Muscle Activation Among Supine, Prone, and Side Position Exercises With and Without a Swiss Ball

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Background: Prone, supine, and side position exercises are employed to enhance core stability.

Hypothesis: Overall core muscle activity would be greater in prone position exercises compared with supine and side position exercises.

Study Design: Controlled laboratory study.

Methods: Eighteen men and women between 23 and 45 years of age served as subjects. Surface electrodes were positioned over the upper and lower rectus abdominis, external and internal obliques, rectus femoris, latissimus dorsi, and lumbar paraspinals. Electromyography data were collected during 5 repetitions of 10 exercises, then normalized by maximum voluntary isometric contractions (MVIC). Differences in muscle activity were assessed using 1-way repeated-measures analysis of variance, while t tests with a Bonferroni correction were employed to assess pairwise comparisons.

Results: Upper and lower rectus abdominis activity was generally significantly greater in the crunch, bent-knee sit-up, and prone position exercises compared with side position exercises. External oblique activity was significantly greater in the prone position compared with side position exercises. Internal oblique activity was significantly greater in the prone bridge (plank) on ball and prone on ball with left and right hip extension compared with side position exercises. Lumbar paraspinal activity was significantly greater in the 3 side position exercises compared with all remaining exercises. Latissimus dorsi activity was significantly greater in the prone on ball with left and right hip extension and prone bridge (plank) on ball and on toes compared with the crunch, bent-knee sit-up, and prone and side bridge (plank) on knees positions. Rectus femoris activity was significantly greater in the prone on ball with left hip extension, bent-knee sit-up, or prone bridge (plank) on toes compared with the remaining exercises.

Conclusion: Prone position exercises are good alternatives to supine position exercises for recruiting core musculature. Side position exercises are better for oblique and lumbar paraspinal recruitment.

Clinical Relevance: Because high core muscle activity is associated with high spinal compressive loading, muscle activation patterns should be considered when prescribing trunk exercises to those in which high spinal compressive loading may be deleterious.

Keywords: EMG; low back pain; lumbar spine; sit-up; rectus abdominis

The core musculature includes both deep and superficial muscles of the lumbopelvic-hip complex: internal oblique, transversus abdominis, transversospinalis, quadratus lumborum, psoas major and minor, rectus abdominis, external oblique, erector spinae, latissimus dorsi, gluteus maximus and medius, hamstrings, and rectus femoris. Although several studies have examined core muscle recruitment during the crunch and bent-knee sit-up exercises, it is not
completely understood how core muscle recruitment compares between the supine, prone, and side positions with and without a Swiss ball. Core muscle strengthening can decrease lower extremity injury risk and enhance performance. Moreover, core muscle strengthening may also help decrease the risk of injuries to the lumbar spine by enhancing spinal stability.

Core exercises performed in prone and side positions, with and without a Swiss ball, are increasingly popular in rehabilitation clinics and fitness facilities. Several studies examined core muscle recruitment while performing prone and side bridge exercises with and without a Swiss ball. During the side bridge exercise, greater internal oblique activity occurs using a Swiss ball compared with a stable-surface bench. Greater rectus abdominis, external oblique, and internal oblique activity occurs in the side bridge exercise compared with the crunch exercise. No significant difference in rectus abdominis activity occurs during prone and side bridge exercises, but significantly greater external oblique and lumbar paraspinal activity is seen in the side bridge exercise compared with the prone bridge exercise. The crunch and side bridge exercises are effective in activating the internal oblique and transversus abdominis, while the side bridge is effective in recruiting the quadratus lumborum. To date, prone and side bridge exercises have only been performed with body weight supported on the arms and feet, which are the most difficult positions, but not with weight supported on the knees, which is an easier position. While select core and lower extremity muscle activity during prone and side position exercises is known, studies have not examined their effects on recruiting latissimus dorsi muscle activity. The latissimus dorsi is an upper extremity muscle, but its origin into the thoracolumbar fascia helps provide core stability.

The purpose of this study was to compare core muscle activity among supine, prone, and side position exercises with and without a Swiss ball. Our hypotheses are: (1) overall core muscle activity will be greater in the prone compared with supine position, (2) rectus femoris activity will be similar between the supine bent-knee sit-up and prone exercises on ball or toes, and (3) side position exercises will produce greater internal and external oblique and lumbar paraspinal activity and less rectus abdominis activity compared with prone and supine position exercises.

**METHODS**

**Subjects**

Written informed consent was in accordance with and approved by the Institutional Review Board at California State University, Sacramento. Nine men and 9 women served as subjects. Mean (SD) age, mass, and height were: 27.7 (7.7) years, 61.1 (7.8) kg, and 165.0 (7.0) cm, respectively, for women and 29.9 (6.6) years, 73.3 (7.2) kg, and 178.1 (4.3) cm, respectively, for men.

