The Use of Real-Time Ultrasound Imaging for Biofeedback of Lumbar Multifidus Muscle Contraction in Healthy Subjects

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Study Design: Randomized controlled trial.
Objective: To determine if the provision of visual biofeedback using real-time ultrasound imaging enhances the ability to activate the multifidus muscle.
Background: Increasingly clinicians are using real-time ultrasound as a form of biofeedback when re-educating muscle activation. The effectiveness of this form of biofeedback for the multifidus muscle has not been reported.
Methods and Measures: Healthy subjects were randomly divided into groups that received different forms of biofeedback. All subjects received clinical instruction on how to activate the multifidus muscle isometrically prior to testing and verbal feedback regarding the amount of multifidus contraction, which occurred during 10 repetitions (acquisition phase). In addition, 1 group received visual biofeedback (watched the multifidus muscle contract) using real-time ultrasound imaging. All subjects were reassessed a week later (retention phase).
Results: Subjects from both groups improved their voluntary contraction of the multifidus muscle in the acquisition phase ($P<.001$) and the ability to recruit the multifidus muscle differed between groups ($P<.05$), with subjects in the group that received visual ultrasound biofeedback achieving greater improvements. In addition, the group that received visual ultrasound biofeedback retained their improvement in performance from week 1 to week 2 ($P>.90$), whereas the performance of the other group decreased ($P<.05$).
Conclusion: Real-time ultrasound imaging can be used to provide visual biofeedback and improve performance and retention in the ability to activate the multifidus muscle in healthy subjects. *J Orthop Sports Phys Ther 2006;36(12):920-925.* doi:10.2519/jospt.2006.2304

Key Words: *lumbar spine, motor learning, sonography, stabilization, trunk exercises*

There is considerable evidence for the important role played by the lumbar multifidus muscle in segmental stabilization of the lumbar spine. Biomechanical studies have highlighted the role of the multifidus muscle in provision of segmental stiffness,[19,25] control of the spinal segment's neutral zone,[17,18] and its capacity to stabilize the spine when spinal stability is challenged.[14,15] This information, concerning the role of the multifidus in normal function, underpins clinical approaches that have been developed incorporating rehabilitation of this muscle to promote segmental stability.[10] These rehabilitation programs may have long-term benefits in reducing the risk of recurrent low back pain (LBP). A randomized controlled trial was conducted on patients with first episode acute LBP, all of whom received medical management and, in addition, 1 group was taught to activate the segmental multifidus while receiving visual feedback using real-time ultrasound imaging.[10] Results showed that while pain and disability resolved within 4 weeks, size and symmetry of the multifidus muscles did not recover spontaneously in the control group. Subjects in the exercise group

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This study was approved by the Medical Research Ethics Committee (MREC) at The University of Queensland, Australia. I affirm that I have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript.
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restored between side symmetry of the muscle and long-term follow-up revealed that subjects in the control group had a higher LBP recurrence rate.[7]

Ultrasound imaging has been used in the past to document anthropometric properties of the multifidus muscle in normal subjects,[6,9,10,12,21,23] and reliability of performing these measures has been previously demonstrated.[6,9,21,23] Impairments of the multifidus muscle have been documented in subjects with LBP using imaging techniques. There is evidence that the cross-sectional area of the multifidus is selectively decreased compared with other lumbopelvic muscles in patients with chronic LBP.[2] Multifidus muscle atrophy has been successfully quantified in magnetic resonance, computed tomography, and ultrasound imaging studies in terms of both decreased muscle size[1,12] and presence of alterations in muscle consistency (due to fatty deposits or fibrous/connective tissue infiltration).[13]

