IJSPT

ORIGINAL RESEARCH

LATERAL ABDOMINAL MUSCLE SYMMETRY IN COLLEGIATE SINGLE-SIDED ROWERS

Norman W. Gill, PT, D.Sc., OCS, FAAOMPT[1]
Beth E. Mason, PT, D.Sc., OCS[2]
J. Parry Gerber, PT, Ph.D., ATC, SCS[3]

ABSTRACT

Purpose/Background: Although side to side symmetry of lateral abdominal muscle thickness has been established in healthy individuals, it is unknown whether abdominal muscle symmetry exists in athletes with asymmetrical physiological demands, such as those of single-sided rowers. The purpose of this study was to examine the oarside versus the non-oarside lateral abdominal musculature thickness in collegiate single-sided rowers, as measured by ultrasound imaging (USI).

Methods: The study was a prospective, cross-sectional, observational design. Thirty collegiate crew team members (17 males, 13 females, age 19.8 ± 1.2 years) characterized as single-sided rowers participated. Resting muscle thickness measurements of the transversus abdominis (TrA), internal oblique (IO), and external oblique (EO) muscles were obtained via USI. Comparisons of absolute and relative muscle thickness between oarside and non-oarside were performed using paired t-tests. Potential differences based on gender, rowing experience, and history of low back pain were investigated using mixed model analysis of variance.

Results: There were no clinically significant differences in absolute or relative thickness of the TrA, IO or EO on the oarside versus the non-oarside. There were no significant side to side differences in the relative muscle thickness of the TrA, IO or EO based on gender, rowing experience, or history of low back pain.

Conclusions: In this sample of single-sided rowing athletes, no clinically significant side to side differences in lateral abdominal muscle thickness were observed. Despite the asymmetrical functional demands of single-sided rowers in this study, thickness of the lateral abdominal muscles was symmetric.

Level of Evidence: 4

Key Words: crew, sweep rowing, transversus abdominis, ultrasound imaging.

[1] Army-Baylor University Doctoral Fellowship in Orthopaedic Manual Physical Therapy, Brooke Army Medical Center, Fort Sam Houston, TX, USA
[2] Carl R. Darnell Army Medical Center, Fort Hood, TX, USA
[3] Army – Baylor University Doctoral Residency in Sports Medicine Physical Therapy, West Point, NY

This study was approved by the Institutional Review Board, Department of Clinical Investigation, United States Military Academy. The views expressed in this manuscript are those of the authors and do not reflect the official policy of the Department of Army, Department of Defense, or U.S. Government. All authors are employees of the United States government. This work was prepared as part of their official duties, and as such, there is no copyright to be transferred. There has been no financial affiliation (including research funding) or involvement with any commercial organization that has direct financial interest in any matter included in this manuscript.

INTRODUCTION

Thirty-two percent of intercollegiate rowers experience back pain during their college career.[1] Many theories have been proposed to explain this high incidence of back pain such as exposure of rowers to cyclic loading in flexion and rotation, muscle imbalances of the back and leg muscles, and muscular dysfunction or motor control errors in maintaining spinal stability.[1,2,3,4,5] One may theorize that rowers who always row on the same side of a scull, known as single-sided or "sweep" rowers, could create side to side muscular imbalances and subsequently develop a greater risk for back pain.

During the rowing stroke, the trunk serves to both create and transfer forces from the legs and arms to the oar.[1] The lateral abdominal muscles provide trunk stability throughout the stroke to allow for powerful movements of the upper and lower extremities. The transversus abdominis (TrA), internal oblique (IO) and external oblique (EO) have been shown by electromyography (EMG) to be active during both the drive and recovery parts of the stroke, but are especially active in the latter part of the drive as an eccentric contraction to slow or control extension of the spine.[1] Because the single-sided rower consistently experiences asymmetric torque bias due to the demands of an off-set load from one oar, unilateral muscular demands may be placed on the abdominals and therefore create muscular asymmetries or imbalances.