**Pretest**

All subjects became familiar with all exercises during a pretest session that took place approximately 1 week prior to the
Electromyographic Measurements

Electromyographic (EMG) marker placement procedures have been previously described and were as follows: upper rectus abdominis, lower rectus abdominis, external oblique, internal oblique, latissimus dorsi, rectus femoris, and lumbar paraspinals. A reference electrode was positioned over the skin of the right acromion process.

Data Collection

EMG data were sampled at 1000 Hz using a Noraxon MyoSystem unit (Noraxon USA, Inc). The Noraxon amplifier bandwidth filtered the EMG signal from 10 to 500 Hz and is reported to have an input impedance of 20 Mohm and a common-mode rejection ratio of 130 dB.

Prior to performing the exercises, EMG data from each muscle tested were collected during two 5-second maximum voluntary isometric contractions (MVIC) to normalize the exercise EMG data, and these MVIC tests have been previously described. To classify low to high muscle activities, 0% to 20% MVIC was
EMG data were collected during 5 repetitions for each exercise and in a randomized order using the 3-second cadence described previously. Approximately 2 minutes of rest was given between each exercise trial.

Each subject rated each exercise using a 15-point perceived exertion rating scale where 6 was no perceived exertion; 7 was very, very light; 9 was very light; 11 was fairly light; 13 was somewhat hard; 15 was hard; 17 was very hard; 19 was very, very hard; and 20 was maximum perceived exertion.²

**Data Processing**

Raw EMG signals were full-wave rectified and smoothened with a 10-ms moving average window (linear envelope) for all exercise and MVIC trials. EMG signals were then averaged over the entire 3-second exercise duration of each repetition, and EMG data were normalized for each muscle and expressed as a percentage of a subject’s highest corresponding MVIC trial.⁹,¹¹ Normalized EMG data were averaged over the 5 repetition trials performed for each exercise⁹,¹¹ and then used in statistical analyses.
Data Analysis

One-factor repeated-measures analysis of variance (ANOVA) was employed to assess differences in normalized EMG muscle activity among exercises, while t tests with a Bonferroni correction were employed to assess pairwise comparisons. To minimize the probability of type I errors, a Bonferroni adjustment was performed ($0.05/9$). The adjusted level of significance employed was $P = 0.006$.

RESULTS

Significant differences ($P < 0.001$) in muscle activity were seen between exercises in supine, prone, and side positions with and without a Swiss ball (Table 1). Computed with supine position exercises (crunch and bent-knee sit-up), prone position exercises (with hip extension, prone bridge on ball, prone bridge on toes) demonstrated similar upper and lower rectus abdominis, internal oblique, and lumbar paraspinal activity; approximately 10% to 100% more external oblique activity; approximately 110% to 160% more latissimus dorsi activity; and several times more rectus femoris activity compared with the crunch. The prone on ball with left hip extension exercise generated approximately 50% more rectus femoris activity compared with the bent-knee sit-up, while the bent-knee sit-up generated over twice as much rectus femoris activity compared with the prone bridge (plank) on ball exercise. Compared with supine and prone position exercises, side position exercises (side crunch on ball and side bridge on toes and knees) generally demonstrated significantly less upper and lower rectus abdominis, internal oblique, and latissimus dorsi (prone exercises only) activity as well as rectus femoris activity (except crunch and prone bridge [plank] on ball) but significantly greater lumbar paraspinal activity. Performing prone and side position exercises were perceived easiest on the knees and more difficult on the toes or feet (Table 2). The prone on ball with hip extension exercises were rated as the most difficult to perform.

DISCUSSION

Muscle Activity Between Prone and Supine Position Exercises

The hypothesis that overall core muscle activity would be greater in prone than supine position exercises was supported by the results. The greater effectiveness in core muscle recruitment of the prone on ball with hip extension exercises compared with the crunch and bent-knee sit-up implies that these exercises are good alternatives to the crunch and bent-knee sit-up, although they are also more difficult to perform (Table 2). Greater demand exercises, such as the hip extension and prone bridge on toes exercises, may be appropriate for higher level individuals or performed in the latter stages of a progressive abdominal strengthening program.

Strong core muscles help stabilize the core by compressing and stiffening the spine, and have been shown to decrease injury risk and enhance performance. The prone bridge (plank) on toes was 2 to 3 times more effective in latissimus dorsi and rectus femoris recruitment compared with the crunch. However, because the rectus femoris attempts to anteriorly tilt the pelvis and accentuate lumbar lordosis, exercises that generate moderate or high rectus femoris activity may not be desirable, especially in individuals with weak abdominal musculature or lumbar pathology. Several studies reported findings similar to the current study.

