Physical Therapy in Sport 22 (2016) 6–10

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original research

Effect of feedback techniques for lower back pain on gluteus maximus and oblique abdominal muscle activity and angle of pelvic rotation during the clam exercise

Eun-kyung Koh [a], Kyue-nam Park [b], Do-young Jung [c, *]

[a] Department of Physical Therapy, Masan University, Changwon, Republic of Korea
[b] Department of Physical Therapy, College of Medical Science, Jeonju University, Republic of Korea
[c] Department of Physical Therapy, College of Tourism & Health, Kinesiopathologic Science Institute, Joongbu University, Geumsan, Republic of Korea

ARTICLE INFO

Article history:
Received 14 July 2015
Received in revised form
4 February 2016
Accepted 25 April 2016

Keywords:
Clam exercise
Lower back pain
Pelvic rotation
Gluteus maximus

ABSTRACT

Objectives: This study was conducted in order to determine the effect of feedback tools on activities of the gluteus maximus (Gmax) and oblique abdominal muscles and the angle of pelvic rotation during clam exercise (CE).
Design: Comparative study using repeated measures.
Setting: University laboratory.
Participants: Sixteen subjects with lower back pain.
Main outcome measures: Each subject performed the CE without feedback, the CE using a pressure biofeedback unit (CE-PBU), and the CE with palpation and visual feedback (CE-PVF). Electromyographic (EMG) activity and the angles of pelvic rotation were measured using surface EMG and a three-dimensional motion-analysis system, respectively. One-way repeated-measures ANOVA followed by the Bonferroni post hoc test were used to compare the EMG activity in each muscle as well as the angle of pelvic rotation during the CE, CE-PBU, and CE-PVF.
Results: The results of post-hoc testing showed a significantly reduced angle of pelvic rotation and significantly more Gmax EMG activity during the CE-PVF compared with during the CE and CE-PBU.
Conclusion: These findings suggest that palpation and visual feedback is effective for activating the Gmax and controlling pelvic rotation during the CE in subjects with lower back pain.

1. Introduction

Lower back pain is a common musculoskeletal problem with high incidence, affecting about 80% of the population at some time in their lives (Lawrence et al., 1998). Uncontrolled motion and insufficient stability in the lumbopelvic region have been suggested by previous studies as causes of lower back pain (Hodges, 2011; McGill, 1997; O'Sullivan, 2005; Panjabi, 2003). Uncontrolled lumbopelvic motion has been defined as excessive or early lumbopelvic motion during limb movements (Hoffman, Johnson, Zou, & Van Dillen, 2012). Repeated and sustained uncontrolled lumbopelvic motion associated with limb movements during functional activities may induce physical stress in specific tissues in the lumbopelvic region, resulting in cumulative microtrauma and lower back pain (McGill, 1997; O'Sullivan, 2005; Sahrmann, 2002).

Some studies have examined the relationship between lower back pain and lumbopelvic movement patterns during limb movement of hip rotation in a prone position (Gombatto, Collins, Sahrmann, Engsberg, & Van Dillen, 2006; Scholtes & Van Dillen, 2007; Scholtes, Norton, Lang, & Van Dillen, 2010). Earlier and more lumbopelvic motion was shown by patients with lower back pain than by a healthy control group during hip internal or external rotation (Gombatto et al., 2006). Restriction and control of lumbopelvic motion during limb movements have been considered effective treatment methods for the management of lower back pain (McGill, 1997; O'Sullivan, 2005; Sahrmann, 2002).

Clinicians commonly instruct patients with lower back pain to control lumbopelvic motion during hip internal and external

* Corresponding author. Department of Physical Therapy, Joongbu University, 201 Daehak-ro, Chubu-myeon, Geumsan-gun, Chugnam 312-702, Republic of Korea. Tel.: +82 41 750 6764.
E-mail addresses: kohpt@masan.ac.kr (E.-k. Koh), knpark@jj.ac.kr (K.-n. Park), ptsports@joongbu.ac.kr (D.-y. Jung).

http://dx.doi.org/10.1016/j.ptsp.2016.04.004
1466-853X/

rotation in various positions. Several feedback tools (e.g., tactile feedback using hand, verbal instructions, and corrections; visual feedback; and pressure biofeedback) have been employed to manage uncontrolled lumbopelvic movement in the transverse plane during hip motion (Comerford & Mottram, 2012). Previous studies have found that restricting uncontrolled pelvic rotation using tactile and verbal feedback can be helpful in improving symptoms during prone hip internal or external rotation in patients with lower back pain (Van Dillen, Maluf, & Sahrmann, 2009; Van Dillen, Sahrmann, Norton, Caldwell, McDonnell, & Bloom, 2003). Although various feedback methods to monitor lumbopelvic motion have been suggested, no study has investigated which type of feedback is most effective for patients with lower back pain during limb movements.

