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Journal of Bodywork & Movement Therapies (2010) **xx**, 1—13

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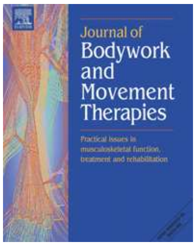

ULTRASOUND IMAGING

Application of rehabilitative ultrasound in the assessment of low back pain: A literature review

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Received 12 February 2010; received in revised form 3 July 2010; accepted 7 July 2010

KEYWORDS
Low back pain;
Ultrasound imaging;
Multifidus;
Transverse abdominis;
Review

Summary Low back pain (LBP) is one of the most common work-related conditions affecting all populations both in industrialized and non-industrialized countries, with reported high prevalence and incidence rates and huge direct and indirect costs. Among various suggested causes of LBP, dysfunction of back muscles, particularly lumbar multifidus and transverse abdominis, has been the subject of considerable research during last decades. Of the available imaging techniques, ultrasound (US) imaging technique is increasingly used to assess muscle dimensions and function as a valid, reliable and non-invasive approach. The purpose of the present study was to review the previously published studies (1990—2009) concerning the merit of US imaging of lumbar and abdominal muscles with particular attention to its clinical application in patients with LBP. Studies showed wide variation in terms of methodology, sample size, procedure, definition of LBP, heterogeneous sample, method of analyzing US imaging, US imaging parameters, etc. However, a convincing body of evidence was identified that supports US imaging as a reliable and valid tool both to differentiate patients with LBP from normal subjects and to monitor the effect of rehabilitation programs.

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doi:10.1016/j.jbmt.2010.07.003

Introduction

Low back pain (LBP) is one of the most prevalent work-related conditions affecting all populations both in industrialized and non-industrialized countries (Jin et al., 2004; Mohseni-Bandpei et al., 2006, 2007). It is the fifth most common reason for all visits to physicians in the United States (Hart et al., 1995). Approximately one quarter of adults in the United States reported having LBP lasting at least one day in the past 3 months (Deyo et al., 2006). A high prevalence rate and associated economic and social costs have been reported due to LBP in France (Gourmelen et al., 2007). In Iran, a lifetime prevalence of LBP in the nursing population and pregnant women was reported to be 62% and 84%, respectively (Mohseni-Bandpei et al., 2006, 2009) associated with 33.7% of work absenteeism during the past month in nurses (Mohseni-Bandpei et al., 2006). In the United States the total incremental direct health care costs attributable to LBP were estimated to be $26.3 billion in 1998 (Luo et al., 2004). In addition, indirect costs related to days lost from work were substantial, with approximately 2% of the United States work force compensated for back injuries each year (Andersson, 1999). Although indirect costs may be mainly borne by the corresponding social insurance institutions, a significant financial burden can still be imposed on the patients. The costs have been estimated to be 0.7% of Gross Domestic Product (GDP) in Sweden and 1.7% of GDP in the Netherlands (Ekman et al., 2005). A German cost-of-illness study estimated total costs of back pain at around €17 billion, equating to 0.9% of the GDP (Wenig et al., 2009).

Dysfunction of the back muscles has been a focus of many studies. The muscles in the lower back area are divided into two groups: global and local (Bergmark, 1989). Some research has demonstrated that there are altered activation patterns of the trunk muscles as they relate to the concept of spinal stability (Cresswell et al., 1992, 1994; Hodges and Richardson, 1996). In healthy subjects, it is suggested that the transverse abdominis (TrA) is the first muscle to be activated and contracted before limb movement, regardless of the direction of motion (Hodges and Richardson, 1996). In individuals with LBP, the contraction of the TrA are reported to be significantly delayed and to follow direction-specific patterns, indicating a potential for decreased spinal stability and fundamental problems with motor control (Hodges and Richardson, 1997, 1998). Several studies have identified significant ipsilateral muscle atrophy of lumbar multifidus (MF) in individuals with unilateral LBP compared with healthy subjects (Hides et al., 1994, 1995, 1996).

It was reported by Panjabi (1992) that MF and TrA have a greater role than other muscles in lumbar stability and showed a more decreased cross-sectional area (CSA) in chronic LBP patients (Akbari et al., 2008; Hides et al., 2008a; Mannion et al., 2008).

Therapeutic exercises have been developed for individuals with LBP over time. Recently, there has been an emphasis on a specific type of exercise that aims to restore stability in the lumbar spine (Richardson and Jull, 1995; Wilke et al., 1995; Cholewicki and McGill, 1996). It is believed that the mechanism for pain relief with this specific type of exercise is through enhanced stability of the lumbar spine segments (Richardson and Jull, 1995). Several muscles are targeted, particularly the TrA, lumbar MF, and other paraspinal, abdominal, diaphragmatic, and pelvic floor musculature. Given the widespread clinical use of lumbar stabilization exercise, it is necessary to critically assess the evidence of their efficacy in patients with chronic LBP (O'Sullivan et al., 1997; Koumantakis et al., 2005; Cairns et al., 2006; Goldby et al., 2006; Ferreira et al., 2007).

