Research Report

Abdominal Muscle Response During Curl-ups on Both Stable and Labile Surfaces

Background and Purpose. With the current interest in stability training for the injured low back, the use of labile (movable) surfaces, underneath the subject, to challenge the motor control system is becoming more popular. Little is known about the modulating effects of these surfaces on muscle activity. The purpose of this study was to establish the degree of modulating influence of the type of surface (whether stable or labile) on the mechanics of the abdominal wall. In this study, the amplitude of muscle activity together with the way that the muscles coactivated due to the type of surface under the subject were of interest. Subjects. Eight men (mean age=23.3 years [SD=4.3], mean height=177.6 cm [SD=3.4], mean weight=72.6 kg [SD=8.7]) volunteered to participate in the study. All subjects were in good health and reported no incidence of acute or chronic low back injury or prolonged back pain prior to this experiment. Methods. All subjects were requested to perform 4 different curl-up exercises—1 on a stable surface and the other 3 on varying labile surfaces. Electromyographic signals were recorded from 4 different abdominal sites on the right and left sides of the body and normalized to maximal voluntary contraction (MVC) amplitudes. Results. Performing curl-up exercises on labile surfaces increased abdominal muscle activity (eg, for curl-up on a stable surface, rectus abdominis muscle activity was 21% of MVC and external oblique muscle activity was 5% of MVC; for curl-up with the upper torso on a labile ball, rectus abdominis muscle activity was 35% of MVC and external oblique muscle activity was 10% of MVC). Furthermore, it appears that increases in external oblique muscle activity were larger than those of other abdominal muscles. Conclusion and Discussion. Performing curl-ups on labile surfaces changes both the level of muscle activity and the way that the muscles coactivate to stabilize the spine and the whole body. This finding suggests a much higher demand on the motor control system, which may be desirable for specific stages in a rehabilitation program. [Vera-Garcia FJ, Grenier SG, McGill SM. Abdominal muscle response during curl-ups on both stable and labile surfaces. *Phys Ther*. 2000;80:564–569.]

Key Words: *Abdominal muscle, Gym ball, Low back, Rehabilitation, Stable/labile, Swiss ball.*

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The use of labile (movable) surfaces underneath the subject for stability training of the injured low back is becoming more popular.[1] Recent work has demonstrated the importance of the abdominal muscles in ensuring sufficient spine stability to prevent buckling and enhancing function.[2–4] The optimal muscle recruitment schemes chosen by the motor control system determine the resultant stability together with the spine load that results from active muscle forces. In our view, clinical issues include the need to understand the effects of using labile surfaces to challenge the muscular system during rehabilitative exercise.

In order to choose the most appropriate exercises, we contend that data are needed on activation of the muscles that collectively form the abdominal wall during tasks performed on labile surfaces. Some work that our group conducted, which involved implanting intramuscular electrodes into the components of the abdominal wall, supported the impression that the rectus abdominis muscle is recruited primarily to create trunk flexion, whereas the obliques are recruited for a variety of reasons (eg, to enhance spine stability,[2] to assist challenged breathing during exercise or due to disease,[5] to generate lateral bending and twisting torque[6]). Some work has been conducted to document the loads imposed on the spine during various abdominal exercises,[7] but the effect of labile surfaces was not examined. However, the curl-up (as described by McGill[1]), as an abdominal exercise, has been shown to produce reasonable levels of activity in the rectus abdominis muscle while minimizing the resultant spine load and has been adapted into several low back fitness programs (for example, see McGill[8]).

The next stage in developing the scientific foundation is to document the degree of modulating influence of the type of surface (whether stable or labile) on the mechanics of the abdominal wall. Specifically, in this study, the amplitude of muscle activity and the way that the muscles were coactivated due to the type of surface under the subject were of interest.

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The test protocol was approved by the University of Waterloo Office of Human Research Ethics Committee.