Ultrasound imaging (USI) has been shown to be a reliable and valid non-invasive method for assessing the thickness of the lateral abdominal muscles. Hides et al[6] validated resting measurements including thickness of the lateral abdominal muscles using magnetic resonance imaging (MRI) as the gold standard. Rankin et al[7] showed excellent intrarater reliability when using USI to measure the lateral abdominal muscles with intraclass correlation coefficients (ICCs) across all muscles measured on the same day to be between 0.98-0.99 (95% confidence interval [CI]: 0.91-1.0) and across all muscles measured 7 days apart to be 0.96-0.99 (95% CI: 0.85-1.0).

There are several studies pertaining to symmetry of the lateral abdominal musculature using both MRI and USI.[6,7,8,9,10] Abdominal symmetry can be explored by examining each of the lateral abdominal muscles with respect to their absolute thickness or their relative thickness. Relative thickness provides a value normalized to the individual and therefore may be a better measure. The relative thickness value is expressed as the percent thickness of the individual muscle in relationship to the total lateral abdominal thickness.[7] In healthy adults, Rankin et al[7] found near perfect symmetry for all abdominal muscles when relative thickness of these muscles was assessed (all muscles exhibited less than 1.5% difference between sides). Few investigations regarding potential asymmetry of the abdominal muscles have been reported. Springer et al[8] found no difference in TrA thickness based on hand dominance, and Springer and Gill[9] found lateral abdominal thickness to be symmetrical in a lower extremity unilateral amputee population despite asymmetrical functional demands.

In contrast, Hides et al[11] reported abdominal asymmetry in athletes (elite cricketers) who participated in a sport that requires asymmetrical functional demands. Specifically, they found the IO was larger on the side contralateral to the dominant arm. The TrA, however, was found to be symmetric. Aside from the study by Hides et al[11], potential abdominal asymmetry has not been explored in athletes from other sports with asymmetrical physiological demands. Therefore, it is currently unknown whether abdominal asymmetry exists in other athletes, such as those who row on the same side of a scull.

The primary purpose of this study was to examine the oarside versus the non-oarside abdominal musculature in collegiate single-sided rowers, as measured by USI. The authors expected that no differences would be found outside of established abdominal muscle thickness symmetry normative values. A secondary purpose of this study was to examine any interaction effects between abdominal muscle thickness symmetry and gender, rowing experience, and history of back pain in collegiate single-sided rowers.

METHODS

Study Design

This was a prospective, cross-sectional, observational study approved by the West Point Institutional Review Board.

Subjects

Thirty collegiate crew team members out of a team of 70 rowers from the United States Military Academy Crew Team volunteered to participate in the study. Subjects were included if they were healthy, single-sided rowers. Subjects were excluded if they rowed bilaterally, or participated in the team in a capacity that was not solely rowing (coxswain or coach), or who had been injured or ill causing them to have missed training for more than two consecutive sessions at some point during the previous 6 weeks. Subjects were not excluded from the study if they experienced back pain at the time of the study, or during the previous 6 weeks, as long as the back pain did not interfere with the training as specified.

After completing the informed consent and information privacy paperwork, subjects completed an intake questionnaire with demographic information including age, gender, side of rowing (oar on left or oar on right side of scull), and incidence of back pain since the beginning of their rowing career. Those with current or a history of back pain completed a Modified Oswestry Disability Index (ODI) and a Fear Avoidance Behavior Questionnaire (FABQ) which included both a 7-item scale assessing fear-avoidance beliefs about work (FABQ work scale [FABQW]; score range, 0-42) and a 4-item scale assessing fear-avoidance beliefs about physical activity (FABQ physical activity [FABQPA] scale; score range, 0-24). Higher scores on the FABQW and FABQPA indicate that the individual has elevated fear-avoidance beliefs.[12] High levels of test-retest reliability (ICC = .70-.90 for FABQ; ICC = .90 for ODI) and have been reported with these instruments.[12,13,14,15]

Image Acquisition

Subjects were all given the same verbal instructions. They were instructed to lie supine on a plinth with the head resting at 15 degrees of flexion on a pillow and with their knees flexed over a pillow. Subjects were instructed to lie quietly and relaxed, with their arms behind their head, breathing comfortably while looking at the ceiling.

