10 to 0.31 mm. For m-mode, ICC varies from 0.82 to 0.98 and the SEM varies from 0.35 to 0.66 mm.[18,25,45–47,50–52] The reliability studies involved small sample sizes, as they were done to establish the protocol to be used in a larger study designed to test a research hypothesis. Springer et al. found that an average of three trials at rest and with the ADIM reduces the SEM by more than 50%.[46] Half of the studies averaged only two trials per session. SEM values remain relatively high compared to the resting thickness of TrA. TrA muscle thickness at rest can be as little as 3.6 mm in females positioned in supine crook lying.[45] The intra-rater and inter-rater reliability of measuring TrA in healthy subjects has been studied using different transducer locations.

TABLE 1. Reliability of RUSI Measures of the Transversus Abdominis Muscle in Healthy Subjects

					Intra-Rater Reliability		Inter-Rater Reliability	
Ref	Sample Size	Mode	Transducer Location/Imaging Protocol	Outcome	Relative (ICC)	Absolute (SEM, mm)	Relative (ICC)	Absolute (SEM, mm)
18	22	m	Between 12th rib and ASIS / 3 outcome measures on 3 different occasions	supine	0.94	0.35	None	None
				standing	0.88	0.66		
				treadmill walking (3 kph)	0.88	0.56		
46	32	b	Superior to iliac crest along mid-axillary line / At rest and during ADIM	1 trial	NR	NR	0.93-0.99	0.32-0.80
				3 trials			0.98–1	0.13–0.35
51	19	b	Midway between the inferior angle of the rib cage and the iliac crest / At rest, contracted; changes in slide	3 measures on same image	0.78–0.97	NR	NR	NR
				3 trials	0.62–0.82			
				across 2 days	0.63–0.85			
25	13	b, m	25 mm anteromedial to the midpoint between ribs and ilium / 3 measures done on 2 separate days	b-mode	0.99	NR	NR	NR
				m-mode	0.98			
				b-mode and m-mode	0.82			
45	10	b	Below rib cage in direct vertical alignment with ASIS / At rest, 2 trials taken each 1 week apart	2 trials	0.98–0.99	NR	NR	NR
				test-retest	0.96–0.99			
50	10	b	Halfway between ASIS and lower rib along anterior axillary line / During inspiration and expiration, 2 measures, supine lying and sitting on: chair, gym ball and gym ball lifting the left foot off the floor		0.97–0.99	NR	NR	NR
47	30	b	Superior to iliac crest along mid-axillary line / During ADIM, 2 measures		0.93–0.98	0.13–0.31	NR	NR
52	15	b	Superior to iliac crest along mid-axillary line / 3 measures	at rest	0.98	0.1	NR	NR
				during ADIM	0.97	0.2		

RUSI: rehabilitative ultrasound imaging; TrA: transversus abdominis; ICC: intra-class correlation coefficient; SEM: standard error of measurement; ASIS: anterior superior iliac spine; NR: not reported; ADIM: abdominal drawing in maneuver.

When comparing two transducer locations to measure TrA thickness, a significant difference was found between the two sides in both genders.[45]

Bunce et al. used a hands-free transducer fixed to a belt to measure TrA activity during the functional task of walking in 22 subjects (Table 1).[18,26] The increase in muscle thickness during functional tasks may exceed 1 mm,[26] and that may explain why the SEM value of measures taken during walking is lower than the SEM measures taken during standing. The potential exists for changes to be observed beyond the error of the measurement.[18,26] These preliminary results show good agreement between measurements taken in different positions and those taken using a hands-free transducer during weight-bearing functional tasks.