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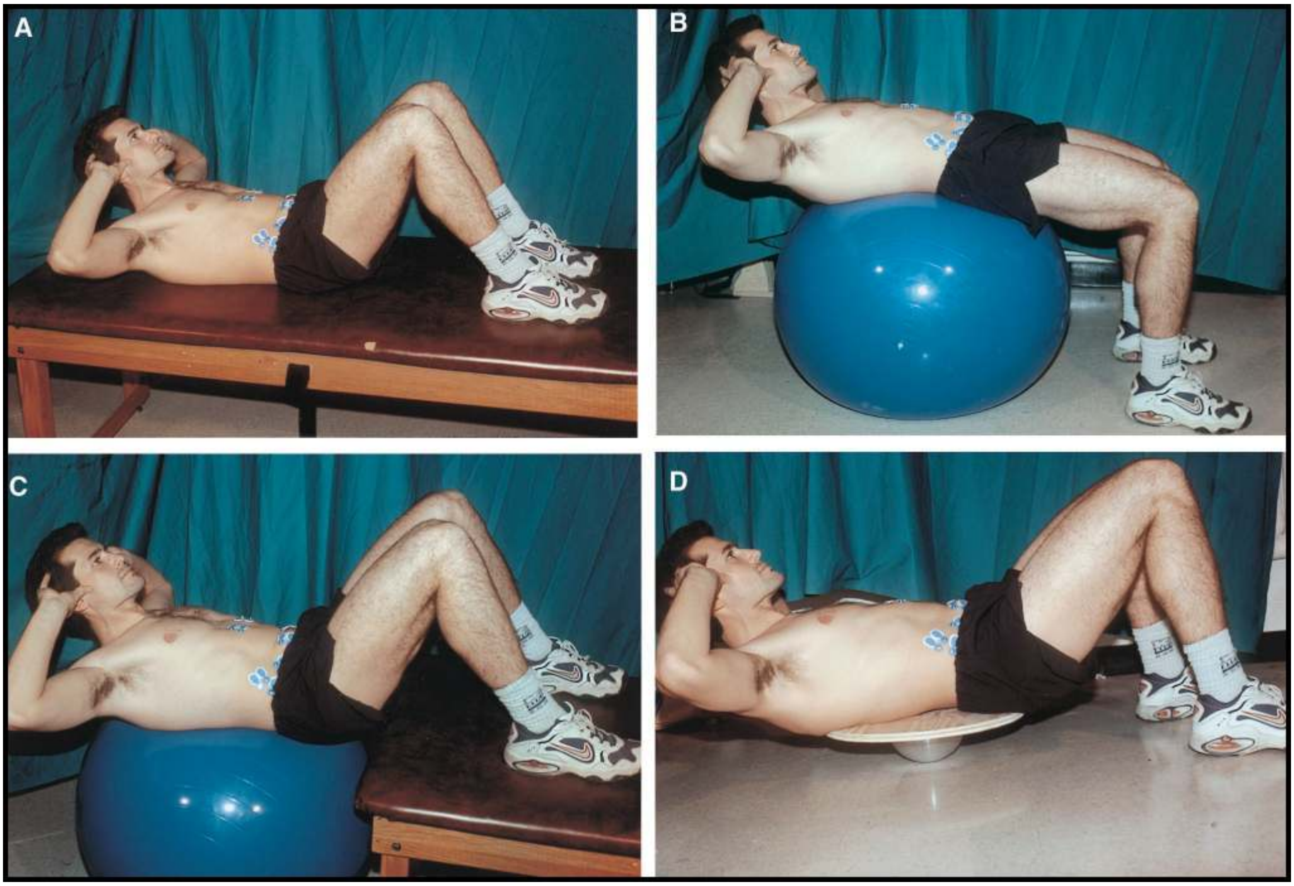

Figure 1.
Four different curl-up exercises used in the study: (A) curl-up on stable bench (task A), (B) curl-up with the upper body over a labile gym ball and with feet flat on the floor (task B), (C) curl-up with the upper body over a labile gym ball and with feet on a bench (task C), (D) curl-up with the upper body supported by a labile wobble board (task D).

Method

Subjects

Eight men (mean age=23.3 years [SD=4.3], mean height=177.6 cm [SD=3.4], mean weight=72.6 kg [SD=8.7]) volunteered to participate in this study. All subjects were in good health and reported no history of acute or chronic low back injury or prolonged episodes of back pain prior to this experiment. Their history of abdominal muscle exercising was neither investigated nor controlled. Subjects completed an information and "informed consent" document approved by the University of Waterloo Office of Research.

Tasks

All subjects were requested to perform 4 different curl-up exercises. The subjects were familiarized with the 4 tasks. The first task (task A) was to do a traditional curl-up on a padded bench with the subject's feet flat on the bench surface and both knees and hips flexed (Fig. 1). The subject's hands were placed behind the head, and just the head and shoulders were elevated from the bench surface. This was considered to be a stable surface. The next 3 tasks varied based on the type of labile surface. For the second task (task B), the subject's torso was supported over a gym ball and the feet were placed flat on the floor. Ball inflation was checked between subjects to ensure that the diameter remained at 70 cm prior to each test. For the third task (task C), the subject's feet rested on a bench at the same height as the ball. For the fourth task (task D), the ball was replaced with a round wobble board with 3 degrees of freedom, and the subject's feet were placed flat on the floor. Each isometric curl-up hold lasted approximately 6 seconds, from which the last 2 seconds were selected for analysis. Two minutes of rest was provided between tasks.

