

## [ Sports Physical Therapy ]

# Surface Electromyographic Analysis of Core Trunk and Hip Muscles During Selected Rehabilitation Exercises in the Side-Bridge to Neutral Spine Position

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**Background:** Strengthening of core hip, trunk, and abdominal muscles has been utilized with injury prevention and low back pain and has the potential to improve athletic performance.

**Hypothesis:** During a side-bridge, trunk and thigh muscles on the ipsilateral weightbearing side would produce greater activation than their counterparts on the contralateral nonweightbearing side.

**Study Design:** Descriptive laboratory study.

**Methods:** Twelve females and 13 males participated. Electromyography (EMG) signals were gathered for 5 right-sided muscles (rectus abdominis [RA], external oblique [EO], longissimus thoracis [LT], lumbar multifidus [LM], and gluteus medius [GM]) during 3 repetitions of 4 side-bridging exercises (trunk-elevated side support [TESS], foot-elevated side support [FESS], clamshell, and rotational side-bridge [RSB]) performed bilaterally in random order using surface electrodes. EMG signals were normalized to peak activity in maximum voluntary isometric contraction (MVIC) trials and expressed as a percentage. Descriptive EMG data were calculated for EMG recruitment (% MVIC) and compared between right side up and right side down conditions and between exercises with 2-way repeated-measures analyses of variance at  $\alpha = 0.05$ .

**Results:** RSB created the most muscle activation in 3 of 4 recorded trunk muscles (RA, 43.9% MVIC; EO, 62.8 % MVIC; and LT, 41.3% MVIC). Activation of the GM exceeded 69% MVIC for TESS, FESS, and RSB. With the exception of the RA in RSB and LT in TESS, recruitment within muscles of the ipsilateral weightbearing trunk and thigh (% MVIC) was significantly greater than their counterparts on the nonweightbearing trunk and thigh for all muscles during the side-bridge exercise conditions.

**Conclusion:** Muscle recruitment was greater within muscles of the ipsilateral weightbearing trunk and thigh for all examined muscles except RA during RSB and LT during TESS. Activation at or above 50% MVIC is needed for strengthening. Activation of the GM and EO meets these requirements.

**Clinical Relevance:** Side-bridge exercises appear to provide strengthening benefits to core hip, trunk, and abdominal muscles on the ipsilateral weightbearing side.

**Keywords:** side plank; core musculature; therapeutic exercises; electromyography

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A major component of physical therapy practice centers on the selection of the most appropriate therapeutic exercises. Core hip, trunk, and abdominal muscles function like guy wires surrounding the spine, which stabilize the spine.<sup>21,22</sup> Muscle weakness of core hip, trunk, and abdominal muscles has been verified in patients with patellofemoral pain syndrome,<sup>16,28</sup> iliotibial band syndrome,<sup>13,27</sup> anterior cruciate ligament injuries,<sup>14,31</sup> and ankle joint instability.<sup>2,24</sup> Knowledge of the core hip, trunk, and abdominal muscles activated in specific exercises is paramount to achieving successful outcomes. Strengthening core hip, trunk, and abdominal muscles may also improve athletic performance.<sup>3,25,29</sup>

Horizontal isometric side support, or side-bridge to neutral, can activate muscles of the posterior abdominal wall (quadratus lumborum and psoas major), abdomen (rectus abdominis, external oblique, internal oblique, and transversus abdominis), and back (lumbar erector spinae). An additional merit to the neutral side-bridge is the challenge to torso muscles without high lumbar compressive loading associated with back extension or trunk curls.<sup>18,19</sup>

Last, if the side-bridge exercise is biomechanically analyzed, there are 3 main forces acting on the body: gravity acting on the center of mass (COM) and the 2 ground reaction forces acting in the opposite direction at the points where the body contacts the floor. Together, these forces tend to cause the body to “sag” or “bow.” It is the responsibility of the muscles on the ipsilateral weightbearing side to contract against the effects of gravity and body mass to maintain correct alignment. Understanding the activation of the core hip, trunk, and abdominal musculature in specific side-bridging exercises will be useful in clinical decision making regarding the prescription of therapeutic exercises.