Active hip external rotation exercises, such as the top leg turnout in a side-lying position, the bent-leg fall out in a supine position, and the single leg rotation in a prone position, have been recommended to encourage control of lumbopelvic motion using feedback in the clinic (Comerford & Mottram, 2012; Hoffman, et al., 2012; Kisner & Colby, 2012; Scholtes et al., 2010). In the side-lying, hip external rotators can be more activated in response the weight of the body segment than in the prone or supine position because side-lying is antigravity position. The top leg turnout maneuver in a side-lying position, termed the clam exercise (CE), is commonly recommended to strengthen the hip abductors and external rotators. Willcox and Burden (2013) demonstrated that CE was more effective in activating the gluteus maximus (Gmax) when performed by healthy subjects in a neutral than in a reclined pelvic position. Additionally, it is important that the neutral pelvic position of patients with lower back pain be maintained during the CE using various forms of feedback. Although a neutral pelvic position is effective for activating Gmax during the CE, no study has determined which feedback technique is most effective for maintaining a neutral pelvic position in patients with lower back pain.

Thus, the purpose of this study was to determine the effect of feedback tools on the activities of Gmax and oblique abdominal muscles, and angle of pelvic rotation during the CE. This study was based on the following hypotheses: performing the CE using palpation and visual feedback (CE-PVF) and using a pressure biofeedback unit (CE-PBU) will result in (1) less pelvic rotation, and (2) more Gmax muscle activity compared with performing the CE without feedback.

2. Methods

2.1. Participants

Sixteen subjects (9 males, 7 females) with chronic non-specific lower back pain participated in this study. Participants were recruited via poster, telephone and word of mouth from Masan University in South Korea. The subjects were aged 22.4 ± 2.5 (mean ± SD) years and had a height of 169.3 ± 7.4 cm and body weight of 64.2 ± 12.1 kg. The inclusion criteria used in this study required that subjects have chronic or recurrent low back pain of more than 3 months duration during daily activities and that they have some level of disability, with scores of at least 20% on the Oswestry Disability Index. Volunteers with neuromuscular problems, musculoskeletal pain other than lower back pain, metabolic diseases, or functional limitations in daily activity were excluded. Subjects were advised of the testing procedures, and all provided informed consent. The Institutional Review Board (IRB) at Joongbu University approved all procedures in this study.

2.2. Instruments

The Noraxon TeleMyo system was used for Surface EMG data collection. EMG data were analyzed using Noraxon MyoResearch 1.06 XP software. To measure the angle of pelvic rotation during CE, we used a 3D motion-analysis system with six cameras (BTS Smart-DX500, Milan, Italy). Kinematic data were analyzed using motion-capture software (BTS SMART-Analyzer, Milan, Italy). A Stabilizer pressure biofeedback unit (Chattanooga Group Inc, Hixson, TN, USA), consisting of an inflatable air bag connected to a pressure gauge, was used to monitor pelvic motion during CE-PBU.

2.3. Procedures

Prior to electrode placement, the skin was shaved to reduce impedance and cleaned with alcohol swabs. The distance between each pair of electrodes was 2 cm, and electrodes were attached parallel to the direction of the muscle fibers. EMG electrodes over the ipsilateral and contralateral external oblique muscles (IEO and CEO) were attached midway between the anterior superior iliac spine (ASIS) and the rib cage. Electrodes for the ipsilateral and contralateral internal oblique muscles (IIO and CIO) were attached at 2 cm inferomedial to the ASIS. The Gmax electrode was attached at half the distance from the second sacral vertebra to the greater trochanter (Cram & Kasman, 1998).

To measure the angle of pelvic rotation during CE, three retroreflexive markers were attached to the bilateral PSIS and the highest point of the iliac crest in side-lying (Fig. 1). Before collection of kinematic data, the acquisition volume was calibrated to be calculated with laboratory references to a global coordinate system using a calibration kit.