Further studies need to identify other methods of reducing the SEM. Seven potential ways to reduce SEM have been identified. One strategy is to measure muscle thickness at multiple locations along the muscle belly.[53] A second strategy is to measure over multiple trials due to the variability in submaximal or maximal contractions.[49] A third strategy is related to training of the assessor. Most studies do not mention the skill level of the assessor. Hides et al. examined intra-rater and test-retest reliability with a novice assessor, having 9 hours of training and an expert.[42] Reliability was lower than that reported with other studies (ICC = 0.62–0.85, Table 1).[51] A fourth strategy relates to training the subject prior to the actual testing, as incorrect activation of TrA may influence the reliability of the measure. A fifth strategy relates to maintaining consistent patient position and orientation, and the matching inward pressure of the ultrasound transducer, particularly when measuring during limb motions, or during any task that could increase the intra-abdominal pressure.[16] A sixth strategy is to limit extra motion produced by the transducer, which would result in an image that is based on transducer movement rather than on changes in muscle thickness.[49] A seventh strategy is to measure at the same point in the cycle of respiration. During inspiration, abdominal expansion causes a thinning of TrA.[50,54,55] In some studies, resting muscle thickness was measured at the end of quiet inspiration when there was no detectable EMG activity,[56] at the end of expiration,[45,51] or without reference to the respiratory phase.[25] These seven strategies are important considerations to improve reliability when examining the TrA in people with and without LBP.

c. Validity

The concurrent construct validity of RUSI in measuring TrA muscle thickness has been established using EMG measurements of muscle activity. Hodges et al. found a curvilinear relationship between RUSI and EMG.[15] As TrA contracts, the muscle shortens in length and thus increases in thickness. During an isometric activity, the initial changes in muscle thickness occurred from a resting state to 20% of the maximal voluntary contraction (MVC), and then plateaued with MVC > 20%. This curvilinear relationship is in agreement with results seen in other peripheral muscles.[57–59] During an isometric (fixed-end) contraction at a low force, initial small changes produce relatively large changes in the muscle fascicle length, and the change in muscle fascicle length gradually becomes smaller as the force increases.[60] RUSI detects lower levels of TrA muscle activity (12% MVC), but cannot discriminate between moderate and strong contractions.[60] In contrast, McMeeken et al. plotted the data and found a linear relationship between changes in TrA muscle thickness and EMG activation during an isometric contraction.[25] Plotting EMG activity and muscle thickness at each level of MVC, the evidence appears to support each study.[25] However, the authors did not determine whether a curvilinear relationship could have fit their data more accurately.[25] Due to the small sample sizes, it is unclear whether the evidence supporting the relationship between EMG and muscle thickness in TrA is curvilinear or linear.

As MRI is widely considered the gold standard for measuring muscle morphology, Hides et al.[42] compared MRI measures of trunk CSA and RUSI measures of changes in TrA thickness at rest and with the ADIM. During ADIM, trunk CSA symmetrically decreased significantly on both sides and correlated with RUSI measurements of muscle thickness (ICC = 0.84 to 0.94) and fascial slide (ICC = 0.78–0.91). The anterior slide of the TrA fascia has been proposed as a proxy measurement for CSA.[49] The mean (SD) slide was 1.54 (0.38) cm and 1.48 (0.35) cm for the left and rights sides, respectively. This study was done on 13 male elite healthy cricket players; therefore, the high correlations may not be found in the general population. Overall, there is minimal literature supporting the criterion validity of RUSI in measuring TrA muscle thickness with trunk CSA.

Table 2 summarizes the differences in imaging protocols, study populations, and statistical analyses that may account for different results when comparing TrA thickness and EMG activity. Given that there are differences in thickness of TrA associated with gender and body mass index (BMI, kg/m^2),[45,46] it is important to take these factors into account. Longer contractions and shorter rest periods used in one protocol may have resulted in greater muscle fatigue, and this may explain the plateau seen at the higher-intensity contractions.[15] The curvilinear relationship may explain the isometric contraction used in Hodges et al.,[15] whereas a linear relationship may be more indicative of a concentric contraction measured during ADIM.[25] Future studies should include larger samples of men and women with standardized protocols for patient position, point in the respiratory cycle, and length of TrA contraction and rest intervals. Measuring TrA at the end of relaxed expiration, when the respiratory muscles are relaxed and the glottis is open to avoid bracing, seems appropriate for minimizing error. MVC should be performed prior to data collection, and a set % of MVC should be performed. Inclusion of different types of TrA contractions (e.g., isometric, concentric) as well as comparing trunk muscle activity to peripheral muscle activity will give a better understanding of the relationship between EMG activity and RUSI measurements of TrA thickness in healthy versus pathological conditions.