Data Collection

Electromyographic signals were recorded from 4 different abdominal sites on the right and left sides of the body. Pairs of silver-silver chloride electromyographic (EMG) surface electrodes were placed 3 cm apart, center to center, on the skin over the following muscles: upper rectus abdominis muscle (approximately 3 cm lateral and 5 cm superior to the umbilicus), lower rectus abdominis muscle (approximately 3 cm lateral and 5 cm inferior to the umbilicus), external oblique muscle

Table 1.
Average Muscle Activity Normalized as a Percentage of Maximal Voluntary Contraction for the Four Curl-up Tasks and for the Right and Left Sides of the Rectus Abdominis, External Oblique, and Internal Oblique Muscles[a]

Right Side Exercise	URAR		LRAR		OER		OIR	
	Average	SD	Average	SD	Average	SD	Average	SD
CU	21.76	10.6	20.87	10.5	4.73	4.3	11.53	7.5
CUBF	46.71	22.0	54.76	17.0	21.21	12.5	19.27	7.9
CUBB	33.44	13.3	34.49	8.2	9.24	6.07	17.11	8.3
CUPT	38.70	17.7	36.59	11.5	7.37	5.92	16.14	10.0
Left Side Exercise	**URAL**		**LRAL**		**OEL**		**OIL**	
	Average	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**
CU	20.58	12.1	19.83	9.7	4.62	2.2	10.98	8.4
CUBF	46.50	27.2	52.97	22.1	19.75	10.0	19.79	7.4
CUBB	35.09	17.6	34.44	11.7	11.28	7.7	16.47	9.8
CUPT	39.75	28.2	36.02	13.4	9.12	7.0	16.08	10.2

[a] CU=curl-up on stable bench (task A); CUBF=curl-up with the upper body over a labile gym ball and with both feet flat on the floor (task B); CUBB=curl-up with the upper body over a labile gym ball and with both feet on a bench (task C); CUPT=curl-up with the upper body supported by a labile wobble board (task D); URAR=upper portion of rectus abdominis muscle, right side; LRAR=lower portion of rectus abdominis muscle, right side; URAL=upper portion of rectus abdominis muscle, left side; LRAL=lower portion of rectus abdominis muscle, left side; OER=external oblique muscle, right side; OIR=internal oblique muscle, right side; OEL=external oblique muscle, left side; OIL=internal oblique muscle, left side.

(approximately 15 cm lateral to the umbilicus), and internal oblique muscle (halfway between the anterior superior iliac spine of the pelvis and the midline, just superior to the inguinal ligament). The EMG signals were amplified to produce approximately ±4 V, then A/D converted via a 12-bit, 16-channel A/D converter at 1,024 Hz (full-wave rectified and low-pass filtered with a Butterworth filter at 2.5 Hz to create a linear envelope of the activity). The average value of the muscle activity over the 2-second sample was then normalized to each subject's maximal myoelectric activity (or maximal voluntary contraction [MVC]) at each muscle site (obtained through a series of maximal exertion tasks[9] and expressed as a percentage of this value). Maximal voluntary contractions were obtained in isometric maximal exertion tasks. The subjects were manually braced for flexor moment while in a sit-up position for the rectus abdominis muscle; the same posture was used for the oblique muscles, but subjects also attempted isometric twisting efforts (although no twist took place).

Slide film recorded the external body segment position in the sagittal plane of the subjects during their performance of each curl-up exercise to confirm correct positioning. It was important to confirm that the torso posture remained constant between tasks to ensure valid EMG signals from the muscles underneath the electrodes.

Data Reduction

These abdominal challenging activities were also ranked according to their average EMG amplitude. A 2-way analysis of variance was performed on the maximum EMG levels from each task for each of the 4 abdominal muscle sites ($P \leq .05$). A Tukey Honestly Significant Difference *post hoc* test was used to identify specific differences.