Among various imaging techniques, such as magnetic resonance imaging (MRI) and computerized tomography (CT) scanning, US imaging which involves sending short pulses of US into the body and using reflections received from tissue interfaces to produce images of internal structures, has been developed during the past 50 years with widespread application in medicine, particularly in gynaecology and obstetrics, internal medicine, surgery, orthopaedics, neurology and paediatrics. The application and usefulness of US in the field of musculoskeletal system has been demonstrated in many studies (i.e., Harcke et al., 1988; Kaplan et al., 1990; van Holsbeeck and Introcaso, 1992; Chhem et al., 1994). US has also been used as a direct assessment of atrophy and hypertrophy of different muscles (e.g., Stokes and Young, 1986; Hides et al., 1992; Hides et al., 1994; Stokes et al., 2007) as well as in evaluation of the efficacy of the rehabilitation programs (e.g., Hides et al., 1996; Teyhen et al., 2005; Raney et al., 2007). Despite the high image resolution provided by CT and MRI techniques and high dependency of US imaging on the expertise of the operator, US imaging was found preferable to other imaging techniques because of low examination costs, lack of exposure to ionizing radiation and ready availability (Chhem et al., 1994; Hides et al., 1998).

The reliability and validity of new diagnostic procedures are important issues to consider with respect to clinical application. Reliability is the extent to which the repeated measurements of a technique by different people and instruments, at different times and places get similar results. Validity refers to the instrument's capability to measure what it was intended to measure (Domholdt, 2005). The reliability and validity of measurement of muscle size using US imaging have been investigated in different muscles and found to be a reliable (Stokes and Young, 1986; Martinson and Stokes, 1991; Hides et al., 1992) and a valid (Sipila and Suominen, 1993: Hides et al., 1995) technique. However, they suffer some methodological flaws.

Two aspects of muscle function that can be assessed using imaging techniques are muscle size and muscle contraction. The clinical relevance of these techniques is that they allow documentation of morphology and dynamic muscle function in both healthy subjects and those with acute and chronic LBP. Detection of changes in MF and TrA muscle size and motor control in people with LBP compared with healthy subjects may provide valuable information which can be used to guide rehabilitation approaches (Stokes and Young, 1986; Martinson and Stokes, 1991; Hides et al., 1992, 1994, 1995; Sipila and Suominen, 1993; Hodges and Richardson, 1996, 1998; Hodges et al., 2003) The method of choice for recording anticipatory muscle activity has been intramuscular electromyography (EMG) (Danneels et al., 2002; Moseley et al., 2002; Mohseni-Bandpei et al., 2000; Vasseljen et al., 2006).

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Although EMG seems to be a superior method in small experiments confined to the laboratory, the complexity and discomfort of this invasive method may not be well suited for large clinical trials. If muscular timing discrepancies in LBP patients are proved to consistently correlate to pain status, there is a need for a more practical recording method than intramuscular EMG in clinical settings. One such method could be US imaging applied in motion-mode (M-mode), where an image of muscle tissue deformation is updated several hundred times a second (Vasseljen et al., 2006).

A number of studies have been carried out to investigate local muscles activity, and to attempt to differentiate LBP patients from normal subjects using US, with contradictory findings (Hides et al., 1994; Lee et al., 2006; Hides et al., 2007a; Kiesel et al., 2007a; Akbari et al., 2008; Kiesel et al., 2008). The aim of the present study was to review the previously published studies (1990—2009) concerning the merit of US imaging of lumbar and abdominal muscles, with particular attention to its clinical application in monitoring progress of patients with chronic LBP undergoing rehabilitation programs.

Methods

A literature search for the period 1990—2009 was conducted, using PubMed, ProQuest, Science Direct, Thomson, EMBASE, OVID, CINAHL and MEDLINE databases. The following keywords were used: Ultrasonography, Ultrasound imaging, Low back pain, Back muscles, Multifidus, Transverse abdominis, Muscle size, Reliability and Validity. In addition, references given in relevant publications were also used. Studies were required to meet the following criteria:

1. an empirical study design employing US imaging;
2. spinal or abdominal muscles (i.e., multifidus, transverse abdominis, ...) were measured;
3. human subjects were studied, both normal subjects and patients with LBP and
4. the article was a full report published in a peer reviewed journal in the English language.

If no abstract was present, or if, based on title and abstract, it was not clear whether an article should be included, the whole article was checked. Articles were included if they met all these four inclusion criteria. Two reviewers (LG and ME) read all the abstracts, and the third and fourth reviewers (MAMB and HB) separately have read a random sample of the abstracts. A consensus meeting was arranged to reach agreement on any differences between all reviewers. Finally, a snowball search was carried out, in which reference lists of the selected articles were checked for which titles including US and LBP.

The outcome of a study was identified as "positive" if the authors concluded there was a difference in muscle size recorded by US imaging between LBP and normal subjects or in a specific group or particular condition of the study population. The outcome of a study was classified as "negative" if the authors concluded that there was no difference in muscle size between LBP and normal subjects as measured by US imaging. These definitions of the "positive" and "negative" are used throughout this paper.

Results

The literature search yielded 178 articles using the above keywords. The inclusion criteria were met by 36 articles (Hides et al., 1992; Kennelly and Stokes, 1993; Hides et al., 1994, 1995, 1996; Eisele et al., 1998; Bunce et al., 2002; Critchley and Coutts, 2002; Coldron et al., 2003; Hodges et al., 2003; Ferreira et al., 2004; McMeeken et al., 2004; Watanabe et al., 2004; Stokes et al., 2005; Teyhen et al., 2005; Ainscough-Potts et al., 2006; Hides et al., 2006; Lee et al., 2006; Pressler et al., 2006; Rankin et al., 2006; Springer et al., 2006; Vasseljen et al., 2006; Hides et al., 2007a, 2007b; Kiesel et al., 2007a, 2007b; Norasteh et al., 2007; Raney et al., 2007; Wallwork et al., 2007; Akbari et al., 2008; Hides et al., 2008a, 2008b; Kiesel et al., 2008; Mannion et al., 2008; Koppenhaver et al., 2009; Wallwork et al., 2009). Table 1 provides details of the studies in chronological order from 1990 to March 2009. The most important reasons for exclusion were the article was not in English language; Lumbar and abdominal muscles were not assessed; an US imaging technique was not used.