3. Use of RUSI as a Treatment Tool for Transversus Abdominis Dysfunction

Motor learning is a key factor in retraining dysfunctional TrA in certain individuals with LBP. The premise for using RUSI as a treatment tool for TrA dysfunction is based on

TABLE 2. Imaging Protocols Used to Compare TrA Thickness and EMG Activity

Ref	Subjects and Positioning	Location of Transducer	Length of Contractions
15	3 healthy males, reclined sitting	10 cm from midline at midpoint between ribs and ilium	5-sec contractions, with 1–2 min rest between
25	9 healthy subjects (4 males), supine, knees flexed to 20°	25 mm anteromedial to the midpoint between ribs and ilium	2–3 sec contractions with 3 min rest between

TrA: transversus abdominis; EMG: electromyography.

the principles of motor learning. A theory proposed by Fitts and Posner considers learning as occurring in three main stages: cognitive, associative, and autonomous.[61] During the cognitive phase, focus is on feedback, movement sequence, and instruction during repetitive practice.[22] This initial phase may be where visual biofeedback from RUSI plays a role to improve voluntary activation of the muscle. RUSI also provides knowledge of results (KR),[62] presenting information to the learner about the outcome of the task (e.g., increase in muscle thickness in centimeters). It can also provide knowledge of performance (KP), information related to movement characteristics that contribute to a particular performance outcome (e.g., showing a RUSI real-time video during or after the performance of the task).[63] It is important to distinguish motor learning from performance. Learning is inferred whereas performance is observable. Performance is the ability to demonstrate a permanent improvement in an observable behavior during a retention or transfer test conducted without feedback.[64]

Table 3 summarizes the randomized controlled trials (RCT) using RUSI to enhance performance and motor learning with respect to TrA activation. RUSI is reported to facilitate learning the ADIM in a population with and without LBP, thus reducing the number of trials needed to correctly perform the ADIM.[44,65] Although RUSI appears to facilitate initial learning of ADIM, no significant group difference was observed in retention of correct ADIM performance 4 days following training (Table 3).[44] Due to the small number of individuals in each group who successfully learned the ADIM, this study was underpowered to detect a true difference; thus the contribution of RUSI to retention is inconclusive for healthy subjects.[44,65] The results summarized in Table 3 suggest that the effectiveness of RUSI in enhancing motor learning and performance in individuals with LBP may depend on the duration of symptoms. RUSI biofeedback did not enhance ADIM performance in individuals with a history of LBP of less than 3 months.[48] In contrast, motor learning of the ADIM was enhanced in a group of individuals with chronic LBP (greater than 76 months).[65] These results suggest that RUSI may be beneficial as a biofeedback tool for individuals with more chronic LBP; however, rater bias may have occurred in this study, as the person who instructed the ADIM also assessed the subjects during the initial and retention testing.[65] In the other studies summarized in Table 3, the assessors were blinded to the training condition.[48,66] Despite the Level 1 evidence, the interpretation of the results is limited because RUSI was used as both the intervention and the outcome measure in these trials.

TABLE 3. Randomized Controlled Trials Using RUSI to Provide Feedback in the Form of Knowledge of Performance (KP) and Knowledge of Results (KR) Regarding TrA Muscle Performance

Trial Protocol	Henry et al.[44]	Worth et al.[65]	Teyhen et al.[48]
Population	Healthy adults	LBP	LBP
Subject Position	Supine	Supine	Quadruped, sitting, supine
Type	Group 1: minimal verbal (n = 16) Group 2: verbal + tactile (n = 16) Group 3: same as Group 2 + RUSI (n = 16)	Group 1: verbal + tactile (n = 10) Group 2: same as Group 1 + RUSI (n = 9)	Group 1: verbal + tactile cues (n = 15) Group 2: same as Group 1 + RUSI (n = 15)
Timing	KP: concurrent (visual) KR: terminal (verbal)	KP: concurrent (visual) KR: terminal (verbal)	KP: concurrent (visual) KR: terminal (verbal)
Frequency	After 1st trial, then after every other trial	After every trial	During every trial
Motor Performance Results	RUSI Group met performance criteria in less trials ($p < 0.001$)	RUSI Group met performance criteria in less trials ($p < 0.001$)	No difference in performance criteria between groups
Motor Learning Results	No difference between groups on retention test 2 days later	No difference between groups on retention test 4 days later	No difference between groups on retention test ~ 4 days later

RUSI: rehabilitative ultrasound imaging; TrA: transversus abdominis.