Ultrasound imaging has been successfully used to provide visual feedback of muscle activation. Dietz et al[3] showed that 32 of 56 women that were unable to activate their pelvic floor muscles learned correct activation patterns with less than 5 minutes of ultrasound biofeedback training. Two studies have investigated the effectiveness of using real-time ultrasound imaging to provide biofeedback of activation of the abdominal muscles.[5,24] Henry and Westervelt[5] showed that biofeedback using real-time ultrasound imaging decreased the number of trials needed for asymptomatic subjects to consistently draw in the abdominal wall and activate the transversus abdominis muscle. Teyhen et al[24] studied subjects with LBP and showed that in the short-term, addition of biofeedback using real-time ultrasound imaging among subjects that were already able to draw-in the abdominal wall, did not further enhance the subjects' performance. This finding may have been related to a ceiling effect, and also highlights the fact that biofeedback might be more useful in specific subgroups of patients with LBP. The studies of Hides et al[7,10] used ultrasound imaging to provide visual feedback of multifidus muscle activation to subjects with LBP, but results were not compared with a group who performed the specific exercises without the addition of visual feedback.

It is useful to consider how visual feedback may enhance the process of learning to contract a muscle. The explanation may be provided by examining the principles of motor learning. Visual feedback may enhance learning effectiveness when subjects find it difficult to "get the idea" of the contraction required. Clinicians have reported that patients with LBP often find the multifidus muscle more difficult to activate than the transversus abdominis or pelvic floor muscles.[11] In these patients, many changes are likely to occur in the elements of motor control required for joint stabilization and protection. One key theory of motor learning was proposed by Fitts and Posner[4] and considered that learning involves 3 main stages: the cognitive, associative, and autonomous phases. In the cognitive phase, attention is given to feedback, movement sequence, and instruction during repetition and practice. It is during this first phase of motor relearning that visual biofeedback from ultrasound imaging may provide the most benefit. One additional form of feedback that has been documented in motor relearning literature is knowledge of results (KR). KR is information concerning outcome provided to the learner after the performance of a task.[22] As real-time ultrasound imaging can be used to measure the increase in muscle thickness that occurs when the muscle contracts, this information (amount of increase in millimeters) can provide biofeedback in the form of KR to the subjects. This information could enhance learning of the motor skill of activating the multifidus.

The aim of this study was to determine if 2 forms of biofeedback improved motor performance and retention of an isometric contraction of the multifidus muscle in individuals in the cognitive stage of learning. The forms of biofeedback selected were KR alone (amount of increase in muscle thickness that occurred on contraction) and KR plus visual feedback (visual observation of muscle contraction). To avoid the confounding influences of pain and muscle inhibition, a healthy subject population was selected.

METHODS

Subjects

A total of 25 healthy normal adult volunteers aged 18 to 25 years were studied. Both genders were included with subjects randomly allocated to 1 of 2 groups by selection of a sealed envelope containing either number 1 or 2. Group 1 (knowledge of results [KR] alone) contained 10 females and 3 males (mean ± SD, 19.1 ± 2.1 years) and group 2 (KR plus visual feedback) contained 9 females and 3 males (mean ± SD, 19.9 ± 2.2 years). Exclusion criteria included current LBP, history of LBP, previous lumbar injury or surgery, known neuromuscular or joint disease, significant spinal abnormality (eg, scoliosis), prior experience with biofeedback using ultrasound imaging, prior training in cognitive activation of the multifidus muscle, and any sports or fitness training (greater than 3 times per week) involving the low back muscles performed within the past 3 months. All subjects gave their informed consent. The study was approved by the Medical Research Ethics Committee at The University of Queensland, Australia.