In all studies, the authors reported differences in US imaging measures recorded in LBP subjects compared with normal, or within the various diagnostic subgroups of LBP; when tested in one, or more postural positions or when a relationship was found, compared with a gold standard (e.g., MRI).

Of the 36 studies, 9 monitored rehabilitation programs, including stabilization exercises, manipulation, traction, abdominal hollowing exercises, abdominal draw-in maneuvers, motor control exercises, and general exercises (Hides et al., 1996; Critchley and Coutts, 2002; Teyhen et al., 2005; Kiesel et al., 2007b; Raney et al., 2007; Akbari et al., 2008; Hides et al., 2008b; Kiesel et al., 2008; Mannion et al., 2008). All studies reported positive results in US imaging parameters after rehabilitation programs (Table 2).

Fourteen studies of the 36 studies selected (Hides et al., 1992; Kennelly and Stokes, 1993; Hides et al., 1994; Eisele et al., 1998; Coldron et al., 2003; Watanabe et al., 2004; Stokes et al., 2005; Ainscough-Potts et al., 2006; Lee et al., 2006; Rankin et al., 2006; Springer et al., 2006; Hides et al., 2007b; Hides et al., 2008a; Wallwork et al., 2009), investigated muscle dimensions in different positions in healthy subjects or correctly identified patients with LBP from normal subjects based on US imaging findings. Only one study tried to identify the relationship between pain intensity and US imaging findings and in which no relationship was found between these two variables. Table 3 provides details of studies in which muscle size was measured in both healthy subjects and patient population using US.

Nine of the 36 studies (Bunce et al., 2002; McMeeken et al., 2004; Watanabe et al., 2004; Teyhen et al., 2005; Pressler et al., 2006; Hides et al., 2007a; Norasteh et al., 2007; Wallwork et al., 2007; Koppenhaver et al., 2009) specifically looked at the reliability of employing US imaging on patients, normal subjects, or both and seven studies (Hides et al., 1995; Hodges et al., 2003; Ferreira et al., 2004; McMeeken et al., 2004; Hides et al., 2006; Vasseljen et al., 2006; Kiesel et al., 2007a) investigated the validity of US imaging. Tables 4 and 5 provide details of studies investigating the reliability and validity of US in the assessment of different muscles.

Table 1 Details of trials evaluating lumbar and abdominal muscles using US imaging in LBP.

Author (year)	Subjects (numbers)	Measuring items (muscle)	Intervention/position	Conclusion
Hides et al. (1992)	NLBP (48)	CSA (MF)	Right and left sides and also between males and females	Positive. CSA of MF was symmetrical between right and left sides. Muscle shape differed between the males and females
Kennelly and Stokes (1993)	Adolescent idiopathic scoliosis (20)	CSA (MF)	Right and left sides of the curve	Positive. A significant difference was found in CSA of lumbar MF between the two sides of curve
Hides et al. (1994)	ALBP (26), NLBP (51)	CSA (MF)	The effect of LBP on muscle size	Positive. A significant difference was found in CSA of MF between-side and between the two groups at one level
Hides et al. (1995)	NLBP (10)	Thickness (MF)	To compare MRI findings with US imaging	Positive. Muscle size could be recorded by US imaging
Hides et al. (1996)	LBP (39)	Thickness (MF)	Medical treatment and specific localized exe.	Positive. Muscle recovery was more rapid and more complete in favor of exercise group
Eisele et al. (1998)	A = NLBP (30), B = discopathy (20), C = LBP (40)	CSA (Paraspinal)	To investigate the change of the ultrasonic texture of the paraspinal lumbar muscle	Positive. A significant difference was found in muscle size among three groups
Critchley and Coutts (2002)	CLBP (20), NLBP (24)	Thickness (abdominal)	Hollowing in four-point kneeling	Positive. A significant difference was found between the two groups after treatment
Bunce et al. (2002)	NLBP (22)	Thickness (TrA)	Different positions (supine, standing, walking)	Positive. US was found to be a reliable tool to assess the TrA size
Coldron et al. (2003)	NLBP (20)	Thickness (MF)	Different positions (prone, side lying)	Positive. No significant difference was found in muscle size in different positions
Hodges et al. (2003) (31)	NLBP (13)	Thickness (TrA, IO, EO, TAnt, Br, Bi)	Isometric DF, isometric elbow flex. Intra-abdominal pressure	Positive. US imaging can be used to detect low levels of muscle activity but cannot discriminate between moderate and strong contractions
Watanabe et al. (2004)	NLBP (30)	Thickness (ES)	Three different positions: maximum flexion, neutral position, maximum extension	Positive. A significant difference was found in ES thickness in different positions
Ferreira et al. (2004)	CLBP (10), NLBP (10)	Thickness (TrA, IO, IE)	US imaging was compared with EMG findings	Positive. A relationship was found between the presence of LBP and asymmetry of muscle size using US imaging and EMG
McMeeken et al. (2004)	NLBP (9), NLBP (13)	Thickness (TrA) and EMG activity	US imaging was compared with EMG findings	Positive. A significant correlation was found between US imaging and EMG activity. US was also found to be a reliable tool in measuring muscle thickness
Stokes et al. (2005)	NLBP (120)	Thickness (MF)	Normal reference data for multifidus size	Positive. Normal references ranges reported for lumbar multifidus but no clinically significant correlation was found between CSA and anthropometric measures