Thus, the purpose of this study was to quantify muscle activation of the rectus abdominis (RA), external oblique (EO), lumbar multifidus (LM), longissimus thoracis (LT), and gluteus medius (GM) with surface electromyographic (EMG) analysis for 4 exercises, performed bilaterally, requiring the use of core abdominal, back, and hip musculature. Therefore, we hypothesized that the tested muscles would produce more activation when on the ipsilateral weightbearing side compared with the contralateral nonweightbearing side.

## METHODS

### Subjects

All procedures were approved by an institutional review board. Subjects composed a sample of convenience and were recruited from the School of Health Sciences, Mayo Clinic College of Medicine, Rochester, Minnesota. To be included in the study subjects ranged in age from 20 to 39 years and reported no history of previous of spinal subluxation, dislocation, or fracture; shoulder tendinopathy, bursitis, impingement, or adhesive capsulitis; neurovascular complications; or any condition that limited physical activity for greater than 2 days over the past 6 months. Persons with acute low back pain (ALBP) were excluded from participating. Those with current

complaints of neuromuscular pain, numbness, or tingling in the lower extremity and back were excluded. Prior to data collection, potential participants performed a series of 3 standing deep knee squats and demonstrated pain-free normal active range of motion of the lumbar spine, hip, knee, ankle, and foot. Subjects viewed a video that demonstrated the correct performance of each of the 4 side-bridging exercises. Thirty healthy subjects volunteered to participate; 5 subjects were excluded from participating because they were unable to correctly perform 1 or more of the side-bridge exercises with good form (Table 1).

### Instrumentation

Raw EMG signals were collected with Bagnoli™ DE 3.1 double-differential EMG sensors (Delsys Inc).

### Testing Procedure

#### Electrode Placement

Using previously described techniques,<sup>1,6,10,13</sup> surface electrodes were positioned over the muscle belly of the following right-sided muscles:

- RA: 3 cm lateral and 3 cm superior to the umbilicus to avoid the thickest layer of adipose tissue<sup>6,10</sup>
- EO: Midway between the anterior superior iliac spine and rib cage parallel to the muscle fibers<sup>6,10</sup>
- LT: 2 cm lateral to the T9 spinous process parallel to the muscle mass<sup>1</sup>
- LM: 2 cm lateral to the lumbosacral junction<sup>7</sup>
- GM: Anterosuperior to the gluteus maximus and just inferior to the iliac crest parallel to the muscle fibers<sup>6</sup>

The electrodes were configured in parallel with the muscle fibers. A common ground electrode was placed on the skin overlying the medial malleolus of the right ankle.

To avoid cross-talk, the electrodes were placed 2 cm lateral to the T9 spinous process parallel to the muscle mass for the LT and 2 cm lateral to the lumbosacral junction for the LM.<sup>7,8</sup> The interelectrode distance between these surface electrodes diminished the opportunity for cross-talk.<sup>10</sup>

#### Manual Muscle Testing

EMG activity collected during the side-bridge exercises was normalized to maximum voluntary isometric contraction (MVIC).<sup>17,26,30</sup> Using the break test, muscle test procedures were modeled<sup>15</sup> and modified so ankles were held when applicable (RA, EO, LT, and LM testing) for support. In addition, external resistance was applied by the investigator to ensure the effort given by subjects was maximal (Figure 1, Appendix 1, available online at [sph.sagepub.com/supplemental](http://sph.sagepub.com/supplemental)).

Each subject performed 3 repetitions of 4 bilateral exercises (Figure 2, Appendix 1) in random order. A metronome set at 40 beats per minute was used to standardize the rate of movement of the hips across subjects. Successful performance of each

