Quantification of the Differences in Electromyographic Activity Magnitude Between the Upper and Lower Portions of the Rectus Abdominis Muscle During Selected Trunk Exercises

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Research Report

Quantification of the Differences in Electromyographic Activity Magnitude Between the Upper and Lower Portions of the Rectus Abdominis Muscle During Selected Trunk Exercises

Background and Purpose: Controversy exists around exercises and clinical tests that attempt to differentially activate the upper or lower portions of the rectus abdominis muscle. The purpose of this study was to assess the activation of the upper and lower portions of the rectus abdominis muscle during a variety of abdominal muscle contractions. **Subjects.** Subjects (N=11) were selected from a university population for athletic ability and low subcutaneous fat to optimize electromyographic (EMG) signal collection. **Methods.** Controlling for spine curvature, range of motion, and posture (and, therefore, muscle length), EMG activity of the external oblique muscle and upper and lower portions of rectus abdominis muscle was measured during the isometric portion of curl-ups, abdominal muscle lifts, leg raises, and restricted or attempted leg raises and curl-ups. A one-way repeated-measures analysis of variance was used to test for differences in activity between exercises in the external oblique and rectus abdominis muscles as well as between the portions of the rectus abdominis muscle. **Results.** No differences in muscle activity were found between the upper and lower portions of the rectus abdominis muscle within and between exercises. External oblique muscle activity, however, showed differences between exercises. **Discussion and Conclusion.** Normalizing the EMG signal led the authors to believe that the differences between the portions of the rectus abdominis muscle are small and may lack clinical or therapeutic relevance. [Lehman GJ, McGill SM. Quantification of the differences in electromyographic activity magnitude between the upper and lower portions of the rectus abdominis muscle during selected trunk exercises. *Phys Ther*. 2001;81:1096–1101.]

Key Words: *Electromyography, Exercise therapy, Low back pain, Rectus abdominis muscle.*

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Controversy exists around exercises and clinical tests that attempt to differentially activate the upper or lower portion of the rectus abdominis muscle. There is no doubt that the rectus abdominis muscle is the major flexor of the torso[1] compared with other muscles in the abdominal wall and that it plays a minor role in spine stability.[2] However, the clinical question remains regarding the usefulness of attempting to preferentially train either the upper or lower portion of the muscle.

Clinical tests designed to evaluate the strength of the lower portion of the rectus abdominis muscle may be unnecessary if the upper and lower portions of this muscle are essentially equally active, not only with respect to each other but regardless of the maneuver performed. However, only clinical trials could determine whether one exercise results in a better clinical outcome. The results of recent studies[3,4] indicate that differences in activation between the upper and lower portions of this muscle may exist among different exercises. However, in neither study were the electromyographic (EMG) signals normalized. Without normalization (ie, expressing the EMG signal as a percentage of the maximum activity that muscle can generate), different muscles can not be quantitatively compared.[5] For example, concluding that the lower abdominals have less EMG activity than the upper abdominals when the signals are not normalized may not be due to the ability to preferentially recruit.

Numerous factors exist that can influence the magnitude of the EMG signal. The amount of subcutaneous tissue under the electrodes, changes in electrode spacing during movement, and muscle movement relative to the electrodes during changes in limb position and changes in muscle length during movement can influence the magnitude of the EMG signal.[6] For these reasons, the difference in activity between the 2 portions of the rectus abdominis muscle, together with the relevance of this difference to clinical practice, is still unknown.

Using EMG as a quantitative tool requires additional rigor (additional to normalization) to assess the implications of comparative activity.[6] Sarti et al[3] found differences in EMG activity between the upper and lower segments of the rectus abdominis muscle in subjects who performed dynamic exercises with limb and trunk movement. Because the exercises were accompanied by movement, spinal curvature and muscle length would change during the exercises. Because muscle length and skeletal geometry modulate force output and what the electrode can detect, both spine curvature and torso geometry

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Both authors provided concept/research design, writing, project management, subjects, and consultation (including review of manuscript before submission). Mr Lehman provided data collection and analysis. Dr McGill provided fund procurement, facilities/equipment, and clerical support.

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Figure 1.
Curl-up. Subject raises his shoulders and neck off the bench while curling his rib cage toward his pelvis.

Figure 2.
Abdominal muscle lift. While lying supine with knees bent, the subject attempts to raise his neck and shoulders straight off the bench without curling up. The neck is held straight, and the subject attempts to raise his trunk while keeping it straight.

should be maintained to facilitate comparison between rectus abdominis muscle segments. Changes in these factors during movements may result in differences in recorded electrical activity not due to changes in motor unit activity. In an attempt to negate the influence of these factors, we attempted to maintain a consistent amount of spinal flexion in our study. Anatomical evidence[7] indicating separate innervation to the different portions of the rectus abdominis muscle (ie, segments innervated independently) suggests that the possibility exists for differential recruitment to occur. The controls instituted in our study were done in an attempt to eliminate the confounding factors in EMG recordings associated with movements.