B. Imaging of Multifidus Muscles

1. Functional Anatomy of Multifidus Muscles and the Dysfunction Observed in Individuals with Low Back Pain

The lumbar Mf muscles consist of short, triangular muscular bundles originating from the posterior aspect of the sacrum, aponeurosis of erector spinae, posterosuperior iliac spines, sacroiliac ligaments, and mammillary processes of lumbar vertebrae.[28] Muscular bundles that insert between two to five spinal levels caudally are the superficial fibers of the multifidus (SMf), whereas those that cross only two spinal levels are the deep fibers of the multifidus (DMf).[67] A recent review of the literature challenges the common clinical belief that the DMf act tonically while SMf acts phasically.[67] Saunders et al.[36] recorded muscle activity using intramuscular electrodes during gait and found that both DMf and SMf are activated phasically during ipsilateral and contralateral heel strike. Mosley et al. found that DMf is active in a nonspecific direction in a feedforward manner during rapid arm movements,[68] while SMf activity depends on the direction of the arm movement. Input from higher centers likely elicits different activation patterns during functional tasks.[68] The emerging evidence of the DMf and SMf activation patterns will need to be supported by larger sample sizes as well as examining whether the activations change during an episode of LBP.

Segmental stiffness and stabilization is provided by Mf muscles to control segmental spinal movement, as observed in biomechanical studies.[69] In one study, seven cadaveric lumbar spine specimens devoid of soft tissue were loaded in flexion/extension, and cables simulating the lumbar musculature revealed that Mf muscles contribute to two-thirds of the stiffness at the L4/5 level.[70] It is important to consider that all trunk muscles contribute to spinal stability[71–75] and that the forces on the vertebral column may differ *in vivo* as compared with the forces simulated *in vitro*.

a. Co-contraction with Transversus Abdominis During Function

Like TrA, DMf is also active in a non-direction-specific feedforward manner in preparation for perturbations of the spine.[68] Although Mf and TrA act as spine stabilizers, evidence to support that these muscles co-contract during the ADIM or functional tasks is lacking.[67] As of yet, no study has recorded EMG activity in both these muscles simultaneously. Although the training to achieve co-activation of TrA and Mf muscles may not restore typical activation patterns, this may compensate for other deficits by restoring intervertebral stability.[67]

b. Evidence of Multifidus Wasting and Recovery in Low Back Pain

Large single-blind RCTs provide strong evidence that retraining Mf during the early phases of rehabilitation reduces the recurrence of LBP. This has been shown in individuals following the first episode of acute LBP,[13] in individuals with spondylolysis and spondylolisthesis,[10] and in individuals with moderately chronic LBP.[11]

The Mf muscle CSA can decrease rapidly with the first episode of acute LBP (within 3 days of onset) and does not appear to recover spontaneously.[7,12] Muscle wasting is isolated to one vertebral segment level ipsilateral to the painful side[7] and is associated with histochemical changes.[76] The rapid ipsilateral and segmental reduction in CSA localized to the site of injury indicates that the mechanism of wasting was not generalized atrophy from disuse. Rather, it may be that perceived pain inhibits the specific vertebral level via the long loop reflex.[77] However, Kiesel et al. found no statistical difference in Mf size on the painful side or side-to-side asymmetry in 56 subjects with acute LBP using RUSI.[52] Conflicting findings may be due to different sample population groups, as Hides et al. examined a younger population (aged 17–46 years) with first-time acute LBP with unilateral symptoms,[7] while Kiesel et al. studied a slightly older sample (aged 18–60 years) that included individuals with acute and chronic LBP.[52] In a computed tomography (CT) study examining individuals with chronic LBP, generalized atrophy was found, but the Mf CSA area was increased on the symptomatic side.[78] Thus adaptive changes may occur in chronic LBP subjects.[52,78] There are still discrepancies in the literature as to whether side-to-side differences in Mf muscle thickness exist at the segment of dysfunction, and chronicity may play a factor in these conflicting findings.