Ultrasound images were obtained using the Sonosite Titan (Sonosite, Inc., Bothell, WA) with a 5 MHz, 60 mm curvilinear array, and all measurements were performed by one evaluator. The evaluator was a Physical

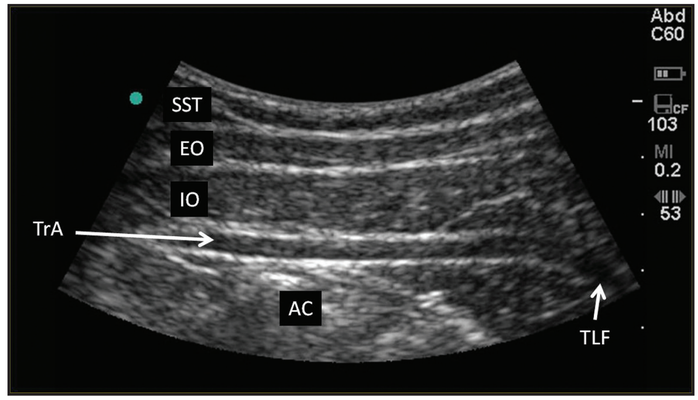

Figure 1. *Ultrasound image of the lateral abdominal muscles. Abbreviations: TLF, Thoracolumbar Fascia; AC, Abdominal Contents; TrA, Transversus Abdominis; IO, Internal Oblique; EO, External Oblique; SST, Superficial Soft Tissue.*

Therapist with 13 years of clinical experience and 5 years of experience working with USI. The evaluator was trained in the measurement technique to include a 4 hour group continuing education course and a subsequent 8 hour one on one training session with an experienced imager. The evaluator demonstrated excellent intrarater reliability measuring the lateral abdominals in this training session on 10 healthy individuals with an $ICC_{(3,3)}$ of .97 for the TrA muscle, and .98 for the IO and EO muscles.

Images were acquired of the lateral abdominal muscles using the technique similar to Teyhen et al.[16] (Figure 1). The center of the transducer was placed along the mid axillary line in the transverse plane just above the iliac crest. The transducer was positioned along the intersection of the hyperechoic portion of the TrA and the anterior reach of the lateral abdominal wall was placed on the far-left of the screen. The transducer angle was modulated slightly as needed to facilitate the best image of the fascial lines. The image was frozen at the end of the subject's respiration[17,18,19,20] and this served as the index image. The ultrasound machine was then placed in dual screen mode so that a second image of the same spot on the same side could be located and frozen. After measurements of the first two images were documented, the second image was unfrozen and a third image on the same side was captured, using the index image as a guide to ensure best possible placement of the transducer head on the same portion of the muscle. This sequence was then repeated on the opposite side. Three images were taken on each side.

Table 1. *Demographics of subjects (n = 30).*

Characteristics	All Subjects (n=30)
Age (years; mean ± SD)	19.8 ± 1.2
Gender (n)	
Female	13
Male	17
Height (cm; mean ± SD)	179.2 ± 8.9
Weight (kg; mean ± SD)	80.0 ± 9.7
BMI (m/kg^2; mean ± SD)	24.9 ± 0.8
Rowing Experience (n)	
Novice (< 1 year)	12
Advanced (> 1 year)	18
Back Pain (n)	
Left Side	2
Right Side	4
Central/Bilateral	4
Modified Oswestry Disability Index (%)	7.7 ± 7.3
Fear Avoidance Behavior Questionnaire	
FABQW (mean ± SD)	15.8 ± 3.8
FABQPA (mean ± SD)	12.4 ± 8.2

BMI= Body Mass Index; FABQW= Fear Avoidance Beliefs Questionnaire work subscale; FABQPA= Fear Avoidance Beliefs Questionnaire physical activity subscale

Measurements

Measurements were performed similar to Teyhen et al[21] on all three images for each side and later averaged. The screen was covered in acetate and grease pencil markings were placed at the center of each dual screen input to identify the site where the measurements were taken, 3.5 cm from the insertion of the TrA into the anterior abdominal fascia. The evaluator was blinded to the oarside of the athlete.