During prone on ball with hip extension exercises, the pelvis and spine are stabilized and maintained in a neutral position due to isometric abdominal/oblique muscle actions. In contrast, the bent-knee sit-up and crunch actively flex the trunk by concentric muscle actions during the upward motion. The lumbar spinal flexion may be contraindicated in certain populations with lumbar disc pathologies or osteoporosis or posterolateral disc herniations. Lumbar spinal flexion is only 3° during the crunch but approximately 30° during the bent-knee sit-up. In addition, the bent-knee sit-up generates greater intradiscal pressure and lumbar compression compared with exercises similar to the crunch, largely due to increased lumbar flexion and hip flexor activity. The crunch may be safer than the bent-knee sit-up for individuals who need to minimize lumbar spinal flexion or compressive forces because of lumbar pathology. In contrast, individuals with facet joint pain, spondylolisthesis, and vertebral or intervertebral foraminal stenosis may not benefit from prone position exercises, which maintain the spine and pelvis in a more extended position, as it may contribute to nerve root compression or facet joint pain. However, trunk flexion exercises like the crunch and bent-knee sit-up may be beneficial for some patients with facet pathology or stenosis, as trunk flexion may help relieve facet joint pain and minimize the risk of nerve root or spinal cord compression due to spinal stenosis.

Muscle Activity Between Prone and Side Position Exercises

Our hypothesis that rectus abdominus activity would be greater in prone than side position exercises and oblique and lumbar paraspinal activity would be greater in side than prone position exercises was largely supported by the results of the current study as well as other studies. However, 1 study reported greater upper rectus abdominis (46% vs 26% MVIC) and internal oblique (57% vs 28% MVIC) activity but less external oblique (51% vs 62% MVIC) activity than the current study. EMG magnitudes may vary among EMG studies due to different EMG normalization methods, which is a limitation when comparing EMG studies. Moreover, EMG magnitudes may vary depending on whether the exercises were performed dynamically or isometrically. Compared with the prone bridge on toes, the side bridge on toes generates significantly greater external oblique (69% vs 47% MVIC) and lumbar paraspinal (42% vs 5% MVIC) activity, but no significant difference in upper rectus abdominis activity, which is similar to the current results.
Table 1. Mean (SD) muscle activity (electromyography) for each muscle and exercise expressed as a percentage of each muscle’s maximum isometric voluntary contraction

| Exercise                                      | Upper Rectus Abdominis* | Lower Rectus Abdominis* | External Oblique* | Internal Oblique* | Lumbar Paraspinal* | Latissimus Dorsi* | Rectus Femoris* |
|------------------------------------------------|-------------------------|-------------------------|-------------------|------------------|-------------------|------------------|----------------|
| Prone on ball with right hip extension        | 43 (21)                 | 44 (11)                 | 56 (32)           | 40 (26)          | 7 (3)^h,i         | 17 (13)          | 9 (5)^h,d,f     |
| Prone on ball with left hip extension         | 41 (24)                 | 39 (19)                 | 39 (19)           | 45 (25)          | 6 (3)^h,i         | 21 (14)          | 35 (18)         |
| Prone bridge (plank) on ball                  | 49 (26)                 | 48 (9)                  | 42 (23)           | 39 (19)          | 6 (2)^h,i         | 17 (10)          | 10 (7)^h,d,f    |
| Prone bridge (plank) on toes                  | 34 (15)                 | 40 (10)                 | 40 (21)           | 29 (12)          | 5 (2)^h,i         | 18 (12)          | 20 (7)^d        |
| Prone bridge (plank) on knees                 | 27 (9)^a,d,e            | 26 (9)^a,b,c,d,e,f      | 22 (14)^c,h,i     | 20 (8)^c,d,e     | 5 (2)^h,i         | 10 (6)^c,d,e     | 7 (5)^h,d,f     |
| Side crunch on ball                           | 21 (11)^a,b,c,d,e       | 16 (7)^a,b,c,d,e,f      | 50 (26)           | 20 (1)^c,d,e     | 22 (7)^i          | 12 (5)^d        | 8 (4)^h,d,f     |
| Side bridge (plank) on toes                   | 26 (15)^a,e             | 21 (9)^a,b,c,d,e,f      | 62 (37)           | 28 (12)^d,e      | 29 (16)           | 12 (10)^d       | 14 (4)^h,d      |
| Side bridge (plank) on knees                  | 17 (10)^a,b,c,d,e,f     | 14 (8)^a,b,c,d,e,f      | 37 (27)^i         | 17 (7)^a,b,c,d,e | 18 (6)^i          | 10 (5)^d,e      | 10 (4)^h,d,e    |
| Crunch                                        | 53 (19)                 | 39 (16)                 | 28 (17)^c,i       | 33 (13)          | 5 (2)^h,i         | 8 (3)^c,d,e,f    | 6 (4)^h,d,f     |
| Bent-knee sit-up                              | 40 (13)                 | 35 (14)^e               | 36 (14)^i         | 31 (11)          | 6 (2)^h,i         | 8 (3)^c,d,e,f    | 23 (12)^d       |

*Significant difference ($P < 0.001$) in muscle activity among abdominal exercises based on a 1-way repeated-measures analysis of variance.

