Measurement of abdominal muscle thickness using M-mode ultrasound imaging during functional activities

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Abstract

Ultrasound imaging has been previously utilized in the measurement of muscle thickness and cross-sectional area in research studies, and advocated as a clinical biofeedback tool in the rehabilitation of transversus abdominis function following episodes of low back pain. This paper describes how the thickness of the abdominal muscles can be quantified with a new measurement technique using M-mode ultrasound. The technique uses a custom-made transducer holder that facilitates measurement of muscle thickness changes during functional activity. Limitations of the technique and potential future applications are discussed. The M-mode ultrasound technique may provide an effective method for the non-invasive measurement of abdominal muscle thickness during functional activities.

1. Introduction

The transversus abdominis (TrA) muscle is reported to be part of a deep muscle cylinder that contributes to the stability of the lumbar spine during function (Richardson et al., 1999). People with low back pain (LBP) may present with different patterns of abdominal muscle activation than those who do not experience LBP (Hodges and Richardson, 1996; Hodges, 1999; O’Sullivan, 2000). If these altered patterns of trunk muscle activity are present and relevant in LBP patients, it is appropriate that such activity can be measured and monitored in the clinical environment. The activity of the Rectus Abdominis, External and Internal Oblique abdominal muscles may be measured by surface electromyography in the clinic. However, the accurate measurement of TrA activity normally requires an invasive EMG technique, which may be impractical in the clinical situation.

Ultrasound imaging (US) provides a potential solution for quantifying abdominal muscle activity. The muscle layers of the abdominal wall can be clearly identified using real-time B-mode US to facilitate the accurate placement of fine-wire electromyography (EMG) electrodes into the TrA (De Troyer et al., 1990; Abe et al., 1996; Hodges and Richardson, 1996). Critchley and Coutts (2002) used US to measure differences in abdominal muscle thickness changes during abdominal hollowing manoeuvres in subjects with low back pain.

Ultrasound imaging is also advocated as a biofeedback tool in the facilitation strategy for the rehabilitation of TrA activity in clinical practice (Richardson et al., 1999). With this clinical application, the real-time ultrasound image provides a visual cue for the patient, as they are able to observe the actual thickening of the muscle when it contracts.

Changes to the thickness of TrA and the other abdominal muscles during specific exercises have been measured (Critchley and Coutts, 2002). However, no studies to date have reported TrA thickness change during a continual period of function, such as walking. This technical and measurement note describes how thickness changes in the abdominal muscles can be measured during functional activities using motion (M)-mode ultrasound.

2. M-mode ultrasound

Motion (M)-mode ultrasound was primarily developed for use in cardiology for diagnostic examinations of the myocardium and heart valves (Picard, 1995; Anderson
and McDicken, 1999). M-mode has also been used for non-cardiovascular applications, such as quantification of diaphragmatic motion during respiration (Blaney et al., 1999) and change of diaphragm thickness in relation to contractile activity (Wait et al., 1989).

A real-time B-mode image depicts a cross-section of anatomical structures. In contrast, M-mode is a stationary, narrow beam that produces a one-dimensional view of the anatomical structures over time. M-mode can be used simultaneously with B-mode to enable the operator to accurately adjust the position of the M-mode beam, which is indicated by a dotted line on the B-mode display (Fig. 1). Information from sound waves reflected back to the transducer from anatomical structures in the US beam is used to produce a depth versus time chart of these structures in the M-mode display. The movement of structures in M-mode is one-dimensional and provides information on structural movement towards or away from the transducer. Orientating the plane of the US beam to capture the movement of anatomical structures of interest enables information to be obtained, over time, in a single image.

3. Transducer holder

Ultrasound imaging is usually performed with the operator holding the transducer to control position. This enables experienced operators to easily adjust the orientation of the US plane when conducting diagnostic examinations. In order to achieve accurate and repeatable measurements, the transducer position needs to be consistent. With appropriate experience, a strict protocol and a stationary subject, a consistent position may be achieved with the operator holding the transducer. However, if a subject is moving, it may be more difficult to control the transducer position for a sustained period.

Feasibility studies using M-mode imaging of the abdominal muscles, during simple functional tasks such as sit to stand indicated that transducer positioning could be satisfactorily maintained by the operators’ hand. However, with more complex functional tasks, such as walking, it proved more difficult for the operator to control the transducer position. Consideration was given to the development of a hands-free method of attaching the transducer to the subject during walking. The authors’ designed a transducer holder and belt to facilitate transducer positioning during walking. A block of high-density foam was used as a holder. The centre was cut away sufficiently to accommodate the transducer. The holder was taped to a belt, made from seat-belt-type material, and incorporated a plastic clasp locking mechanism (Fig. 2).

4. M-mode US measurement technique of the abdominal muscles during functional activities

The US system used for all work carried out to date is the Sonoace 6000C (Medison Co. Ltd, Seoul, Korea)
using a wide-band linear array transducer (frequency = 6–10 MHz) set to 10 MHz. Non-back pain and low back pain volunteers have participated in work that had received ethical approval from the University of Brighton Ethics Committee and the East Sussex Local Research Ethics Committee.