Data Analysis

Descriptive statistics were completed for demographic information, history of back pain, and for the ODI and FABQ questionnaires. Dependent variables were absolute and relative thicknesses of the TrA, IO, EO, and total abdominals (TrA + IO + EO) at rest. The absolute thickness (mm) of the muscles was defined as an average of the three measurements which provides the optimal reduction in error.[8,22] The relative thickness measurement (%) was defined using the following equation:[7]

(absolute individual muscle thickness/absolute total lateral abdominal muscle thickness)*100%

For the primary purpose of this study, the independent variable was "side" (oarside, non-oarside). For the secondary purposes, the independent variables included gender, experience level (novice- less than 1 year rowing, advanced- more than 1 year rowing), and past/current history of back pain. Inferential statistics comparing the mean side to side absolute and relative thicknesses for the primary hypothesis were performed using 2-tailed paired *t*-tests, and the secondary aims were analyzed using 2x2 mixed model analysis of variance (ANOVA). The alpha level was set at .05 for all tests. Data were analyzed using SPSS Statistics v. 18.0 (SPSS, Inc., Chicago, IL).

RESULTS

Subjects

Thirty subjects enrolled and completed the study (17 males, 13 females; age = 19.8 ± 1.2 years). There were no exclusions from the study. Subjects were nearly evenly split on rowing side (16 right, 14 left sided rowers), had an average body mass index of 24.9 ± 0.8, the majority were experienced rowers (60% with greater than 1 year experience), and one-third (n = 10) reported current or previous back pain episodes. Subject demographics details are provided in Table 1.

Table 2. *Absolute thickness (mm) and mean difference side-to-side (mm) for resting measures in collegiate single-sided rowers.**

	All Subjects (n = 30)				
Abdominal Muscle(s)	Oarside	Non-Oarside	Mean Difference	*t*	P
TrA	4.47±0.78 (4.17 – 4.76)	4.70±0.94 (4.35 – 5.05)	.23	-2.17	.038†
IO	10.69 ± 2.13 (9.89 – 11.48)	11.06 ± 2.47 (10.14 – 11.98)	.37	-1.54	.135
EO	10.37 ± 1.98 (9.63 – 11.11)	10.22 ± 2.25 (9.38 – 11.06)	.15	0.68	.503
Total	25.60 ± 3.83 (24.17 – 27.03)	26.01 ± 4.16 (24.45 – 27.56)	.41	-1.08	.291

Abbreviations: TrA, transversus abdominis; IO, internal oblique; EO, external oblique; Total = TrA + IO + EO, measured value.
* Values expressed as mean ± SD (95% CI). †p<.05

Morphometry of the Lateral Abdominal Muscles

There was a significant difference in the absolute thickness of the TrA ($t = -2.17$, $p = 0.038$), oarside mean $\pm$ SD of 4.5 $\pm$ 0.8 mm, non-oarside mean $\pm$ SD of 4.7 $\pm$ 0.9 mm. There were no significant differences in the absolute thickness of the IO, the EO, or the total abdominal thickness from side to side ($t = -1.54$, 0.68, and 1.08, $p =$ 0.135, 0.503, and 0.291 respectively) (Table 2).