Significantly less muscle activity compared with the crunch.

Significantly less muscle activity compared with the bent-knee sit-up.

Significantly less muscle activity compared with the prone on ball with right hip extension.

Significantly less muscle activity compared with the prone on ball with left hip extension.

Significantly less muscle activity compared with the prone bridge (plank) on ball.

Significantly less muscle activity compared with the prone bridge (plank) on toes.

Significantly less muscle activity compared with the prone bridge (plank) on knees.

Significantly less muscle activity compared with the side crunch on ball.

Significantly less muscle activity compared with the side bridge (plank) on ball.

Significantly less muscle activity compared with the side bridge (plank) on toes.

Significantly less muscle activity compared with the side bridge (plank) on knees.
The low to moderate lumbar paraspinal activity in most exercises is similar to other studies. Moderate to high activity from the lumbar paraspinals may be deleterious for those with weak abdominal muscles or lumbar instability because the forces generated from lumbar muscles tend to anteriorly rotate the pelvis and may increase lumbar spine lordosis. The greatest lumbar activity was in the side bridge on toes position, and lumbar and oblique activity are greatest on the side that the side bridge on toes exercise occurs on. High spinal L4 to L5 compressive loading (2726 N) has been reported during the side bridge on toes position, thus should be used cautiously with individuals with lumbar pathology.

Muscle Activity Within Prone Position and Within Side Position Exercises

As hypothesized, core muscle activity was different within prone position exercises and within side position exercises, with approximately 25% to 185% greater abdominal, oblique, latissimus dorsi, lumbar paraspinal, and rectus femoris activity when performed on toes compared with when performed on knees. The prone and side bridge on knees exercises were perceived to be the easiest to perform and produced the lowest amount of core muscle recruitment and produced less lumbar spine compressive loading compared with the side bridge on toes. Core exercises that produce relatively low core muscle activity are often least effective in core stability but more effective in minimizing spinal compressive loading. Therefore, performing prone and side plank exercises on knees may be appropriate to start with in the early stages of an abdominal strengthening program or for those who need to minimize spinal compressive loading due to lumbar pathology, while the more challenging prone or side plank on toes exercise can be employed in the latter stages of rehabilitation.

CONCLUSION

When Swiss ball and floor exercises were performed with similar movement patterns, muscle activity was similar in all or most of the core muscles examined. Core muscle activity and perceived exertion was less for prone and side position exercises performed on knees compared with on toes/feet; thus, performing prone and side position exercises on knees early in spine rehabilitation or training programs (especially in individuals with poor core strength) may be prudent, while gradually progressing these exercises on to the toes/feet and then on a Swiss ball, such as prone on ball with hip extension, which generated the highest core muscle activity and was the most difficult to perform. The prone on ball hip extension exercises produced the greatest core muscle activity, and prone exercises were as or more effective than supine position exercises (crunch and bent knee sit-up) for core muscle activity.

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Table 2. The mean (SD) ratings of perceived exertion among exercises

| Exercise                                | Ratings of Perceived Exertion |
|-----------------------------------------|------------------------------|
| Prone on ball with right hip extension  | 13.1 (1.4)—somewhat hard     |
| Prone on ball with left hip extension   | 13.1 (1.4)—somewhat hard     |
| Prone bridge (plank) on ball            | 11.8 (1.6)—fairly light      |
| Prone bridge (plank) on toes            | 11.9 (1.7)—fairly light      |
| Prone bridge (plank) on knees           | 8.9 (2.1)—very, very light   |
| Side crunch on ball                     | 11.2 (2.2)—fairly light      |
| Side bridge (plank) on toes             | 11.2 (2.2)—fairly light      |
| Side bridge (plank) on knees            | 9.9 (2.0)—very light         |
| Crunch                                  | 10.2 (2.2)—very light        |
| Bent-knee sit-up                        | 10.4 (2.5)—very light        |

*aBased on the following scale: 6, no perceived exertion; 7, very, very light; 9, very light; 11, fairly light; 13, somewhat hard; 15, hard; 17, very hard; 19, very, very hard; and 20, maximum perceived exertion.*
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