2. Use of RUSI as an Evaluative Tool for Assessing Multifidus

a. Imaging Protocols

The standardized position for assessing Mf is side-lying, as some clients cannot tolerate lying prone and position does not affect muscle size measurements at rest.[79] The standardized position optimizes the reliability of the measurement but is not necessarily optimal for Mf training purposes.[16] A curved transducer with a frequency of 5 MHz[19,79] or a linear transducer with a frequency of 7 MHz[17,24] is used. The transducer is placed immediately lateral to the spinous process.[16]

b. Reliability

Table 4 shows that the reliability of RUSI to measures of Mf is fair to excellent (ICC = 0.72–0.98). Unlike most studies involving experienced assessors, Pressler et al. reported a lower reliability (ICC = 0.72) for a novice physical therapist with 3 hours of training and practice,[20] compared with other studies using senior researchers. Although increasing the number of trials reduces the SEM,[46] most studies averaged results from only two trials (Table 4). A low SEM is desirable in order to assess change post-intervention given that the CSA area can be as low as 5.55 cm^2 in females and as high as 7.87 cm^2 in males at L4/L5.[19]

The reliability studies summarized in Table 4 were done to establish the protocol to be used in larger sample size study designs to test hypotheses. The studies have examined Mf at rest in healthy subjects, and a reliable method of measuring Mf muscle

TABLE 4. Reliability of B-Mode RUSI Measures of the Multifidus Muscle at Rest in Healthy Subjects

				Intra-Rater Reliability		Inter-Rater Reliability	
Ref	Sample Size	Protocol	Location	Relative (ICC)	Absolute (SEM)	Relative (ICC)	Absolute (SEM)
19	10	2 trials/session (WS); 2 sessions 1 week apart (BS)	CSA at L4	WS & BS: 0.98–1.0	*WS LOA: –0.25 to 0.5 cm^2 *BS LOA: –0.62 to 0.67 cm^2	NR	NR
20	15 females	1 trial/session; 2 sessions 1 to 4 days apart (BS)	CSA at S1	BS (95% CI): R = 0.80 (0.49–.93) L = 0.72 (0.34–0.90)	BS: R = 0.32 cm2; L = 0.37cm^2	NR	NR
21	8	1 trial at rest (on screen duplicate analysis) and during arm raise (manual image analysis by 2 raters)	PMT at L4	At rest: 0.85	NR	Arm raise: 0.95	NR
22	6	3 trials/session (2 raters) at rest	PMT at L4/5	0.97–0.98	0.31–0.32 cm	0.98	0.31 cm
23	10	3 trials/session (2 raters) at rest	PMT at L2/3	Novice: 0.89 (0.72–0.97) Expert: 0.94 (0.86–0.99)	Novice: 0.11 cm Expert: 0.09 cm	0.96 (0.84–0.99)	0.06
			PMT at L4/5	Novice: 0.88 (0.68–0.97) Expert: 0.95 (0.86–0.99)	Novice: 0.09 cm Expert: 0.06 cm	0.97 (0.87–0.99)	0.05
52	15	3 trials/session at rest	PMT at L4/5	0.99 (0.97–0.99)	SEM: 0.07 cm	NR	NR
			PMT at L5/S1	0.99 (0.97–0.99)	SEM: 0.07 cm		
		3 trials/session during arm lift	PMT at L4/L5	0.98 (0.92–0.99)	SEM: 0.09 cm	NR	NR
			PMT at L5/S1	0.99 (0.96–0.99)	SEM: 0.07 cm		

RUSI: rehabilitative ultrasound imaging; CSA: cross-sectional area of Mf; WS: within session; BS: between sessions; ICC: intra-class correlation coefficient; LOA: Bland and Altman 95% limits of agreement; NR: not reported; CI: confidence intervals; R: right; L: left; SEM: standard error of the measurement; PMT: parasagittal Mf muscle thickness; L: lumbar level; S: sacral level. *Absolute intra-rater reliability not characterized using SEM.

thickness in individuals with LBP has yet to be developed. Measuring Mf muscle during a contraction presents more of a challenge because Mf activation is harder to retrain due to the subtle movement, which is less palpable compared with TrA activation. For the purpose of studying Mf muscle activation, one study measured automatic recruitment during a prone arm lift.[52] Protocols to ensure correct activation during the retraining of an isolated Mf contraction must be developed before evaluating the reliability of RUSI-based measures of Mf muscle morphometry.