There were no significant differences side to side in the relative thickness of the TrA or the IO ($t = -0.63$, -1.37, $p = 0.532$, 0.183 respectively), but there was a significant difference in the relative thickness of the EO ($t = 2.05$, $p = 0.050$) with an oarside mean $\pm$ SD of 41.5 $\pm$ 4.7%, and a non-oarside mean $\pm$ SD of 40.2 $\pm$ 5.0% (Figure 2).

There were no significant differences in relative thickness of the TrA, IO or EO based on gender ($p = 0.460$, 0.915, 0.538 respectively), experience in rowing ($p = 0.154$, 0.622, 0.743 respectively), or history of back pain ($p = 0.075$, 0.602, 0.982 respectively).

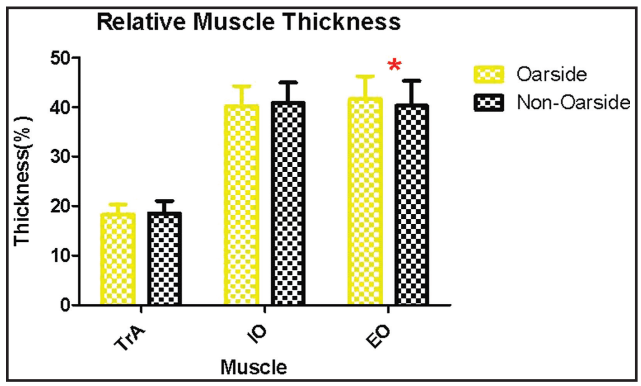

Figure 2. *Relative muscle thickness differences side to side (mean + standard deviation bars). Abbreviations: TrA, transversus abdominis; IO, internal oblique; EO, external oblique; *P = .05, t = 2.05.*

DISCUSSION

This study is the first to describe the morphology of the lateral abdominal muscles in single-side rowing athletes. The current study revealed a statistically significant difference in the absolute thickness of the TrA muscle between the oarside and the non-oarside of the subjects. However, this significant difference of only 0.2 millimeters between means would unlikely be considered to be clinically important. Additionally, the relative thickness of the EO muscle compared oarside to non-oarside was also statistically significantly different, but not likely clinically meaningful, since the means differed by only 1.3%. Recall that normative testing has shown side to side differences up to 1.5% in healthy populations.[7] No differences in relative thickness between oarside and non-oarside lateral abdominal muscles were present, with respect to gender, experience level or back pain. Despite the asymmetrical demands of a single-sided rower, the current study results of abdominal symmetry are consistent with previous studies.[6,7,8,9,10]

Symmetry between sides for the TrA may not be surprising. Hodges et al[23] found that the TrA is activated before the other abdominal muscles during voluntary arm movements, independent of the direction of arm movement. They proposed that the main function of the TrA in trunk control lies in a general stabilization of the spine. Furthermore, Eriksson et al[24] recently demonstrated that expectation of a perturbation may result in a direction-independent function of the TrA muscle in lumbar spine control. Additionally, other researchers have demonstrated that contraction of the TrA muscle and the IO muscle are symmetric even in response to a unilateral limb lifting task and independent of unilateral presentation of LBP.[25] If the primary function of the TrA is general stabilization, it seems plausible that it would be symmetrical in single-sided rowers, despite their asymmetrical demands.

The findings of symmetry in the oarside and non-oarside thickness of lateral abdominal muscles in single-sided rowers may be due to the kinematics of the stroke. Although the rowing stroke places unilateral demands through the abdominal musculature by a laterally off-set load, the rowing motion itself is not highly rotational through the torso when compared to some other asymmetric sports requirements. Perhaps athletes such as pitchers, power hitters, or tennis players would demonstrate more asymmetries in rotational muscles such as the IO and EO. Future research would be required to substantiate that theory.

It is also possible that the lack of side to side differences in lateral abdominal muscle thickness might be attributed to some mechanism in which rowers engage each side of the abdominal muscles (or each muscle) at different phases in the stroke, resulting in a balance that mitigates any measurable thickness differences at rest. EMG studies are lacking in the unilateral rowing athlete, and these types of studies could offer timing data about individual muscle utilization or recruitment throughout the rowing cycle for single-sided rowers.