The purpose of our study was to assess the activation of the upper and lower portions of the rectus abdominis muscle during a variety of abdominal muscle contractions. The methods employed normalized EMG signals together with minimizing muscle movement during isometric contractions to facilitate controlled quantification of segment differences.

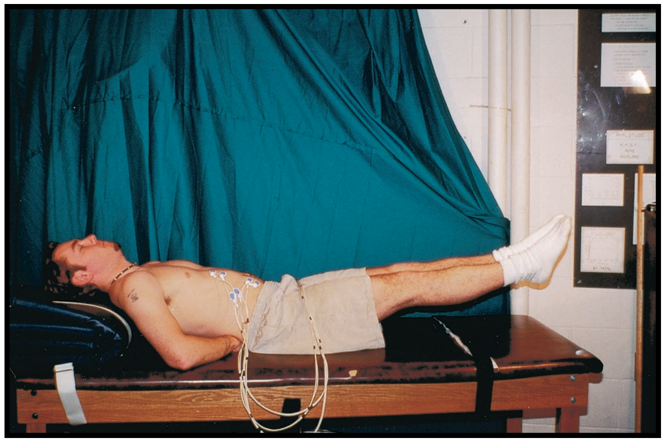

Figure 3.
Leg raise. The subject's neck and shoulders were raised and supported at approximately the height reached when performing a curl-up. This was done in an attempt to control the flexion angle. The subject then raised both straight legs 25 cm off the bench, held that position for 2 seconds, and repeated the task.

Methods

Subjects

To optimize EMG signal collection, subjects (N=11) from a university population were recruited because of their athletic abilities and low subcutaneous fat. Eight of the subjects were varsity athletes in basketball and volleyball, and the remaining subjects had performed abdominal muscle training exercises more than 3 times per week prior to this study. All subjects read and signed informed consent forms approved by the University of Waterloo Office of Research Ethics prior to the experiment.

Instrumentation

Electromyographic activity was monitored in 3 different muscle locations: (1) in the right external oblique muscle (15 cm lateral to the umbilicus, 45° to the horizontal running superior to inferior toward the midline), (2) in the upper portion of the right rectus abdominis muscle (~3 cm lateral to midline on the second to topmost rectus "bead"), and (3) in the lower portion of the right rectus abdominis muscle (~3 cm lateral and 2 cm inferior to the umbilicus). The EMG signals were collected using disposable bipolar silver-silver chloride disk surface electrodes with a diameter of 1 cm that were placed parallel to the muscle fibers with a center-to-center spacing of 2.5 cm. The EMG data were collected and band-pass filtered at 10 and 500 Hz

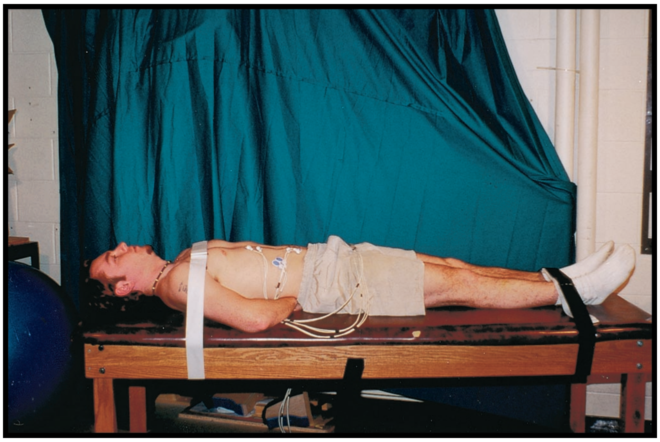

Figure 4.
Isometric leg raise. Lying flat on the bench, the subject's legs and chest were strapped to the bench. The subject was then asked to attempt to raise his legs for 2 seconds at approximately 30% of his maximum effort. The task was then repeated.