Results

Performing a curl-up on the stable bench (task A, Fig. 1) resulted in the lowest amplitude of abdominal muscle activity (for all muscles) observed in any task (approximately 21% of MVC for the rectus abdominis muscle) (Tab. 1). Differences in activity among different exercises are shown in Table 2. The other 3 exercises performed on labile surfaces approximately doubled the abdominal muscle activity. Furthermore, although performing the curl over the gym ball with the feet on the floor (task B) generally doubled activity in the rectus abdominis muscle, activity in the external oblique muscle increased approximately fourfold. For all exercises, the rectus abdominis muscle was much more active (in percentage of MVC) than the oblique muscles. The internal oblique muscle was more active than the external oblique muscle with the exception of task B, where the subject's feet were on the floor and there was the greatest possibility of rolling laterally off the ball. In this task, there was much more co-contraction of the external oblique muscle with the rectus abdominis muscle when compared with other tasks (this is shown in the ratios of muscle activity in Figs. 2 and 3). This task was the most demanding in terms of maintaining whole-body stability.

Another question of interest to us was whether people are able to preferentially recruit upper versus lower portions of the rectus abdominis muscle. Relative ratios of the upper and lower portions of the rectus abdominis

Table 2.
Differences in Muscle Activity Among the Different Exercises[a]

	Muscle							
	URAR	LRAR	OER	OIR	URAL	LRAL	OEL	OIL
CU/CUBF		*	*			*	*	
CU/CUBB								
CU/CUPT								
CUBF/CUBB		*				*		
CUBF/CUPT		*				*		
CUBB/CUPT								

[a] Asterisk (*) indicates difference in average electromyographic activity as a percentage of maximal voluntary contraction ($P<.05$, repeated-measures analysis of variance) between curl-up exercises. CU=curl-up on stable bench (task A); CUBF=curl-up with the upper body over a labile gym ball and with both feet flat on the floor (task B); CUBB=curl-up with the upper body over a labile gym ball and with both feet on a bench (task C); CUPT=curl-up with the upper body supported by a labile wobble board (task D); URAR=upper portion of rectus abdominis muscle, right side; LRAR=lower portion of rectus abdominis muscle, right side; URAL=upper portion of rectus abdominis muscle, left side; LRAL=lower portion of rectus abdominis muscle, left side; OER=external oblique muscle, right side; OIR=internal oblique muscle, right side; OEL=external oblique muscle, left side; OIL=internal oblique muscle, left side.

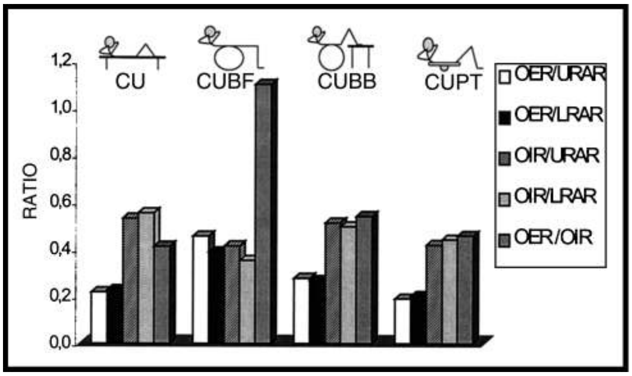

Figure 2.
Amplitudes of right-side muscle pairs expressed as a ratio. CU=curl-up on stable bench (task A); CUBF=curl-up with the upper body over a labile gym ball and with both feet flat on the floor (task B); CUBB=curl-up with the upper body over a labile gym ball and with both feet on a bench (task C); CUPT=curl-up with the upper body supported by a labile wobble board (task D); URAR=upper portion of rectus abdominis muscle, right side; LRAR=lower portion of rectus abdominis muscle, right side; OER=external oblique muscle, right side; OIR=internal oblique muscle, right side.

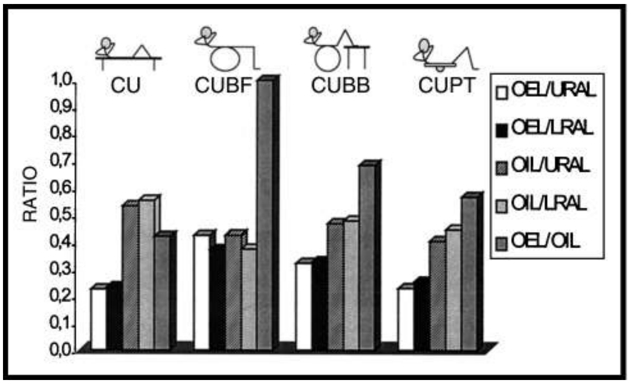

Figure 3.
Amplitudes of left-side muscle pairs expressed as a ratio. CU=curl-up on stable bench (task A); CUBF=curl-up with the upper body over a labile gym ball and with both feet flat on the floor (task B); CUBB=curl-up with the upper body over a labile gym ball and with both feet on a bench (task C); CUPT=curl-up with the upper body supported by a labile wobble board (task D); URAL=upper portion of rectus abdominis muscle, left side; LRAL=lower portion of rectus abdominis muscle, left side; OEL=external oblique muscle, left side; OIL=internal oblique muscle, left side.

muscle (Fig. 4) indicate that the upper region was more active in task D, in which the subject's upper body was supported on the wobble board, whereas the lower region of the rectus abdominis muscle was proportionally more active in task B, in which the subject's upper body was over the gym ball with the feet on the floor. For the other 2 tasks, upper and lower rectus abdominis muscle activity was almost the same. We are still unable to interpret the data as proof of the ability to preferentially recruit different sections of this muscle. Rather, the differences may have been to due to small geometric and postural changes.