The authors of the current study observed that 10 of the 30 subjects in our sample had a history of back pain which was similar to reports in previous studies of collegiate rowers.[26,27] However, no side to side differences in abdominal muscle thickness of the oarside and non-oarside between those with and without a history of back pain were observed. In those having a history of back pain in this study, mean ODI scores measuring disability were under 8% and therefore considered low.[13] Additionally, fear avoidance behaviors were low. Cut off values for abnormal fear avoidance for the behavioral scales have been previously defined as >29 for the FABQW and >14 for the FABQPA.[28] The subjects in the current study scored below these cut offs for the FABQW, but slightly above (mean $\pm$ SD, 15.8 $\pm$ 3.8) for the FABQPA. The higher score on the FABQPA is likely the result of the continued high level activity that these individuals are participating in, despite symptoms of low back pain. These scores, when viewed together, indicate that back pain was likely of minimal relevance in this sample of collegiate rowers.

A few limitations of this study should be considered. One limitation is that these subjects were military cadets who have many physical requirements. In addition to the unique demands of their sport they also participate in other physical training which may provide symmetrical forces on the trunk. However, this level of physical activity that also provides symmetrical movement is likely similar in other rowing athletes who must stay actively involved in general physical conditioning and cross-training activities outside of their normal crew practice.

Additional threats to validity occur in USI studies due to image acquisition or measurement errors. The authors attempted to limit these errors by performing a reliability analysis, using a dual screen display to ensure consistent positioning of the transducer, averaging multiple measures, and blinding the imager to the oarside of the subject to reduce bias.

CONCLUSION

In this sample of collegiate single-sided rowing athletes, no clinically significant side to side differences in lateral abdominal muscle resting thicknesses were observed using USI. While statistically significant differences in the relative thickness of the EO favoring the oarside were found, the mean difference between sides was small (1.3%) which is similar to published normative data. Further, no differences were noted in side to side comparisons of relative thicknesses when accounting for gender, experience in rowing, or history of low back pain. Despite the asymmetrical demands of single-sided rowers in this study, bilateral thickness of the lateral abdominal muscles was symmetric.