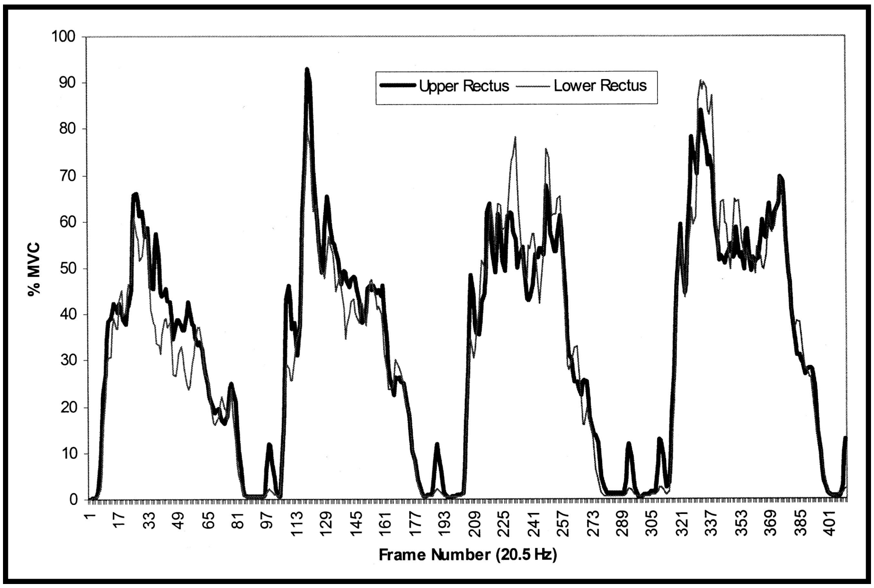

Figure 5.
Electromyograph depicting activity of the upper and lower portions of the rectus abdominis muscle during 4 curl-up exercises. MVC=maximum voluntary contraction, upper rectus=upper portion of rectus abdominis muscle, lower rectus=lower portion of rectus abdominis muscle.

(common mode rejection ratio of 100 dB, 60 Hz) and digitized (ATMIO board*) at 1,024 Hz.

EMG Data Processing

Raw EMG data were full-wave rectified and low-pass filtered (Butterworth filter cutoff frequency of 2.5 Hz) to produce a linear envelope. The signals were then normalized to the amplitude obtained during maximal voluntary contractions (MVC). The MVC procedure to recruit the rectus abdominis muscle required the subjects to attempt to perform a maximal curl-up against a resistance provided by the experimenters. The resistance rendered the action an isometric contraction. The subjects' feet were restrained, and the knees were bent 90 degrees. Subjects were then required to attempt to twist to the left against the resistance to maximally recruit the external oblique muscles. The performance of the MVC allows the muscle activity measured during subsequent tasks to be reported in terms of percentage of MVC. This method of reporting permits comparison across subjects as well as comparison of the relative activation of muscles.[6]

Exercise Movement Tasks

Subjects performed 5 tasks, 4 trials of each task, with 3 minutes of rest between tasks. All tasks were performed with the hands under the lower back in an attempt to maintain a consistent level of spinal flexion. We contend that placing the hands under the lower back would result in a mechanical stop that would not allow the lower back to round out (press flat to the floor) during all of the exercises, and this was our attempt to maintain the same spinal curvature in all conditions. All contractions were isometric and were held for no less than 2 seconds. The tasks were as follows:

Curl-up. The subjects raised their shoulders and neck off the support surface while curling the rib cage toward the pelvis (Fig. 1).

Abdominal muscle lift. While lying supine with the knees bent, the subjects attempted to raise their neck and shoulders straight off the support surface without curling up. The neck was held straight, and the subjects attempted to raise the trunk while keeping it straight (Fig. 2).

Leg raise. The subjects' neck and shoulders were raised and supported at approximately the height reached when performing a curl-up. This was done in an attempt to control the flexion angle. The subjects then raised both straight legs 25 cm off the support surface, held this position for 2 seconds, and repeated the task (Fig. 3).

Isometric leg raise. Lying flat on the bench, the subjects' legs and chest were strapped to the bench. The subjects were then asked to attempt to raise their legs for 2 seconds at approximately 30% of their maximum effort. The choice of 30% was arbitrary and was estimated by the subjects. This task was then repeated (Fig. 4).

* National Instruments Corp, 11500 N Mopac Expressway, Austin, TX 78759.

Table.
Average (SD) (Range) Muscle Activity, Difference Between Rectus Abdominis Muscle Portions and URA/LRA Ratio, and REO Activity During Each Exercise[a]

Exercise	URA	LRA	Difference	URA/LRA (%)	REO
Curl-up	38.44 (13.2) (13.1–55.7)	36.4 (13.9) (12.2–60.0)	2	105.34	19.85
Abdominal muscle lift	36.2 (14.9) (11.6–57.2)	42.6 (17.1) (10.6–70.2)	−6.4	85.03	44.59
Leg raise	39.3 (13.8) (25.2–78.2)	46.9 (17.18) (27.9–79.9)	−7.6	83.94	38.12
Isometric leg raise	31.1 (10.8) (13.8–45.8)	38.7 (14.1) (24.2–71.3)	7.6	80.23	43.47
Isometric curl-up	46.2 (19.6) (20.3–83.2)	39.1 (17.15) (16.3–62.1)	7.1	117.90	17.70

[a] Muscle activity is expressed as a percentage of maximum voluntary contraction. No significant ($P<.05$) differences between rectus abdominis muscle portions was found using a one-way repeated-measures analysis of variance. URA=upper portion of rectus abdominis muscle, LRA=lower portion of rectus abdominis muscle, REO=right external oblique muscle.