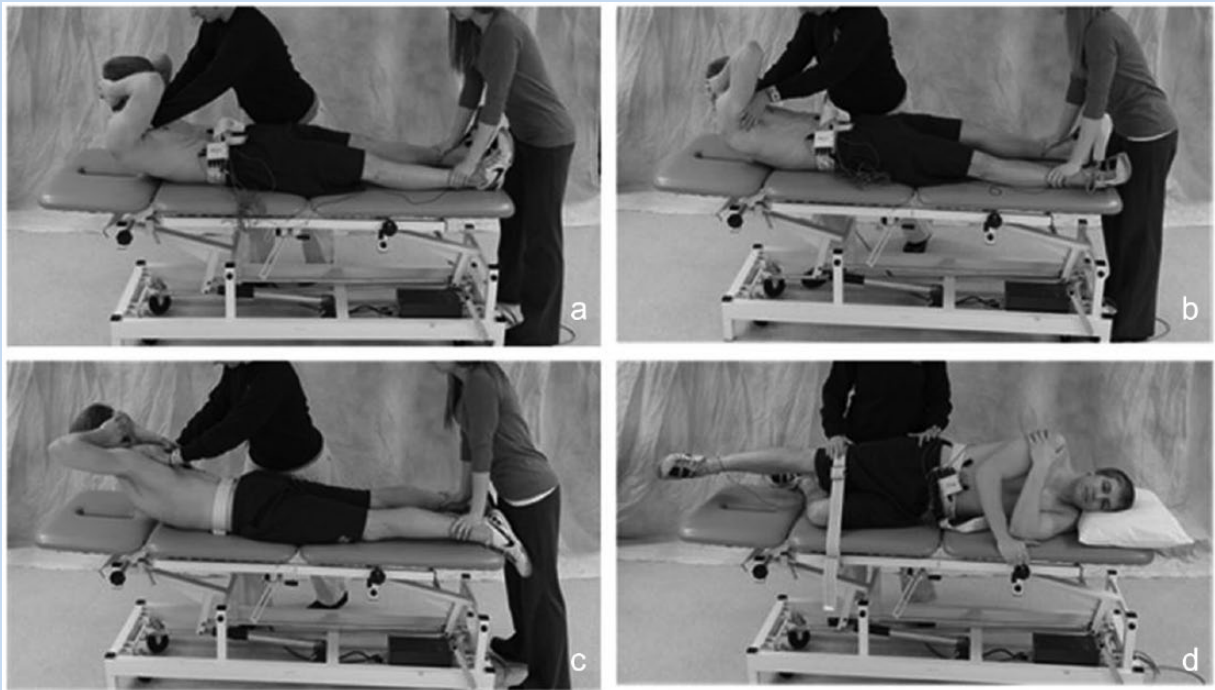


Figure 1. Procedures used to evoke maximum voluntary isometric contractions for (a) rectus abdominis, (b) external oblique, (c) longissimus thoracis and lumbar multifidus, and (d) gluteus medius.



Figure 2. Midpoints of exercises performed. (a) Torso-elevated side support (TESS), (b) feet-elevated side support (FESS), (c) clamshell, and (d) rotational side-bridge (RSB).

Table 1. Subject demographic information

Gender	Age (y)		Height (m)		Mass (kg)		Body Mass Index (kg/m <sup>2</sup> )		Days/Week of Physical Activity	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Male (n = 13)	24.0	2.5	1.8	0.1	81.1	6.9	24.6	1.7	5.2	1.3
Female (n = 12)	23.3	1.2	1.7	0.1	60.2	5.2	21.4	1.5	5.1	1.2

side-bridge exercise was judged by 1 examiner, demonstrating a movement in sequence with the metronome while elevating the trunk in neutral spinal alignment. Failure resulted in exclusion from the study. Subjects were allowed a 2-minute rest between each exercise to avoid fatigue. EMG recruitment data were analyzed for 5 muscles during the 4 exercises performed bilaterally. The dependent variable was normalized peak EMG activity (%MVIC) for each of the muscles. To permit meaningful comparisons among study subjects, raw EMG data were normalized to the MVIC data of the muscle being analyzed. This yielded muscle activation as %MVIC. Peak activation for each muscle was calculated from the normalized data using a 200-ms window about the peak.

To assist with classification of low to high muscle activity of the core hip, trunk, and abdominal muscles during side-bridging exercises, we used a classification scheme.<sup>9,11</sup> Activation from 0% to 20% MVIC was low level, 21% to 40% MVIC moderate level, 41% to 60% MVIC high level, and greater than 60% MVIC very high level.