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Teyhen et al. (2005)	LBP (30)	Thickness (TrA)	Traditional training and traditional training combined with biofeedback	Positive. On average, patients in both groups demonstrated a 2-fold increase in the thickness of the TrA
Ainscough-Potts et al. (2006)	NLBP (30)	Thickness (TrA, IO)	Different positions (supine lying and different sitting positions)	Positive. Muscle thickness could be measured and compared in different positions
Pressler et al. (2006)	NLBP (30)	Thickness (MF)	Right and left sides of multifidus	Positive. US was found to be a reliable tool with reasonable between days intra-rater reliability
Rankin et al. (2006)	NLBP (123)	Thickness (IO, IE, TrA, RA)	Normal reference data for abdominal muscle size	Positive. The pattern of relative muscle thickness was RA $>$ IO $>$ EO $>$ TrA, but no significant difference was found in muscles between the left and right sides
Springer et al. (2006)	NLBP (32)	Thickness (lateral abdominal)	Different positions (rest and while performed ADIM)	Positive. No differences in the thicknesses of TrA muscle were measured during rest or while contracted, based on hand dominance
Vasseljen et al. (2006)	NLBP (10)	Activity onset (MF)	US imaging was compared with EMG findings	Positive. US imaging can detect onset of muscle activity comparably accurate to intramuscular EMG
Hides et al. (2006)	NLBP (13)	Thickness (TrA, IO)	US imaging was compared with MRI findings	Positive. US imaging was correlated with MRI findings in measuring thickness of both TrA and IO muscles
Lee et al. (2006)	CLBP (16), NLBP (19)	CSA (MF)	Different positions (prone lying, upright standing, and 25° and 45° forward stooping)	Positive. A significant difference was found on CSA of MF in different positions
Hides et al. (2007a)	NLBP (19)	Thickness (TrA, IO)	ADIM in a supine hook-lying position	Positive. High reliability of a novice rater was demonstrated for some measurement conditions
Hides et al. (2007b)	NLBP (19)	Thickness (TrA, IO)	Static unilateral weight-bearing	Positive. A significant increase was found in TrA muscle size during static task
Kiesel et al. (2007a)	NLBP (5)	Thickness (MF)	US imaging was compared with EMG findings	Positive. Measuring MF muscle thickness using US imaging was highly correlated with EMG activity of MF in asymptornatic subjects
Kiesel et al. (2007b)	LBP (56), NLBP (20)	Thickness (TrA, MF)	Stabilization, mobilization, direction-specific exe., traction	Positive. A significant difference was found in muscle size after intervention
Raney et al. (2007)	ALBP (9)	Thickness (abdominal)	Spinal manipulation	Positive. Short-term changes in lateral abdominal muscles thickness was recorded post-spinal manipulation
Norasteh et al. (2007)	ALBP (12), NLBP (27)	Thickness (TrA, IO, EO, RA)	During expiration and inspiration in different positions	Positive. US was found to be a reliable tool for both symptomatic and asymptomatic subjects.
Wallwork et al. (2007)	NLBP (10)	Thickness (MF)	Different assessors	Positive. US was found to be a reliable tool for measuring muscle size
Akbari et al. (2008)	CLBP (49)	Thickness (TrA, MF)	Motor control exe. and general exe.	Positive. A significant difference was found in muscle size after intervention

(*continued on next page*)

Table 1 (*continued*)

Author (year)	Subjects (numbers)	Measuring items (muscle)	Intervention/position	Conclusion
Hides et al. (2008a)	NLBP (40), CLBP(50)	CSA and symmetry (MF)	Comparing NLBP with CLBP	Positive. A significant difference was found in multifidus muscle size and symmetry between NLB and patients with CLBP
Hides et al. (2008b)	Elite cricketers with and without LBP (21)	CSA (MF)	Staged stabilization training	Positive. A significant difference was found in muscle size after intervention
Kiesel et al. (2008)	NLBP (6)	Thickness (TrA, MF)	5% hypertonic saline was injected into Longissimus muscle	Positive. US imaging can be used to measure pain-related changes in deep trunk muscle activation
Wallwork et al. (2009)	CLBP (17), NLBP (17)	CSA (MF)	During rest and contraction	Positive. A significant reduction in CSA of MF was found in CLBP group at L5 only
Mannion et al. (2008)	CLBP (14), NLBP (14)	Thickness (TrA, IO, EO)	Abdominal hallowing exe. in hook-lying	Positive. A significant difference was found in both groups after intervention
Koppenhaver et al. (2009)	NLBP (30)	Thickness (TrA, MF)	During rest and contraction	Positive. US was found to be highly reliable for intra-rater and adequately reliable for inter-raters measurements

LBP = low back pain, CLBP = chronic low back pain, ALBP = acute low back pain, NLBP = non-low back pain, MF = multifidus, TrA = transverse abdominis, IO = internal oblique, EO = external oblique, RA = rectus abdominis, exe = exercise, CSA = cross-sectional area, ES = erector spinae, US = ultrasonography, PF = pelvic floor, TAnt = tibialis anterior, Br = brachialis, Bi = biceps brachii, ADIM = abdominal draw-in maneuver, BMI = body mass index, DF = dorsi flexion, Flex = flexion.