Isometric curl-up. In the same position as the isometric leg raise, the subjects attempted to raise their shoulders off the bench at 30% of their maximum effort. This position was held for 2 seconds and then repeated. Measurements were recorded during the isometric hold position.

Supporting the head and shoulders during the leg raise exercise was done in an attempt to achieve the same amount of spinal curvature and electrode spacing during the static hold of the isometric curl-up and the abdominal muscle lift. Maintaining the same amount of spinal flexion while performing static tasks was done in an attempt to control for muscle length, electrode spacing, subcutaneous tissue bulging, and posture. This control allows for possible EMG differences seen between the upper and lower portions of the rectus abdominis muscle to be attributed to fiber recruitment and not experimental factors.

Statistical Analysis

The average EMG activity of the linear envelope was calculated for each task during the 2-second window where the subjects maintained an isometric contraction. The ratios and absolute difference between the upper and lower portion of the rectus abdominis was found for each task within each subject. A one-way repeated-measures analysis of variance (ANOVA) was used to assess differences between tasks and differences between the upper and lower portions of the rectus abdominis muscle. We also used a one-way repeated-measures ANOVA to assess differences in external oblique muscle activity between exercises.

Results

With the one-way repeated-measures ANOVA, we found no differences between the upper and lower portions of the rectus abdominis muscle across all exercises (a typical time history is shown in Fig. 5). The Table presents the average group activity for each exercise and muscle and the average difference between muscle segments for each exercise. There was a reversal of the ratio between upper and lower rectus abdominis muscle activation during leg raises and the isometric curl-up, but these changes were small in terms of percentage of MVC.

Differences in external oblique muscle activity were seen among some of the exercises. The activity during the abdominal muscle lift and the isometric leg raise was greater when compared with the external oblique muscle activity during the curl-up and the isometric curl-up. No other differences were seen.

Discussion

The results of our study demonstrate that for the exercises tested, there were no differences between the upper and lower portions of the rectus abdominis muscle when EMG signals were normalized and posture was controlled. Three reasons may account for the disparity between the results of our study and those of other researchers.[3,4] First, the EMG data in our study were normalized. We believe that normalization of EMG data allows for a better comparison between muscle portions and across people. Second, we attempted to limit sources of error such as changes in muscle length, spinal flexion, and electrode movement caused by skin and fat movement by having the subjects place their hands under the lower back and by using isometric exercises. This approach could help decrease the likelihood that differences in EMG signals are due to these factors instead of differences in recruitment of segments of the muscle. Third, Sarti et al[3] were able to assign subjects to groups that allowed them to find differences between the portions in highly trained "correct" performers. Although biological quantification of the difference in activity was lacking, Sarti et al still demonstrated preferential recruitment in a subset of individuals. We did not confirm this statistically in our study, possibly because we did not use a classification system. However, the possibility exists that some individuals may have a greater ability than others to preferentially activate the different portions of the rectus abdominis muscle (as seen in the study by Sarti et al[3]), but the extent of this difference in terms of a subject's maximum activation level remains unknown. Reversal of the upper and lower rectus abdominis muscle ratio (Table) suggests that preferential recruitment is certainly possible; however, the normalization technique demonstrates that the difference between the portions is small and may have no clinical relevance in the prevention or rehabilitation of injuries.

These findings are relevant to the rehabilitation community because they confirm that a simple curl-up exercise activates the upper and lower portions of the rectus abdominis muscle essentially equally, and therefore strength and endurance adaptations occurring at one section should also occur in the other section. These results do not support the belief that straight leg raises are a necessary condition to activate the lower portion of the rectus abdominis muscle. These results along with the detrimental spinal compression penalty[8] associated with leg raises suggest caution when selecting leg raises in the context of rehabilitation or prevention of low back pain. Challenging the hip flexors is another issue.

Conclusion

No differences in levels were found between the upper and lower portions of the rectus abdominis muscle (although this notion did not extend to the oblique muscles). Thus, it appears that any difference that may exist between the upper and lower portions of the rectus abdominis muscle is small and of questionable clinical, therapeutic, and exercise training importance (in contrast to the oblique muscles).

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