### Statistical Analysis

A sample size of 22 subjects was required to detect a mean difference in EMG recruitment of 10% MVIC (effect size, 0.20) between conditions with a statistical power (1 -  $\beta$ ) equal to 0.80 at  $\alpha = 0.05$ .<sup>12</sup> Descriptive data (means and standard deviations) were calculated from 5 right-sided muscles (RA, EO, LT, LM, and GM) during 4 bilateral exercises (trunk-elevated side support [TESS], foot-elevated side support [FESS], clamshell, and rotational side-bridge [RSB]). Several of the distributions were skewed (Kolmogorov-Smirnov tests of normality at  $P < 0.05$ ). For this reason, data were transformed with the base-10 logarithmic transformation prior to further analysis. Subsequently, the transformed EMG data were compared between right side up (contralateral nonweightbearing side) and right side down (ipsilateral weightbearing side) conditions and between exercises with 2-way repeated-measures analyses of variance at  $\alpha = 0.05$ . Post hoc tests for statistically significant main effects were assessed using Bonferroni corrections for  $\alpha$ . Statistically significant side  $\times$  exercise interactions were interpreted with simple effects tests, also with Bonferroni corrections for  $\alpha$ . All analyses were conducted using SPSS 21.0 statistical software (IBM Corp).

## RESULTS

For FESS and clamshell, muscle activation of core hip, trunk, and abdominal muscles on the ipsilateral weightbearing side was greater compared with the contralateral nonweightbearing side for each of the 5 muscles (Table 2). The same was true in TESS and RSB except for LT and RA, respectively, which showed greater activation on the contralateral nonweightbearing side. Data for the RA, EO, LT, LM, and GM are summarized in Appendix 2 (available at <http://sph.sagepub.com/content/suppl>).

## DISCUSSION

Spinal deformation is resisted by a variety of trunk and abdominal muscles that function like guy wires or cables to provide stiffness or resistance to bending of the vertebral column.<sup>21,22</sup> The motor control system ensures tensions in the torso muscles are balanced so the spine can be stabilized in a neutral position.<sup>19-23</sup> Stability of the vertebral column can be obtained in a neutral spine posture in most people with moderate activation levels of trunk and abdominal muscles.<sup>4,5,22</sup> Rehabilitation of low back disorders has emphasized muscle endurance as opposed to muscle strength.<sup>20,21,23</sup> No single trunk or abdominal muscle is the ideal stabilizer of the neutral spine in a neutral side-bridge position; instead, an aggregate of trunk and abdominal muscles work synchronously.<sup>22</sup> The side-bridge exercises used in the present study have merit because unlike trunk curls in supine and prone extension of the trunk and head, the lateral abdominals are challenged without generating large lumbar compression loads.<sup>19</sup> In the present study, during side-bridge to neutral (clamshell, TESS, and FESS), core hip, trunk, and abdominal muscles on the contralateral nonweightbearing side were much less active than their counterparts on the ipsilateral weightbearing side. Nevertheless, spinal stability was preserved by the internal torque from torso muscles required to support the neutral side-bridge position.<sup>23</sup>

Awareness of which side-bridge exercise is most challenging for each abdominal and back muscle based on %MVIC lets the clinical practitioner select exercises that put appropriate demands on the muscle yet remain within the level of difficulty the patient can tolerate. RSB was different from TESS, FESS, and clamshell because the rolling in and out of side plank

Table 2. Descriptive statistics for the mean peak values of muscle activation (%MVIC) from core hip, trunk, and abdominal muscles of the right leg up (contralateral nonweightbearing limb) and right leg down (ipsilateral weightbearing limb) conditions