c. Validity

Hides et al. compared bilateral CSA measurements at L2 to S1 using MRI and RUSI on two separate days in healthy young individuals.[24] No significant difference was observed in CSA measurements in supine (MRI) and prone lying (RUSI) positions. For both modalities, no significant difference was demonstrated in the CSA of Mf muscles between levels or either side of L2 to S1. Stokes et al. found that measures of parasagittal Mf muscle thickness correlated with measures of Mf muscle CSA in healthy individuals ($r = 0.94–0.96$).[19] This direct correlation may not apply to an LBP population where changes in muscle density are observed.[7] Decreased muscle density can be caused by fatty infiltration of fibers,[80,81] which may increase the echogenicity of muscles, making them appear whiter on the image.[19] This brighter image can also be influenced by the operator's gain settings.[77] Thus, the validity of RUSI to measure changes in fatty tissue in Mf muscle is unknown.

EMG measures of Mf muscle activity are strongly correlated to RUSI measures of changes in Mf muscle thickness ($r = 0.79$, $p < .001$).[21] In agreement with findings for TrA (section B2) and other muscles, this relationship is curvilinear.[15,57–59] A prone arm-lifting task with increasing resistance produced automatic ipsilateral Mf recruitment equivalent to 19% to 34% of maximum effort. In the last two levels of increased load, no significant changes occurred in Mf muscle thickness, while EMG signals continued to increase.[21] The limitation with this study was that volitional contractions were not matched to a set level of activation.[21] In a study using rapid arm-lifting movements, m-mode RUSI was used concurrently with EMG to test the validity of RUSI for measuring onset of Mf muscle activation.[82] With a small systematic delay (21 ms for EMG and 24 ms for RUSI), visual determination of the onset of Mf muscle activation using RUSI was 16 ms less than EMG.[82] In summary, further studies using EMG are required to validate the measures of Mf muscle activation acquired using RUSI.

3. Use of RUSI as a Treatment Tool for Multifidus Dysfunction

Two studies have examined the use of RUSI as a biofeedback tool for treating Mf muscle dysfunction. In a RCT of 25 healthy subjects, the group receiving RUSI biofeedback achieved greater improvements in Mf muscle performance, which were retained 1 week after discontinuing the RUSI feedback.[22] In contrast, the retention of Mf muscle performance in the control group decreased.[22] In the control group, KP was given by means of clinical instructions only, whereas the intervention group was given concurrent visual KP and verbal KR at the end of the performance based in RUSI images and measurements in addition to the clinical instruction.[22] Feedback was given during and after every trial.[22] In a RCT of 41 individuals with acute, first-time unilateral LBP, ipsilateral reduction in CSA of the Mf muscle was found.[12] Symmetry of Mf muscle CSA was restored in the RUSI intervention group within 4 weeks.[12] Furthermore, recurrence rate was lower at 1- and 3-year follow-up in the group who received Mf muscle training using RUSI biofeedback.[12] No information was reported on the frequency, type, and timing of the feedback, nor whether motor learning and performance were assessed.[12] For both studies, a third control group given Mf muscle exercise without RUSI feedback would have been beneficial to determine whether RUSI augmented the recovery of Mf muscle function.[12,22]

III. CLINICAL APPLICATION

To date, the application of RUSI has focused on measuring changes in TrA and Mf muscle thickness during contraction. Muscle morphology is three-dimensional, with changes in length, width, and angulation as the muscle fibers move relative to each other during contractions. Two-dimensional RUSI does not fully quantify the morphological changes. Furthermore, the complexity of muscle function is not captured by changes in morphology alone. As previously discussed (sections A2 and B2), the force of muscle contraction quantified as change in muscle thickness is not directly related to the muscle activity measured by EMG at higher levels of contraction.[15,83] Muscle activation is an important factor in muscle function. Motor control of TrA and Mf muscles involves feedforward mechanisms in preparation for limb movements[32–35] as well as coordinated muscle activation during functional tasks.[36] Although most of these activities are involuntary, retraining dysfunctional TrA and Mf muscles requires isolated voluntary activation. Yet there is no direct evidence to indicate that the inability to perform this task voluntarily is due to altered involuntary motor control. Quantification of motor function is complex; the relationship with other body functions (cognitive, sensory) and systems (neuromusculoskeletal, respiratory, digestive, cardiovascular) also influence motor function.[83] Therefore, the debate continues regarding what outcomes provide the most clinically relevant information for retraining motor function.[83]