Discussion

Performing curl-up exercises on labile surfaces appears to increase abdominal muscle activity. This increase in muscle activity is probably due to the increased requirement to enhance spine stability and whole-body stability to reduce the threat of falling off the labile surface. Furthermore, in order to enhance this stability, it appears that the motor control system selected to increase external oblique muscle activity more than the other abdominal muscles. The use of labile surfaces appears to increase muscle activity levels and coactivation, further challenging endurance capabilities; however, there is no doubt that the spine pays an additional load penalty for this in increased muscle activity. Given the magnitude of spinal loads observed in tasks similar to those studied here,[7] the additional load that occurs with use of labile surfaces may be of concern only for the most fragile of patients.

Although little literature exists to compare with the results of our study, the measurements of abdominal

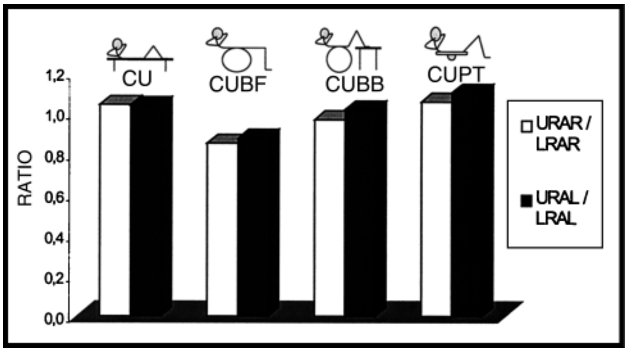

Figure 4.
Amplitudes of the upper and lower portions of the rectus abdominis muscle expressed as a ratio. CU=curl-up on stable bench (task A); CUBF=curl-up with the upper body over a labile gym ball and with both feet flat on the floor (task B); CUBB=curl-up with the upper body over a labile gym ball and with both feet on a bench (task C); CUPT=curl-up with the upper body supported by a labile wobble board (task D); URAR=upper portion of rectus abdominis muscle, right side; LRAR=lower portion of rectus abdominis muscle, right side; URAL=upper portion of rectus abdominis muscle, left side; LRAL=lower portion of rectus abdominis muscle, left side.

muscle activity we obtained compare well with the data of Axler and McGill,[7] who noted that generally curl-ups (at least on stable surfaces) were the safest of those chosen from a wide variety of abdominal muscle exercises. The activity levels observed in the current study (from approximately 20% to 55% of MVC in the rectus abdominis muscle) appear to constitute stimuli to increase both force production (strength) and endurance properties of muscle. Furthermore, the activity levels in the obliques observed in the labile curl-up tasks of our study (ie, from 5% to 20% of MVC in the oblique muscles) suggest a generous margin to ensure "sufficient stability" in a spine positioned in a neutral posture.[2,10] Sarti et al[3] also attempted to address the issue of whether an individual can preferentially the recruit the upper or lower section of the rectus abdominis muscle. Their data suggested that some highly trained individuals were able to preferentially recruit the lower section of the rectus abdominis muscle during specific maneuvers executed during supine lying where the legs and pelvis were raised from the floor. Our data make it difficult to make a conclusive statement on this issue because there were slight postural changes among the 4 tasks and particularly between the 2 tasks that suggested a differential of 20% of MVC between the upper and lower portions of the rectus abdominis muscle.

Interpretation of the data in our study is limited because our subjects were relatively physically fit. Future investigations should include patients with different spinal conditions, of different ages, and so on. Furthermore, the tasks of this study involved holding positions, and there is no doubt that motion would change muscle activity levels. Finally, our tasks were designed to be nonfatiguing, and fatiguing conditions may lead to different results.

Conclusion

Performing curl-ups on labile surfaces changes both the muscle activity amplitude and the way that the muscles coactivate to stabilize both the spine and the whole body. This finding suggests a much higher demand on the motor system, which may be desirable for specific stages in a rehabilitation program as long as the concomitant higher spine loads are tolerable.

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