Discussion

Thirty-six studies employing US imaging in patients with chronic LBP and healthy subjects were reviewed. To the knowledge of the authors, the present review is the first to report on the application of rehabilitative US in the assessment patients with LBP, to measure the muscle size and function in patients with LBP compared with normal subjects, to compare muscle size and function in different conditions and to monitor the effect of rehabilitation programs. This review considered only English language studies. Although this limitation is common in systematic reviews, the possibility of a language bias should be considered.

In all currently reviewed studies, the authors reported positive results, which indicate that US imaging is a useful, reliable and valid method in evaluating lumbar and abdominal muscles thickness. Of those nine studies investigating the reliability and the seven studies which investigated validity of US imaging in LBP or normal population, all reported favorable results. Methodological flaws were found in some studies. The most important flaws were use of small sample size; lack of a common definition for LBP; study designs which combined various diagnostic subgroups of chronic LBP; lack of a standardized method of analyzing US imaging; lack of a reliable US imaging parameters; inter-individual variability in terms of physical fitness, gender, age, etc. (heterogeneous sample). However, the results of this review show support and evidence to the application of US imaging in the field of rehabilitation.

Monitoring rehabilitation programs

As indicated in Table 2, 9 of the studies were carried out to determine the sensitivity of US imaging measurements in monitoring therapeutic interventions such as exercise, manipulation, mobilization, traction. For example, Hides et al. (2008b) have investigated the effect of a staged stabilization training program on CSA of the lumbar MF using US imaging. They measured CSA of the MF at the start and at the completion of a 13-week cricket training camp in 4 elite cricketers with and without LBP. The stabilization program involved voluntary contraction of the MF, TrA, and pelvic floor muscles that progressed from non-weight-bearing to weight-bearing positions and movement training. Pain was also measured on visual analog scale in those with LBP. They demonstrated that improvement in CSA of MF following specific retraining can be detected using US imaging and this was concomitant with a decrease in pain intensity. Mannion et al. (2008) measured thickness of TrA muscle at baseline and after performing abdominal hollowing exercises in hook-lying on normal subjects ($n = 14$) and patients with chronic LBP ($n = 14$). Changes in the thickness of TrA indicated that patients showed improvement in muscle dimensions following rehabilitation programs.

Akbari et al. (2008) compared the effect of motor control exercises with general exercises on 49 patients with chronic LBP who were randomly assigned into either a motor control ($n = 25$) or a general exercises group ($n = 24$). They assessed the thickness of MF and TrA using US imaging, pain on visual analog scale and activity limitation through Back Performance Scale before and after intervention. A 16-session exercise program of 30 min per session was performed by both groups twice per week for 8 weeks. They concluded that the motor control and general exercises both decreased pain intensity and increased the thickness of TrA and MF as well as lumbar mobility in patients with chronic LBP without any signs of spinal instability. The motor control exercises were more effective than general exercises only in reducing pain intensity.

Table 2 Details of trials in which the effect of different interventions was monitored using US.

Author	Subject (number)	Measuring items (muscle)	Intervention	Conclusion
Hides et al. (1996)	LBP (39)	Thickness (MF)	Medical treatment and specific localized exe.	Positive. Muscle recovery was more rapid and more complete in favor of exercise group
Critchley and Coutts (2002)	CLBP (20), NLBP (24)	Thickness (abdominal)	Hollowing exe. in four-point kneeling	Positive. A significant difference was found between the two groups after treatment
Teyhen et al. (2005)	LBP (30)	Thickness (TrA)	Traditional training and traditional training combined with biofeedback	Positive. On average, patients in both groups demonstrated a 2-fold increase in the thickness of the TrA
Raney et al. (2007)	ALBP (9)	Thickness (abdominal)	Spinal manipulation	Positive. Short-term changes in lateral abdominal muscles thickness was recorded post-spinal manipulation
Kiesel et al. (2007b)	LBP (56), NLBP (20)	Thickness (TrA, MF)	Stabilization, mobilization, direction-specific exe, traction	Positive. A significant difference was found in muscle size after intervention
Kiesel et al. (2008)	NLBP (6)	Thickness (TrA, MF)	5% hypertonic saline was injected into longissimus muscle	Positive. US imaging can be used to measure pain-related changes in deep trunk muscle activation
Mannion et al. (2008)	CLBP (14), NLBP (14)	Thickness (TrA, IO, EO)	Abdominal hallowing exe. in hook-lying	Positive. A significant difference was found in both groups after intervention
Hides et al. (2008b)	Elite cricketers with and without LBP (21)	CSA (MF)	Staged stabilization training	Positive. A significant difference was found in muscle size after intervention
Akbari et al. (2008)	CLBP (49)	Thickness (lumbar local stabilizing muscle)	Motor control exe. and general exe.	Positive. A significant difference was found in muscle size after intervention

LBP = low back pain, CLBP = chronic low back pain, NLBP = non-low back pain, MF = multifidus, TrA = transverse abdominis, IO = internal oblique, EO = external oblique, PF = pelvic floor, exe = exercise, CSA = cross-sectional area, ADIM = abdominal draw-in maneuver, BMI = body mass index.

Despite differences in the study sample sizes, selected populations, subcategories of LBP patients, and muscles tested, all studies could be classified as positive. The results of this review therefore indicate that US imaging can be clinically used to evaluate the effect of rehabilitation programs in patients with chronic LBP.