If RUSI is to be integrated into clinical practice, the changes in muscle thickness in TrA and Mf muscles with training need to translate into positive clinical outcomes. Most studies have evaluated TrA and Mf muscles in non-weight-bearing positions, which are not relevant to most daily functional activities. Measures of TrA muscle thickness observed in supine positions are comparable during standing, walking, and unilateral weight bearing.[18,26,51] It is unknown whether changes in Mf muscle morphology in prone positions are similar to those that occur during functional tasks. RUSI measures TrA muscle morphology reliably in standing and walking,[18,26] and bilateral activation of TrA muscles was observed in a simulation of functional activity involving a unilateral weight-bearing activity in a supine position.[27] This bilateral muscle activation seen in a unilateral weight-bearing supine position has not been measured during standing and walking. Understanding the relationship between RUSI measurements of TrA and Mf muscle and functional activities is important in order to confirm clinical relevance of these findings.

Another challenge in integrating RUSI into clinical practice is the training of physical therapists to use this tool. Accurate measurements are highly dependent on mastering the knowledge and skills required for image generation, measurement, and interpretation.[16] In Canada, a RUSI residency program for licensed physical therapists is offered by J. Whittaker in British Columbia.[84] It includes a total of 25 consecutive hours of training with senior therapists, in a one-on-one format involving some lectures, pre-assigned and daily readings, and practical sessions.[84] Compared to training received by an ultrasound technician, this residency program is not extensive. However, the application of ultrasound imaging is restricted to measures of muscle morphology in the lumbopelvic region. It is unclear whether 25 hours is sufficient for mastering this skill, especially as ongoing mentoring would be needed.

Rehabilitation of LBP has moved away from patho-anatomical classifications, toward classification systems based on clinical examination and history. One such approach is the treatment-based classification (TBC) system,[85] which classifies patients into four main categories: (1) direction-specific exercises (flexion or extension), (2) mobilization (manipulation), (3) stabilization, or (4) traction. Therefore, it is important to identify subgroups of patients with LBP for appropriate clinical decision-making. Of note, deficits in the ability to generate muscle thickness changes in TrA and Mf were observed in all TBC categories.[52] Using RUSI, Hicks et al. developed a preliminary clinical prediction rule for determining which people with LBP will respond to a stabilization exercise program.[86] Further research is needed to determine whether RUSI aids in identification and treatment of altered motor control in a subgroup of people with LBP.

RUSI has potential benefits in enhancing clinical decision-making. For clinicians, the extent of atrophy of the TrA and Mf muscles can be underestimated and difficult to measure. Minimal literature exists regarding other methods of measuring ADIM. One study used pressure biofeedback and indicated that it may be a useful tool to assess and retrain abdominal muscle function.[87] RUSI can be used as an assessment tool for identifying TrA and Mf muscle impairments, thus assisting in formulating specific treatment plans. It can be used as an outcome measure for lumbar dysfunction by establishing baseline measurements of TrA and Mf muscle morphometry and documenting changes over time in these outcome measures. Although no studies have reported sensitivity and specificity of RUSI-based measures comparing those with LBP and a healthy control group, RUSI-based measures have been able to detect muscle changes in individuals with pathology and in healthy individuals. As well, RUSI can be used as a treatment tool to provide feedback to both the physical therapist and the client to determine whether the client learns to control TrA and Mf muscles more effectively with verbal or tactile cueing. The potential benefits are appealing, and these questions need to be further explained with future research.