With the subject in a supine position, the US transducer was located in an area between the 12th rib and the iliac crest, and a vertical line from the anterior superior iliac spine and the frontal plane. This is consistent with transducer positions described in other studies (Critchley and Coutts, 2002). The belt was then fastened to provide a firm support for the transducer. The US mode was set to simultaneous B/M mode. The display was set to depict a 60 mm depth of view and the M-mode chart set to 10 s of continuous information. The power and gain were adjusted to provide the optimum clarity of the fascial planes between the abdominal layers. The image was then frozen and saved to the instrument’s hard disc.

From the supine position, the subject was assisted to a comfortable standing position where an image was recorded in the same way as the supine position. Following the standing position, the subject was assisted onto a treadmill, and walked with arms unsupported at 4 kph speed. The time taken to complete 3 strides was timed using a hand-held stopwatch and a mean time for one stride calculated. The image recording was activated at heel-strike on the side of the trunk being scanned. The point of heel-strike activation was located on the saved image and the subsequent heel-strikes were measured by the time previously calculated for each stride.

Most US imaging systems include on-screen measurement software. Muscle thickness can be measured immediately the image is complete using on-screen callipers and would provide a simple and quick measurement method in the clinic environment. For research purposes, saved bitmap images from the US unit hard drive were transferred, via floppy or zip disks, to a desktop computer. The NIH Image measurement software (http://rsb.info.nih.gov/nih-image/) was used to measure the thickness of the abdominal muscles for each image. The advantage of measuring images off-line with this type of software include the facility to enlarge images which provides for more accurate placement of the callipers. The data collection process is also accelerated, as no time is required to measure each image whilst the subject is present and the images can be randomized at a later date, enabling a blinding process for the protocol. Mean thickness calculations were produced for a series of ten measurements taken from the stance and swing phase of walking, and at 1-s intervals for the supine and standing images.

5. Discussion

The use of the custom-made belt helps to maintain consistent transducer placement whilst scanning subjects during a functional activity. While no direct evidence is
available to substantiate this claim, preliminary experimentation has indicated the benefit of hands-free positioning. Potential benefits include the subjects' ability to move relatively unhindered by the close proximity of the researcher and the freedom for the researcher to concentrate on preparing the image without having to constantly observe and control the transducer position. Further investigations would quantify the benefits of a belt support for the transducer compared to a hand-held process. Preliminary studies on the imaging of abdominal muscles using the transducer holder yielded sharper and more consistent M-mode displays than those with the operator-held method. This indicated a higher degree of consistency in maintaining the transducer position using the holder. Further studies will quantify any differences in the reliability of US measurement of the abdominal muscles between a hand-held transducer and the use of the holder. The optimal tension required to hold the belt in position in order to minimize changes to the scan plane is unknown at this time and requires further investigation.

Abdominal muscle thickness changes have been reported with the use of B-mode ultrasound (Critchley and Coutts, 2002), however, the use of M-mode (B/M mode) ultrasound to measure changes in abdominal muscle thickness has not been reported. B-mode US quantification of muscle and fat tissue thickness under changing conditions may require a sequence of individual images. With a split-screen option one image can be saved on-screen, while a second, representing the change of subject position or task, would be saved alongside the first image. This ‘before and after’ format enables a comparison for thickness changes between two images. However, this only provides data for two moments in time. M-mode US is an option with the capacity to provide information, continuously over a period of time in one measurable image.

The measurement technique described in this paper has been reported to be reliable (Bunce et al., 2002). Intraclass correlation coefficients of 0.94 (supine lying), 0.88 (standing) and 0.88 (walking) were calculated for 22 subjects repeated on three separate occasions. Standard error of measurement analysis was calculated as 0.35 mm (supine), 0.66 mm (standing) and 0.56 mm (walking). With muscle thickness changes often exceeding 1 mm during function the potential exists to observe for changes beyond the range of error.

The use of a hands-free application for the transducer and the time dimension provided by M-mode US has shown potential for the evaluation of abdominal muscle activity in functional tasks. If patterns of abdominal muscle thickness change are shown to differ in subjects reporting low back pain during functional activity then the effects of specific rehabilitation programmes may be re-measured in functional conditions. Thickness change is also observable in the internal and external oblique abdominal muscles using this technique, although fibre alignment differences may need to be investigated regarding the thickness change for the different muscles in the same image. The ability to visualize the activation of TrA as both a clinical measure and rehabilitation tool may prove valuable within a clinical setting. This process provides potential for use in clinical setting in addition to the biofeedback approach already advocated (Richardson et al., 1999) and offers opportunities for further use in the clinic for musculoskeletal diagnosis.

Results from studies using M-mode US to measure abdominal muscle thickness change in subjects with and without low back pain are currently being prepared for publication. Measurable differences in thickness between subjects with and without low back pain may confirm and demonstrate the potential for the use of M-mode US as a clinical tool.

References