Reliability

As it is shown in Table 4, nine studies were conducted to assess the reliability of measuring the CSA of MF and abdominal muscles using US imaging. Images were taken in different static and/or dynamic conditions. Static testing involves US imaging during rest position such as supine or prone position, whereas dynamic testing requires subjects to perform a specific movement. Some studies were carried out on healthy subjects. For example, Bunce et al. (2002) assessed average US imaging values of TrA muscle thickness in different positions. Twenty-two healthy subjects (10 men, 12 women), aged 18–44 years old were imaged in supine, standing, and treadmill walking at 3 kph. The mean thickness for TrA muscle was demonstrated to be larger during standing and walking than in supine in 20 out of the 22 volunteers and it was larger in males compared with females in all three positions. The intraclass correlation coefficients (ICCs) were high for TrA muscle thickness in all three positions. They concluded that the application of M-mode US is a reliable method of measuring TrA in supine, standing, and walking positions when comparing images on separate occasions.

Between days reliability becomes an important factor when US imaging is to be used to assess the effect of rehabilitation programs. Quite a few studies have investigated the between days reliability of US imaging in MF and TrA muscles. Only three studies investigated the between days reliability in healthy subjects (McMeeken et al., 2004; Pressler et al., 2006; Koppenhaver et al., 2009). McMeeken et al. (2004) examined the intra-rater reliability of measuring the thickness of TrA muscle in 13 healthy subjects, on two separate days, in supine position when the muscle was relaxed and contracted, using US imaging. They reported high between days reliability with ICC = 0.989 for B mode and ICC = 0.981 for M-mode.

In the study of Wallwork et al. (2007), the intra and inter-rater reliability were assessed on 10 subjects without a history of LBP at the L2–3 and L4–5 levels. The measurements were carried out three times at each level by two different assessors (one experienced and one novice). They reported high intra-rater reliability with ICC = 0.96 and 0.97 at the L2–3 and L4–5 levels, respectively and high inter-rater reliability with ICC = 0.85 and 0.87 at the L2–3 and L4–5 levels, respectively. Finally, they concluded that a novice and an experienced assessor were both able to reliably measure muscle thickness at rest on two different vertebral levels using real-time US imaging.

Please cite this article in press as: Ghamkhar, L., et al., Application of rehabilitative ultrasound in the assessment of low back pain: A literature review, Journal of Bodywork & Movement Therapies (2010), doi:10.1016/j.jbmt.2010.07.003

Table 3 Details of trials in which the muscles' size was measured using US in both healthy subjects and patients with LBP.

Author	Subject (number)	Measuring items (muscle)	Intervention/position	Conclusion
Hides et al. (1992)	NLBP (48)	CSA (MF)	Right and left sides and also between males and females	Positive. CSA of MF was symmetrical between right and left sides. Muscle shape differed between the males and females
Kennelly and Stokes (1993)	Adolescent idiopathic scoliosis (20)	CSA (MF)	Right and left sides of the curve	Positive. A significant difference was found in CSA of lumbar MF between the two sides of curve
Hides et al. (1994)	ALBP (26), NLBP (51)	CSA (MF)	The effect of LBP on muscle size	Positive. A significant difference was found in CSA of MF between-side and between the two groups at one level
Eisele et al. (1998)	A = NLBP (30) , B = discopathy (20) , C = LBP (40)	CSA (paraspinal)	To investigate the change of the ultrasonic texture of the paraspinal lumbar muscle	Positive. A significant difference was found in muscle size among three groups
Coldron et al. (2003)	NLBP (20)	Thickness (MF)	Different positions (prone, side lying)	Positive. No significant difference was found in muscle size in different positions
Watanabe et al. (2004)	NLBP (30)	Thickness (ES)	Three different positions: maximum flexion, neutral position, maximum extension	Positive. A significant difference was found in ES thickness in different positions
Stokes et al. (2005)	NLBP (120)	Thickness (MF)	Normal reference data for multifidus size	Positive. Normal references ranges reported for lumbar multifidus but no clinically significant correlation was found between CSA and anthropometric measures
Ainscough-Potts et al. (2006)	NLBP (30)	Thickness (TrA, IO)	Different positions (supine lying and different sitting positions)	Positive. No differences in the thicknesses of TrA muscle were measured during rest or while contracted, based on hand dominance
Lee et al. (2006)	CLBP (16), NLBP (19)	CSA (MF)	Different positions (prone lying, upright standing, and 25° and 45° forward stooping)	Positive. A significant difference was found on CSA of MF in different positions
Rankin et al. (2006)	NLBP (123)	Thickness (IO, IE, TrA, RA)	Normal reference data for abdominal muscle size	Positive. The pattern of relative muscle thickness was RA > IO > EO > TrA, but no significant difference was found in muscles between the left and right sides
Springer et al. (2006)	NLBP (32)	Thickness (lateral abdominal)	Different positions (rest and while performed ADIM)	Positive. Asymmetry in the lateral abdominal muscles was found in patients with LBP compared with those without LBP
Hides et al. (2007b)	NLBP (19)	Thickness (TrA, IO)	Static unilateral weight-bearing	Positive. A significant increase was found in TrA muscle size during static task
Hides et al. (2008a)	NLBP (40), CLBP (50)	CSA and symmetry (MF)	Comparing NLBP with CLBP	Positive. A significant difference was found in multifidus muscle size and symmetry between NLB and patients with CLBP
Wallwork et al. (2009)	CLBP (17), NLBP (17)	CSA (MF)	During rest and contraction	Positive. A significant reduction in CSA of MF was found in CLBP group at L5 only.

LBP = low back pain, ALBP = acute low back pain, CLBP = chronic low back pain, NLBP = non-low back pain, CSA = cross-sectional area, exe. = exercise, TrA = transverse abdominis, MF = multifidus.

Table 4 Details of trials investigating the reliability of US imaging assessment of low back muscle.