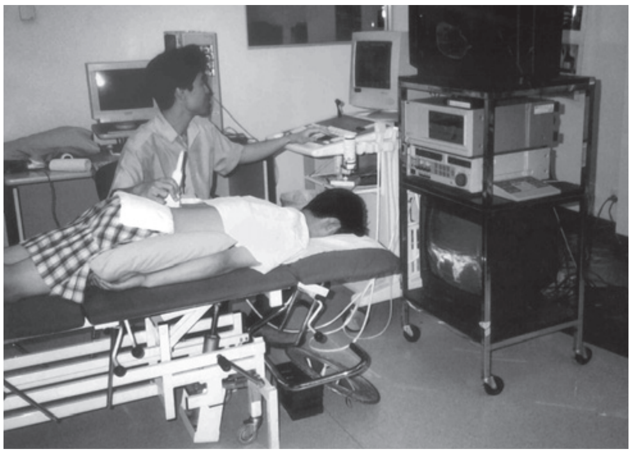

FIGURE 1. The patient was positioned in prone lying with a pillow placed under the hips to minimize the lumbar lordosis. The subject was able to see the ultrasound image by looking through the hole in the bed and into a mirror reflecting the image from a television monitor linked to the ultrasound equipment. The multifidus muscle was imaged in parasagittal (longitudinal) section, allowing visualization of the zygapophyseal joints, muscle bulk, and thoracolumbar fascia.

Assessment of Multifidus Muscle Thickness and Contraction

Ultrasound imaging assessment of multifidus muscle thickness was conducted using Diasonics Synergy ultrasound imaging apparatus equipped with a 5-MHz curvilinear transducer (NEC Corporation, Tokyo, Japan). The subject was positioned in prone lying, with a pillow placed under the abdomen to minimize the lumbar lordosis (Figure 1). The multifidus muscle was imaged in parasagittal (longitudinal) section, as per Hides et al,[6,9,10] allowing visualization of the zygapophyseal joints, muscle bulk, and thoracolumbar fascia. The left multifidus muscle was imaged at the L4-5 vertebral level. Linear measurements (multifidus muscle thickness measures) using on-screen calipers were made in all cases from the tip of the L4-5 zygapophyseal joint to the superior border of the multifidus muscle (Figure 2). Reliability of conducting thickness (or anteroposterior) measurements of the multifidus muscle in axial images under ''rest'' conditions has been previously reported by one of the authors.[6] This was established by analysis of variance (ANOVA) and calculation of the coefficient of variation (CV, 3%). Prior to the present study, a reliability trial was performed on 6 healthy normal subjects (mean age, 20.3 ± 1.7 years) not involved in the main study. Each subject was positioned in the standard testing position. Three separate ultrasound images were obtained at rest and the anteroposterior (thickness) measurement was conducted on parasagittal images by each assessor. Intraclass correlation coefficients (ICC) and standard error of measurement (SEM) were used to determine intrarater and interrater reliability. Results of the $ICC_{1,1}$ for intrarater reliability in week 1 were 0.98 for rater 1 (SEM, 0.31 cm) and 0.97 for rater 2 (SEM, 0.32 cm). The result of the $ICC_{2,3}$ for interrater reliability was 0.98 (SEM, 0.31 cm).

To assess multifidus muscle contraction, the difference between the multifidus muscle thickness at rest and during contraction was calculated. A split-screen technique was used to make this measurement more reliable. First, an image of the multifidus muscle was obtained at rest and saved on the left hand side of the screen. The subject was then asked to recruit the muscle while the contraction was observed on the right half of the screen. When the patient had performed the contraction, the image was saved and measurements were conducted at rest and on contraction using calipers. The split-screen technique allowed the 2 images to be compared to check that the same anatomical orientation had been maintained in both cases (Figure 3).

Procedure

Prior to testing in the acquisition phase, all subjects received the same initial explanation relating to the multifidus muscle. The anatomical location of the multifidus muscle was demonstrated using a model of the lumbar spine, and pictures of the muscle were provided and explained. A demonstration of an isometric contraction of the biceps was performed as a simple example of the type of contraction required in the multifidus muscle. Subjects were further instructed to take a relaxed breath in and out, hold the breath out, and then try to ''swell'' or contract the muscle. They were also instructed not to move their spine or pelvis when they contracted the muscle (ie, the type of muscle contraction required was a slow gentle sustained contraction). It was explained to the subjects that the contraction would be detected and measured using the ultrasound imaging equipment,