REFERENCES

1. Pollock CL, Jenkyn TR, Jones IC, et al. Electromyography and kinematics of the trunk during rowing in elite female rowers. *Med Sci Sports Exerc*. 2009;41:628-636.
2. Parkin S, Nowicky AV, Rutherford OM, et al. Do oarsmen have asymmetries in the strength of their back and leg muscles? *J Sports Sci*. 2001;19:521-526.
3. Solomonow M, Zhou BH, Baratta RV, et al. Biomechanics of increased exposure to lumbar injury caused by cyclic loading: Part 1. Loss of reflexive muscular stabilization. *Spine (Phila Pa 1976)*. 1999;24:2426-2434.
4. Solomonow M, Baratta RV, Zhou BH, et al. Muscular dysfunction elicited by creep of lumbar viscoelastic tissue. *J Electromyogr Kinesiol*. 2003;13:381-396.
5. Stallard MC. Backache in oarsmen. *Br J Sports Med*. 1980;14:105-108.
6. Hides J, Wilson S, Stanton W, et al. An MRI investigation into the function of the transversus abdominis muscle during "drawing-in" of the abdominal wall. *Spine*. 2006;31:E175-178.
7. Rankin G, Stokes M, Newham DJ. Abdominal muscle size and symmetry in normal subjects. *Muscle Nerve*. 2006;34:320-326.
8. Springer BA, Mielcarek BJ, Nesfield TK, et al. Relationships among lateral abdominal muscles, gender, body mass index, and hand dominance. *J Orthop Sports Phys Ther*. 2006;36:289-297.
9. Springer BA, Gill NW. Characterization of lateral abdominal muscle thickness in persons with lower extremity amputations. *J Orthop Sports Phys Ther*. 2007;37:635-643.
10. Mannion AF, Pulkovski N, Toma V, et al. Abdominal muscle size and symmetry at rest and during abdominal hollowing exercises in healthy control subjects. *J Anat.* 2008;213:173-182.
11. Hides J, Stanton W, Freke M, et al. MRI study of the size, symmetry and function of the trunk muscles among elite cricketers with and without low back pain. *Br J Sports Med.* 2008;42:509-513.
12. George SZ, Fritz JM, Childs JD. Investigation of elevated fear-avoidance beliefs for patients with low back pain: a secondary analysis involving patients enrolled in physical therapy clinical trials. *J Orthop Sports Phys Ther*. 2008;38:50-58.
13. Fairbank JC, Pynsent PB. The Oswestry Disability Index. *Spine*. 2000;25:2940-2952; discussion 2952.
14. Fritz JM, Whitman JM, Flynn TW, et al. Factors related to the inability of individuals with low back pain to improve with a spinal manipulation. *Phys Ther*. 2004;84:173-190.
15. Waddell G, Newton M, Henderson I, et al. A Fear-Avoidance Beliefs Questionnaire (FABQ) and the role of fear-avoidance beliefs in chronic low back pain and disability. *Pain*. 1993;52:157-168.
16. Teyhen DS, Gill NW, Whitaker J, et al. Rehabilitative ultrasound imaging of the abdominal muscles. *J Orthop Sports Phys Ther*. 2007;37:450-467.
17. Ainscough-Potts AM, Morrissey MC, Critchley D. The response of the transverse abdominis and internal oblique muscles to different postures. *Man Ther*. 2006;11:54-60.
18. De Troyer A, Estenne M, Ninane V, et al. Transversus abdominis muscle function in humans. *J Appl Physiol*. 1990;68:1010-1016.
19. Misuri G, Colagrande S, Gorini M, et al. In vivo ultrasound assessment of respiratory function of abdominal muscles in normal subjects. *Eur Respir J*. 1997;10:2861-2867.
20. Strohl KP, Mead J, Banzett RB, et al. Regional differences in abdominal muscle activity during various maneuvers in humans. *J Appl Physiol*. 1981;51:1471-1476.
21. Teyhen DS, Miltenberger CE, Deiters HM, et al. The use of ultrasound imaging of the abdominal drawing in maneuver in subjects with low back pain. *J Orthop Sports Phys Ther*. 2005;35:346-355.
22. Koppenhaver SL, Parent EC, Teyhen DS, et al. The effect of averaging multiple trials on measurement error during ultrasound imaging of transversus abdominis and lumbar multifidus muscles in individuals with low back pain. *J Orthop Sports Phys Ther*. 2009;39:604-611.
23. Hodges PW, Richardson CA. Relationship between limb movement speed and associated contraction of the trunk muscles. *Ergonomics*. 1997;40:1220-1230.
24. Eriksson AE, Thorstensson A. Trunk muscle reactions to sudden unexpected and expected perturbations in the absence of upright postural demand. *Exp Brain Res*. 2009;196:385-392.
25. Teyhen DS, Williamson JN, Carlson NH, et al. Ultrasound characteristics of the deep abdominal muscles during the active straight leg raise test. *Arch Phys Med Rehabil.* 2009;90:761-767.
26. McGregor AH, Anderton L, Gedroyc WM. The trunk muscles of elite oarsmen. *Br J Sports Med*. 2002;36:214-217.
27. Teitz CC, O'Kane JW, Lind BK. Back pain in former intercollegiate rowers. A long-term follow-up study. *Am J Sports Med*. 2003;31:590-595.
28. Al-Obaidi SM, Beattie P, Al-Zoabi B, et al. The relationship of anticipated pain and fear avoidance beliefs to outcome in patients with chronic low back pain who are not receiving workers' compensation. *Spine (Phila Pa 1976)*. 2005;30:1051-1057.