Author	Subject (number)	Measuring items (muscle)	Conclusion
Bunce et al. (2002)	NLBP (22)	Thickness (TrA)	Positive. US was found to be a reliable tool for measuring muscle thickness in different positions (both standing and walking)
McMeeken et al. (2004)	NLBP (9), NLBP (13)	Thickness (TrA)	Positive. High ICC was reported for between days reliability (for B mode and for M-mode). The ICC for between transducer reliability was also reported to be high
Watanabe et al. (2004)	NLBP (30)	Thickness (ES)	Positive. Sufficient intra-observer and inter-observer reproducibility was found for US imaging in measuring thickness of ES muscles
Teyhen et al. (2005)	LBP (30)	Thickness (lateral abdominal)	Positive. A high intra-rater reliability of measuring lateral abdominal muscle thickness was achieved
Pressler et al. (2006)	NLBP (30)	Thickness (MF)	Positive. The high between days inter-rater reliability was reported for the right and left sides of multifidus at S1 level
Hides et al. (2007a)	NLBP (19)	Thickness (TrA, IO)	Positive. High reliability of a novice rater was demonstrated for some measurement conditions
Wallwork et al. (2007)	NLBP (10)	Thickness (MF)	Positive. US was found to be a reliable tool for measuring muscle size. There was no systematic difference in muscle size measured across operators in the measurement of thicknesses at the L2—3 and at the L4—5 vertebral level
Norasteh et al. (2007)	ALBP (12), NLBP (27)	Thickness (TrA, IO, EO, RA)	Positive. US was found to be a reliable tool for measuring muscle thickness in both symptomatic and asymptomatic subjects
Koppenhaver et al. (2009)	NLBP (30)	Thickness (TrA, MF)	Positive. US was found to be highly reliable for intra-rater and adequately reliable for inter-raters measurements

ALBP = acute low back pain, NLBP = non-low back pain, CSA = cross-sectional area, exe. = exercise, IO = internal oblique, EO = external oblique, RA = rectus abdominis, TrA = transverse abdominis, MF = multifidus, EMG = electromagnetic, SEM = standard error of measurement, ICC = intra correlation coefficient.

Table 5 Details of trials investigating the validity of US imaging assessment of low back muscle.

Author	Subject (number)	Measuring items (muscle)	Conclusion
Hides et al. (1995)	NLBP (10)	CSA (MF)	Positive. Significant correlation was found between CSA measurements using US imaging and MRI
Hodges et al. (2003)	NLBP (13)	Architectural parameters (TrA, IO, EI, Ta, Br, Bic)	Positive. US imaging was correlated with EMG findings in detecting low levels of muscles contractions but no correlation was identified in discriminating between moderate and strong contractions
Ferreira et al. (2004)	LBP (10), NLBP (10)	Thickness (TrA, IO, EO)	Positive. A relationship was found between the presence of LBP and asymmetry of muscle size using US imaging and EMG
McMeeken et al. (2004)	NLBP(9), NLBP(13)	Thickness (TrA) and EMG activity	Positive. A significant correlation was found between US imaging and EMG activity
Vasseljen et al. (2006)	NLBP (10)	Activity onset (MF)	Positive. M-mode US imaging at high time resolution can detect onset of muscle activity comparably accurate to intramuscular EMG
Hides et al. (2006)	NLBP (13)	Thickness (TrA, IO)	Positive. US imaging was correlated with MRI findings in measuring thickness of both TrA and IO muscles
Kiesel et al. (2007a)	NLBP (7)	Thickness (MF)	Positive. Measuring MF muscle thickness using US imaging was highly correlated with EMG activity of MF in asymptornatic subjects

LBP = low back pain, NLBP = non-low back pain, CLBP = chronic low back pain, CSA = cross-sectional area, EMG = electromyography, US = ultrasonography, MRI = magnetic resonance imaging, MF = multifidus = , TrA = transverse abdominis, IO = internal oblique, EO = external oblique, T.Ant = tibilias anterior, Br = brachialis, Bic = biceps brachii.

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Some other studies were carried out on patients with LBP. In a study conducted by Norasteh et al. (2007), 12 patients with acute LBP and 27 normal subjects were selected. Within and between days reliability were tested on abdominal muscles in supine, sitting, and standing positions. They reported that there is high reliability on measuring muscle thickness not only in asymptomatic subjects but also in symptomatic subjects. These results suggest that US imaging in chronic LBP is as reliable as in healthy subjects.

Together these results suggest US imaging to be a reliable measures in the assessment of lumbar and abdominal muscles, and acceptable for clinical application, in both LBP and normal populations.

Discriminating chronic LBP subjects from non-LBP

Some studies focused onto the discrimination of chronic LBP from normal subjects. Results suggest that there is adequate evidence to support US as a valid instrument to detect muscle delayed activation particularly in MF and TrA in chronic LBP (Hides et al., 1994; Ainscough-Potts et al., 2006; Hides et al., 2007b).