Muscle	Right LE Orientation	Exercise			
		TESS	FESS	Clamshell	RSB
Rectus abdominis	Up	5.6 ± 5.0	3.9 ± 2.5	3.9 ± 3.1	43.9 ± 18.0
	Down	12.8 ± 6.5	14.8 ± 17.5	9.9 ± 6.5	36.8 ± 16.2
External oblique	Up	11.7 ± 8.2	23.3 ± 13.0	7.0 ± 8.3	60.2 ± 25.2
	Down	37.2 ± 22.7	29.2 ± 21.9	29.2 ± 15.0	62.8 ± 28.3
Longissimus thoracis	Up	20.2 ± 19.8	22.5 ± 21.4	15.5 ± 18.5	36.7 ± 18.1
	Down	19.1 ± 13.6	33.6 ± 21.6	22.1 ± 29.1	46.0 ± 28.1
Lumbar multifidus	Up	11.3 ± 9.2	12.5 ± 12.9	9.4 ± 9.8	14.4 ± 18.5
	Down	33.6 ± 16.8	33.5 ± 16.4	22.4 ± 13.3	30.5 ± 18.9
Gluteus medius	Up	48.1 ± 24.3	38.1 ± 23.3	20.1 ± 14.1	46.8 ± 22.9
	Down	73.6 ± 30.6	69.9 ± 24.2	49.6 ± 22.7	71.0 ± 30.1

FESS, foot-elevated side support; LE, lower extremity; RSB, rotational side-bridge; TESS, trunk-elevated side support.

demanded additional torso muscle activation to control isometric bending and twisting torque applied to the vertebral column.<sup>23</sup> Because RSB created most recruitment in 3 of 4 torso muscles (RA, 43.9% MVIC; EO, 62.8% MVIC; and LT, 46% MVIC), this is the most strenuous side-bridge exercise condition. The clamshell exercise condition demonstrated the least muscle activation for each of 4 torso muscles studied, which indicates that clamshell was the easiest of the 4 side-bridge exercises to perform.

### Limitations

Several limitations exist within this study. Results from this study cannot be generalized beyond the young, healthy, and active population. The same-day reliabilities of surface EMG recordings from the 5 muscles during the side-bridge to neutral position were not estimated. Nevertheless, using an intraclass correlation coefficient (ICC<sub>3,1</sub>), the same core hip, trunk, and abdominal muscles yielded the same day test-retest ICCs that ranged from 0.86 to 0.93.<sup>10</sup> During side-bridge exercises, we were unable to record EMG activity from 2 important core stabilizers, the quadratus lumborum (QL) and transversus abdominis (TA), because intramuscular fine wire electrodes were not inserted.

### CONCLUSION

When subjects performed side-bridging exercises, the RA, EO, LT, LM, and GM were recruited (%MVIC) more on the ipsilateral weightbearing side compared with their counterparts on the contralateral nonweightbearing side.

### REFERENCES

1. Arokoski JP, Valta T, Airaksinen O, Kankaanpää M. Back and abdominal muscle function during stabilization exercises. *Arch Phys Med Rehabil*. 2001;82:1089-1098.
2. Beckman SM, Buchanan TS. Ankle inversion injury and hypermobility: effect on hip and ankle muscle electromyography onset latency. *Arch Phys Med Rehabil*. 1995;76:1138-1143.
3. Butcher SJ, Craven BR, Chilibeck PD, Spink KS, Grona SL, Sprigings EJ. The effect of trunk stability training on vertical takeoff velocity. *J Orthop Sports Phys Ther*. 2007;37:223-231.
4. Cholewicki J, McGill SM. Mechanical stability on the in vivo lumbar spine: implications for injury and chronic low back pain. *Clin Biomech*. 1996;11:1-15.
5. Cholewicki J, Panjabi MM, Khachatryan A. Stabilizing function of the trunk flexor-extensor muscles around a neutral spine posture. *Spine (Phila Pa 1976)*. 1997;22:2207-2212.
6. Criswell E, Cram JR. *Cram's Introduction to Surface Electromyography*. Sudbury, MA: Jones & Bartlett; 2011.
7. Danneels LA, Cagnie BJ, Cools AM, et al. Intra-operator and inter-operator reliability of surface electromyography in the clinical evaluation of back muscles. *Man Ther*. 2001;6:145-153.
8. Danneels LA, Coorevits PL, Cools AM, et al. Differences in electromyographic activity in the multifidus muscle and the iliocostalis lumborum between healthy subjects and patients with sub-acute and chronic low back pain. *Eur Spine J*. 2002;11:13-19.
9. DiGiovine N, Jobe F, Pink M, Perry J. An electromyographic analysis of the upper extremity in pitching. *J Shoulder Elbow Surg*. 1992;1:15-25.
10. Ekstrom RA, Donatelli RA, Carp KC. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *J Orthop Sports Phys Ther*. 2007;37:754-762.
11. Escamilla RF, Lewis C, Bell D, et al. Core muscle activation during Swiss ball and traditional abdominal exercises. *J Orthop Sports Phys Ther*. 2010;40:265-276.
12. Faul F, Erdfelder E, Lang AG, Buchner A. G\*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39:175-191.
13. Fredericson M, Cookingham CL, Chaudhari AM, Dowdell BC, Oestreicher N, Sahrmann SA. Hip abductor weakness in distance runners with iliotibial band syndrome. *Clin J Sport Med*. 2000;10:169-175.
14. Hiemstra LA, Goffon WT, Kriellaars DJ. Hip strength following hamstring tendon anterior cruciate ligament reconstruction. *Clin J Sport Med*. 2005;15:180-182.