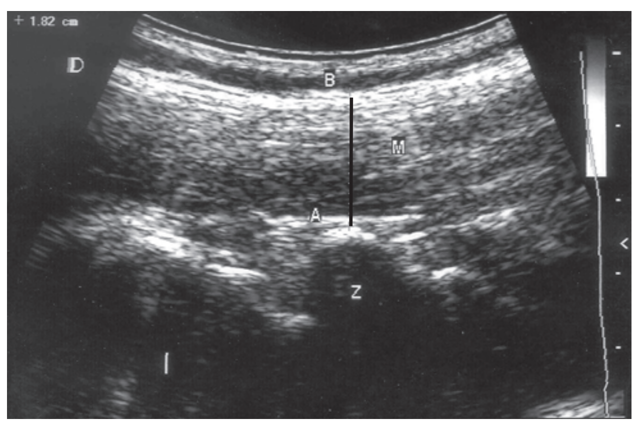

FIGURE 2. Ultrasound image of the multifidus muscle in parasagittal section (A, tip of the L4-5 zygapophyseal joint; B, superficial border of the multifidus muscle; M, multifidus muscle; Z, zygapophyseal joint).

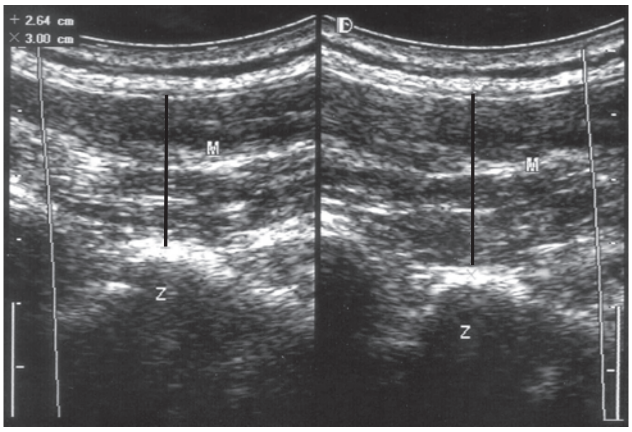

FIGURE 3. Ultrasound image of the multifidus muscle in parasagittal section at rest and on contraction using a split screen (M, multifidus; Z, zygapophyseal joint). Relaxed multifidus muscle thickness, 2.64 cm; contracted value, 3.00 cm.

and that they would have 5 seconds to try to contract the multifidus muscle and hold the contraction. At the end of the 5-second period, the image was saved on the screen and the measurements of the resultant increase in thickness performed. Each subject performed a total of 10 contractions (acquisition phase), as it was thought that greater than this number may induce possible fatigue. Twenty seconds rest was provided between contractions. All subjects received feedback on the number of millimeters of increase in muscle thickness that occurred with contraction of the multifidus (KR), with the aim being to increase this value.

In addition to the provision of KR, subjects in the other group received biofeedback in the form of visual observation of the ultrasound image of the muscle contraction as it occurred (KR plus visual feedback). As the subjects were positioned in prone lying, this was achieved by use of a TV monitor placed on the ground and a mirror, so that the subjects were able to view the screen in the standard testing position (Figure 1). The increase in muscle thickness that occurred with contraction of the multifidus muscle was first demonstrated to subjects in this group by asking them to slowly lift their ipsilateral leg (isotonic contraction). It was explained that if they performed the isometric contraction correctly, they would see an increase in muscle thickness on the screen.

After completing the 10 trials in the acquisition phase, all subjects were asked to return in 1 week for follow-up assessments (retention phase). The assessor who performed the follow-up assessments was blinded to group allocation. A 1-week period between the acquisition phase and the retention phase was chosen in this study as representative of the time span, which commonly exists between treatment sessions in physical therapy practice. Subjects were instructed not to practice the contraction in the interim. Session 2 involved 3 more trials of the same contraction; however, the subjects were not provided with any biofeedback regarding their performance or results for all 3 trials.

Statistical Analysis

For the multifidus muscle contraction measures, the amount of increase in thickness on contraction was expressed as a percentage of the resting muscle thickness. The formula used for each of the 13 trials performed (10 acquisition and 3 retention) was: percentage increase = [(contracted thickness – resting thickness) / (resting thickness)] × 100%. ANOVA was used to examine practice effects for percentage increase in multifidus contraction across the factors of trial (10 repetitions in week 1) and group (between-subject factor). A further repeated-measures ANOVA tested the retention effect of change in the contraction after 1 week without further practice. The factors in this analysis were week, trial (last 3 trials from week 1 and the 3 trials from week 2), and group. The data satisfied the assumption of homogeneity of covariance (Box's M).