There are both advantages and disadvantages to using RUSI. Soft-tissue imaging of muscle using RUSI is comparable to MRI[88] and has the advantages of ease of accessibility and lower cost. It is non-invasive, in contrast with CT and intramuscular EMG, and is relatively quick to administer. The disadvantages of RUSI are that it has a relatively limited field of view and is largely operator dependent for accurate imaging. Furthermore, its clinical effectiveness and safety need to be evaluated in order for cost effectiveness to be established. The frequent use of RUSI (i.e., once or twice per week consecutively) may pose safety concerns for the patient. There are no known adverse effects of RUSI, as higher intensity sound waves are not required as is the case with therapeutic ultrasound machines; however, further research is needed to investigate the effect of frequent use. It is important to note that RUSI does not replace clinical assessment skills and clinical decision-making. Instead, it should be viewed as an adjunctive tool used to enhance the quality of care.[89] Given the challenges of palpating TrA and Mf muscles, the advantages of quantifying muscle activity are clear. However, further investigation is required to establish value added prior to translation of RUSI to the clinical setting.

IV. RECOMMENDATIONS FOR CLINICAL PRACTICE AND FUTURE RESEARCH

RUSI has shown promise as a reliable and valid tool for measuring TrA and Mf muscle morphology in healthy individuals; however, further research is needed to establish the measurement properties of RUSI in people with dysfunctional muscles. Although Stokes (2005) found linear measurements to be predictive of TrA CSA at rest,[19] the predictive value of a linear relationship needs to be established for different states (resting, contracted, atrophied, or hypertrophied),[77] and different subgroups of people with LBP. As well, the relationship between RUSI-based measures and EMG recordings in different subgroups of individuals with LBP and during different types of contractions (concentric, eccentric) needs to be determined. Across-day reliability is key for RUSI to be able to detect changes that occur that are within the margin of measurement error. Standardized protocols are needed for appropriate application in research and clinical practice. Normative data for establishing reference values (i.e., age, gender, height, weight, BMI, ethnicity, geographic distribution, and levels of habitual physical activity) is becoming available for Mf thickness at each spinal level and for TrA thickness.[19,46,90,91] These values are important for the clinical interpretation of RUSI measures.[19] However, the contribution of non-contractile tissue (e.g., fatty infiltrates) to the CSA of the muscle needs to be quantified to determine true muscle size, particular in subjects with chronic pain and aging.[77] This will establish the validity of using RUSI as a tool for estimating changes in muscle function associated with pathological conditions.

The effect of RUSI on client behavior, perception of disability, and chronicity remains to be explored. As seen with MRI, knowledge of pathological condition has led to more disability and surgeries.[92] Similar to the traditional educational approach based on explaining the spinal anatomy, biomechanics, and pathology, RUSI results may create a "labeling effect" (giving a certain diagnosis to a client), which may influence the pain experience.[94,94] Similarly, the focus on the performance of ADIM may also have a negative effect on disability. Future research should address the effect of KP on client perception of disability and its effect on functional outcomes.

The biofeedback principle has been developed through studies on upper- and lower-extremity tasks.[95–98] However, due to the different descending control systems, size of motor units, and available intrinsic feedback in the extremity muscles, this principle may not apply for trunk muscles.[48] Future studies should address how practice schedules (amount of training time, frequency of sessions, number of practice trials per session) and feedback parameters (type, amount of feedback, timing of feedback) affect the learning and training of trunk-muscle activation. As well, the optimal period to test for retention or transfer of learning, and the transference of motor learning in the initial learning position (e.g., crook lying) versus in functional tasks, needs to be tested. In the clinical setting, it is important for the physical therapist to identify substitution patterns that may occur during ADIM, as these can affect the results of the learning process. In future research protocols, a single-blind RCT should be completed to investigate the effect of Mf and TrA muscle training with and without RUSI as biofeedback to test whether RUSI augments learning and improves clinical outcomes. As well, the appropriate timing of feedback using RUSI during the different stages of motor learning has yet to be evaluated.[48] Clearer definitions and parameters of the quantification of performance and transfer of learning needs to be provided in order to understand its functional implications.[66] The short- and long-term clinical outcomes of enhanced motor performance need further investigation.[66] In the clinical setting, questions such as whether RUSI measurement of muscle thickness contraction and timing of contractions change with physiotherapy intervention, as well as whether changes in RUSI measurements correlate with changes in clinical outcomes, need to be explored.[99]

V. CONCLUSION

The current level of evidence for incorporating RUSI into clinical practice is weak; however, the emerging research is promising. Well-designed RCTs are required, and the link between RUSI and clinical outcomes must be addressed. The current literature review has provoked further questions that need to be explored before use of this tool in clinical practice can be recommended.

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