For example, Hides et al. (1994) compared CSA of MF in 26 patients with acute LBP (aged 17–46) with 51 normal subjects (aged 19–32). In all patients, CSA was measured from the 2nd to the 5th lumbar vertebrae (L2–5) and in six patients at S1 level. In all normal subjects, CSA was measured at L4 and in 10 subjects measurements were made from L2–5. They found marked asymmetry in CSA of MF in patients with the smaller muscle being on the painful side, but there was no correlation between the degree of asymmetry and severity of symptoms. In another study (Lee et al., 2006), CSA of MF was measured in 35 males to identify subjects who suffered from chronic LBP. US images were taken on both sides at the L4 and L5 levels with the subjects in prone lying, upright standing, and 25° and 45° forward stooping. In the control group, the CSA of MF increased from prone lying to upright standing and then gradually decreased from 25° to 45° forward stooping. A reverse pattern of the CSA changes was recorded in patients with chronic LBP. It was reported that MF contracts maximally at upright standing in the normal group, while maximum contraction of the muscle occurs at 25° forward stooping in the patient group. The role of MF may be altered in the stabilization of the lumbar spine of chronic LBP patients. Wallwork et al. (2009) compared both the CSA and the ability to voluntarily perform an isometric contraction of the MF muscle at four vertebral levels in 34 subjects with and without chronic LBP. Results showed a significantly smaller CSA of the MF muscle for the chronic LBP group compared with the unimpaired group at the L5 vertebral level and significantly smaller percent thickness contraction for the chronic LBP group compared with the control group at the L5 vertebral level. All studies investigating the discrimination between chronic LBP patients and non-LBP using US imaging, reported positive results with relatively high rate of identification.

Validity

As demonstrated in Table 5, seven studies have evaluated the validity of measuring CSA of MF and abdominal muscles using US imaging. Two studies (Hides et al., 1995; Hides et al., 2006) compared MRI with US imaging measures and five studies (Hodges et al., 2003; Ferreira et al., 2004; McMeeken et al., 2004; Vasseljen et al., 2006; Kiesel et al., 2007a) compared EMG findings with US imaging. Hides et al. (2006) compared two imaging modalities MRI and US imaging used for measurement of the MF thickness. Ten normal females aged 21–31 years were imaged on two separate days using MRI and US imaging. Bilateral measurements were made at each vertebral level from L2 to S1. For both modalities, a significant difference was demonstrated in the CSA of MF between each vertebral level measured. They indicate that if a strict protocol is adhered to, real-time US imaging can be used to document muscle size in young adults and further studies are required to validate the technique in older subjects and in different conditions.

Ferreira et al. (2004) compared US imaging with EMG findings to measure trunk muscle activity on patients with LBP and normal subjects. Ten subjects with recurrent LBP and 10 matched controls were tested during isometric low load tasks with their limbs suspended. Changes in thickness from resting baseline values were obtained for TrA, internal oblique, and external oblique using US imaging. Fine wire EMG was used concurrently. Changes in automatic control of TrA were found in people with LBP and US imaging was considered a feasible non-invasive test of automatic recruitment of the abdominal muscles.

Validity studies examined a number of different muscles. For example, three studies were carried out on MF (Hides et al., 1995; Vasseljen et al., 2006; Kiesel et al., 2007a), four studies on TrA (Hodges et al., 2003; Ferreira et al., 2004; McMeeken et al., 2004; Hides et al., 2006). Kiesel et al. (2007a) determined the relationship between thickness changes of the lumbar MF, as measured by US imaging and EMG findings in 7 normal subjects. They concluded that muscle thickness change as measured by US imaging was highly correlated with EMG findings of MF activity in asymptomatic subjects ($r = 79$, $P < 0.001$). Hides et al. (2006) validated the use of real-time US imaging as a measure of the TrA muscle during a drawing-in of the abdominal wall of 13 healthy asymptomatic male elite cricket players aged 21.3 ± 2.1 years. They were imaged using MRI and US. US imaging of muscle thickness of TrA was found to be highly correlated with measures obtained with MRI (ICC ranging from 0.78 to 0.95). In another study carried out by McMeeken et al. (2004) there was a high correlation ($r = 0.87$, $P < 0.001$) of change in thickness of TrA between US imaging and EMG findings.

Vesseljen et al. (2006) carried out a study to explore whether high-frame rate M-mode US could measure anticipatory muscle responses in the lumbar MF reliably and comparably accurate to intramuscular EMG. On 10 normal subjects, they found M-mode US imaging at high time resolution can detect onset of muscle activity comparably accurate to intramuscular EMG, but with a small systematic delay.

These results indicate that US imaging appears to be a valid measure in the assessment of lumbar muscles, and acceptable for clinical application, in both LBP and normal populations, as all studies reported positive results.

Conclusion

The purpose of this study was to review literature published from 1990 to 2009 concerning the merits of using US imaging

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in the examination of back muscle function. There was a wide variation in methodology, procedures, equipment and muscles tested and variability in sample size, differences in degree and source of LBP patients, the physical fitness of individuals, etc. However, a convincing body of evidence suggests that US imaging is a reliable and valid tool for differentiating LBP patients from normal subjects and monitoring rehabilitation outcome measures. Further research regarding the classification of various subgroups of LBP patients and the identification of individuals at risk of developing LBP is needed.

Acknowledgements

The authors acknowledge the University of Social Welfare and Rehabilitation Sciences and also Mazandaran University of Medical Sciences for financial support of this study. They are also grateful to Dr. Barbara Richardson at the School of Allied Health Professions, Faculty of Health, University of East Anglia for her valuable and constructive comments.

Conflict of interest

None.

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Please cite this article in press as: Ghamkhar, L., et al., Application of rehabilitative ultrasound in the assessment of low back pain: A literature review, Journal of Bodywork & Movement Therapies (2010), doi:10.1016/j.jbmt.2010.07.003

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Please cite this article in press as: Ghamkhar, L., et al., Application of rehabilitative ultrasound in the assessment of low back pain: A literature review, Journal of Bodywork & Movement Therapies (2010), doi:10.1016/j.jbmt.2010.07.003