RESULTS

Results of the ANOVA for practice effects showed no significant interaction effect between the factors of trial and group ($P>.05$), but a statistically significant main effects due to trial ($F = 5.30$, $P<.001$) and group ($F = 5.90$, $P<.05$), indicating that both groups improved their contraction size and the group who received KR and visual biofeedback (mean ± SD increase, 11.57% ± 7.51%) performed consistently better than the group that received only KR (mean ± SD increase, 5.82% ± 3.29%). The means and standard errors for each group across trial are shown in Figure 4.

Results of the ANOVA for retention effects showed a statistically significant interaction effect between week and group ($F = 4.66$, $P<.05$). Post hoc analysis showed that the group who received KR and visual biofeedback retained their improved performance from week 1 (mean ± SD, 13.13% ± 6.82%) to week 2 (mean ± SD, 13.27% ± 9.09%; $F = 0.01$, $P>.9$), while the ability of the subjects that only received KR had a reduction in their ability to contract the multifidus muscles from week 1 (mean ± SD, 6.25% ± 2.83%) to week 2 (mean ± SD, 3.11% ± 2.57%; $F = 23.87$, $P<.001$) (Figure 4).

DISCUSSION

The lumbar multifidus muscle is known to play an important role in segmental stabilization of the spine. There is also considerable evidence of impairments

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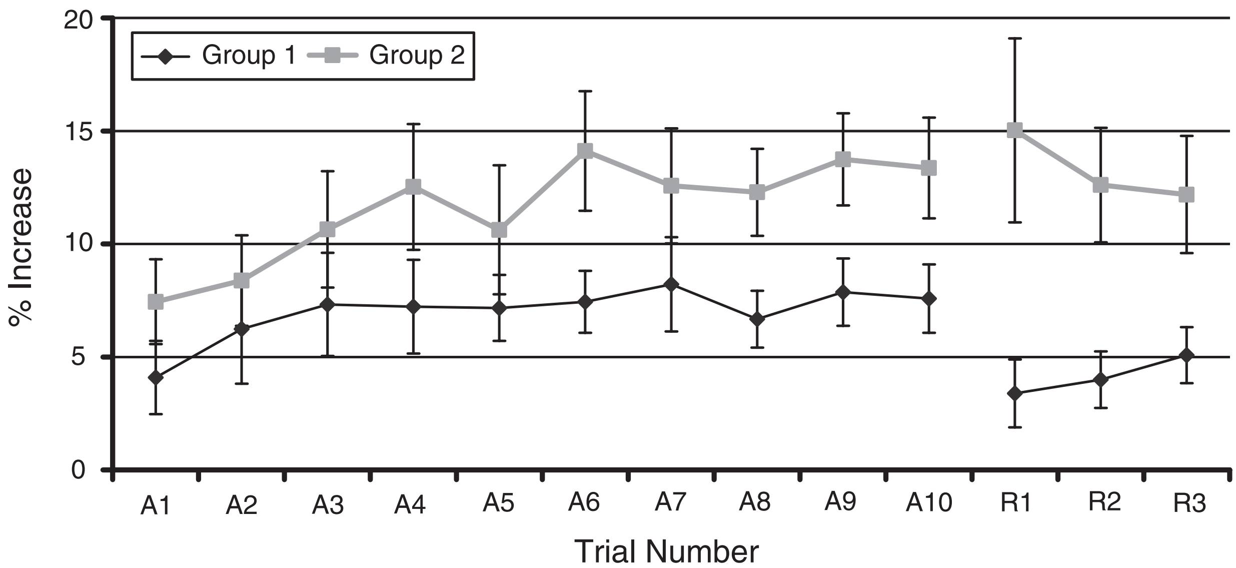