15. Hislop HJ, Montgomery J. *Daniels and Worthingham's Muscle Testing: Techniques of Manual Examination*. 8th ed. St. Louis, MO: Saunders; 2007.
16. Ireland ML, Willson JD, Ballantyne BT, Davis IM. Hip strength in females with and without patellofemoral pain. *J Orthop Sports Phys Ther*. 2003;33:671-676.
17. McGill SM. Electromyographic activity of the abdominal and low back musculature during the generation of isometric and dynamic axial trunk torque: implications for lumbar mechanics. *J Orthop Res*. 1991;9:91-103.
18. McGill S, Juker D, Kropf P. Quantitative intramuscular myoelectric activity of the quadratus lumborum during a wide variety of tasks. *Clin Biomech*. 1996;11:170-172.
19. McGill SM. Low back exercises; evidence for improving exercise regimens. *Phys Ther*. 1998;78:754-765.
20. McGill SM, Childs A, Liebenson C. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil*. 1999;80:941-944.
21. McGill SM. Low back stability; from formal description to issues for performance and rehabilitation. *Exerc Sport Sci Rev*. 2001;29:26-31.
22. McGill SM, Grenier S, Kavcic N, Cholewicki J. Coordination of muscle activity to assure stability of the lumbar spine. *J Electromyogr Kinesiol*. 2003;13:353-359.
23. McGill SM, Karpowicz A. Exercises for spine stabilization: motion/motor patterns, stability progressions, and clinical technique. *Arch Phys Med Rehabil*. 2009;90:118-126.
24. Nicholas JA, Strizak AM, Veras G. A study of thigh muscle weakness in different pathological states of the lower extremity. *Am J Sports Med*. 1976;4:241-248.
25. Shaffer B, Jobe FW, Pink M, Perry J. Baseball batting. An electromyographic study. *Clin Orthop Relat Res*. 1993;292:285-293.
26. Soderberg GL, Knutson LM. A guide for use and interpretation of kinesiological electromyographic data. *Phys Ther*. 2000;80:485-498.
27. Tyler TF, Nicholas SJ, Campbell RJ, Donellan S, McHugh MP. The association of hip strength and flexibility with the incidence of adductor muscle strains in professional ice hockey players. *Am J Sports Med*. 2001;29:124-128.
28. Tyler TF, Nicholas SJ, Mullaney MJ, McHugh MP. The role of hip muscle function in the treatment of patellofemoral pain syndrome. *Am J Sports Med*. 2006;34:630-636.
29. Watkins RG, Uppal GS, Perry J, Pink M, Dinsay JM. Dynamic electromyographic analysis of trunk musculature in professional golfers. *Am J Sports Med*. 1996;24:535-538.
30. White SG, McNair PJ. Abdominal and erector spinae muscle activity during gait: the use of cluster analysis to identify patterns of activity. *Clin Biomech*. 2002;17:177-184.
31. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk. *Am J Sports Med*. 2007;35:1123-1130.

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