FIGURE 4. Graph of the percentage increase in multifidus thickness versus trial number for group 1 (knowledge of results [KR] alone) and group 2 (knowledge of results [KR] plus visual biofeedback) in the acquisition and retention periods. For both groups, the mean percent increase and standard errors were determined for each trial and plotted against the trial number. A1 to A10 represent trials, 1 to 10 in the acquisition phase (week 1), and R1 to R3 represent trials 1 to 3 in the retention phase (week 2).

in the muscle in the presence of LBP, and rehabilitation programs focusing on its re-education have been shown to be successful.[7,10,16] It is worthwhile investigating different techniques that may aid clinicians to rehabilitate the multifidus, as this can be a difficult process.[11]

This study aimed to apply motor learning principles to the exercise skill of isometrically contracting the multifidus by providing knowledge of results (KR) alone to 1 subject group versus KR plus visual feedback to the other. While both KR-alone and KR-plus-visual-feedback conditions improved performance of the motor skill of contraction of the multifidus in the acquisition phase, the group that received KR and visual feedback performed consistently better. Research involving motor learning suggests that performance should improve when KR is given alone.[22] The results of the present study are in agreement with this, as subjects from both groups increased their activation of the multifidus muscle during the acquisition phase. The KR-plus-visual-feedback group also retained more of the motor skill than those receiving KR alone. Similar results supporting the addition of visual feedback were found by Henry and Westervelt,[5] who studied 3 groups of normal subjects in relation to activation of the transversus abdominis muscle. The groups studied received minimal verbal biofeedback alone, verbal plus tactile biofeedback, or verbal, tactile, and visual biofeedback using real-time ultrasound imaging. The group that received the visual ultrasound imaging biofeedback required significantly fewer trials to reach the performance criterion. However, results regarding the retention phase are in conflict with that of Henry and Westervelt,[5] where improvements were seen in the acquisition phase, but were nonsignificant between groups on reassessment, which was conducted within 4 days. The authors did caution interpretation of this finding due to low subject numbers at follow-up.

Clinicians are increasingly using ultrasound imaging to provide biofeedback to enhance muscle re-education and rehabilitation. Hides et al[7,10] successfully used real-time ultrasound imaging to provide biofeedback to subjects with acute LBP in a randomized controlled trial, and other investigators have similarly advocated the benefits of real-time ultrasound imaging for teaching muscle activation.[3,5,11] The principles of motor learning may be used to explain why visual feedback is of benefit for subjects with LBP. In the initial stages of learning any new skill (cognitive stage), time is spent trying to understand the demands of the task, what to do, and what to feel. Clinicians have stressed the difficulty that subjects with LBP report when trying to isometrically activate the multifidus.[11] This may be due to processes such as reflex inhibition.[12] Feedback about the movement pattern is, therefore, important as the internal representations of the movement may not be developed. As subjects with LBP have been shown to have decreased proprioception,[20] which affects their ability to provide and process internal feedback, augmented biofeedback may be indicated.

This study has several limitations. One limitation is that interrater and intrarater reliability study was conducted on the multifidus muscle at rest. Future studies should evaluate the influence of variability known to occur due to muscle activation. Also, the retention test was short-term in nature, and transfer of training, which may be a better measure of learning, was not assessed. The practice schedule involved feedback with each repetition, which may not be optimal in terms of motor relearning.[26] Feedback on each repetition may, however, be appropriate early in the practice of a task (cognitive phase, as per Fitts and Posner[4]) that is difficult to learn, such as multifidus activation in subjects with LBP. Future studies could address these issues in a group with LBP and also assess the appropriateness of biofeedback provided by real-time ultrasound imaging for the different stages of motor learning.

CONCLUSIONS

Real-time ultrasound imaging is currently being used in physiotherapy practice to provide biofeedback of muscle activation. In subjects without LBP, use of ultrasound imaging to provide KR and visual biofeedback enhanced performance of an isometric multifidus muscle contraction in both the acquisition and retention phases of learning. Further research is required to determine the effectiveness of this form of biofeedback for re-education of other muscles and for subjects with LBP.

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