Subjects practiced each intervention (the CE without feedback, CE-PBU, and CE-PVF) for 15 min for familiarization. To perform the CE, the participants were positioned in a side-lying position with the hips flexed at 45°, the knees flexed at 90°, and the spine and pelvis in neutral positions. To maintain the end position of the CE, thee target bar was adjusted for each individual so the top of the knee would touch it when the angle was 25° from starting position in horizontal plane during CE exercise using gravity goniometer located on frontal side of femur shaft. Participants were asked to separate their knees and rotate the top leg upward while keeping the heels together until lateral epicondyle of the femur touch target bar (Fig. 2A).

For the CE-PBU, a Stabilizer pressure biofeedback unit was placed below the trunk between the iliac crest and the distal ribs with the participant in a side-lying position. The air bag was inflated to 40 mmHg pressure, and participants were instructed to maintain the pressure at 35–45 mmHg during the CE-PBU (McBeth, Boehm, Cobb, & Huddleston, 2012) (Fig. 2B). For the CE-PVF,

Fig. 1. Three reflective markers for measuring the angle of pelvic rotation.

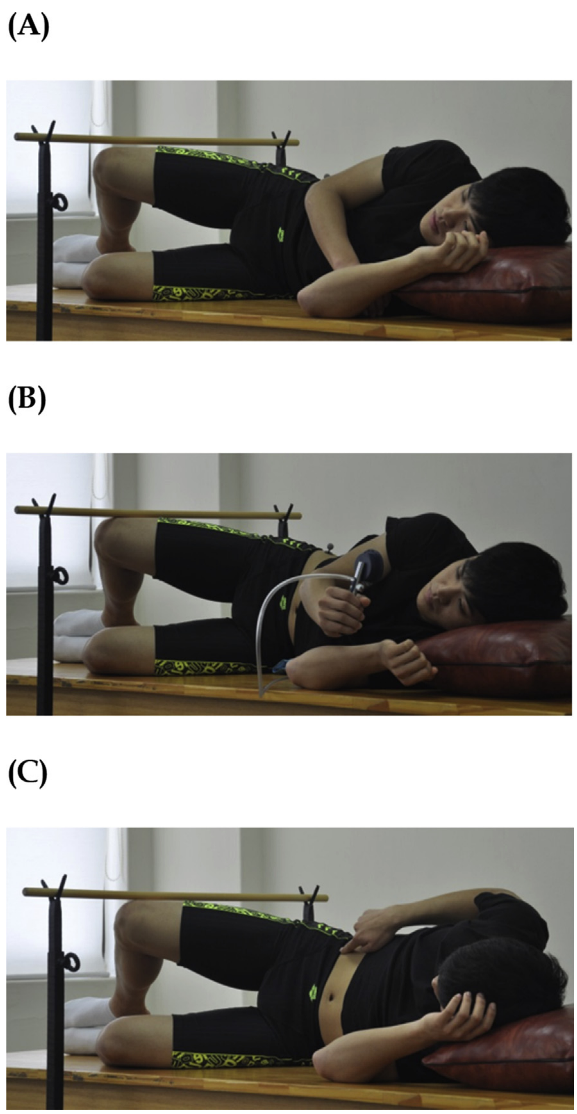

Fig. 2. CE without feedback (A), using PBU (B) and with PVF (C). CE: clam exercise; PBU: pressure biofeedback unit; PVF: palpation and visual feedback.

subjects were instructed to palpate the ASIS using the index finger for tactile feedback and to monitor pelvic movements by visual feedback to control pelvic movement in the horizontal plane (Fig. 2C).

The order of exercises was counterbalanced to reduce fatigue and learning effects across exercises. Muscle activity and kinematic data were recorded while participants maintained the target position for 5 s in each exercise; each exercise was performed three times with 30-s resting intervals. To avoid muscle fatigue, the participants were given a 3-min rest periods between exercise conditions.

Maximum voluntary isometric contraction (MVIC) was measured to normalize EMG data during manual muscle testing as follows (Hislop & Montgomery, 2007): the MVIC of the Gmax was measured with participants in the prone position and the knee flexed to 90°, with resistance applied to the lower part of the posterior thigh during isometric hip extension. The MVIC of the EO and IO were measured in a supine with manual resistance at the shoulders while the participant was bending his trunk toward the contralateral and ipsilateral knee of tested leg, respectively. Participants received standardized verbal encouragement during MVIC testing. The MVIC data were collected three times for 5 s in each position.

2.4. Data processing and statistical analysis

The sampling rate of the EMG signal was set to 1000 Hz, and the bandwidth and notch filter were set to 20–450 Hz and 60 Hz, respectively. The raw EMG signals were processed using a root mean square (RMS) method with a 0.5-s window. The first and last seconds of each exercise were eliminated, and MVIC and EMG data were taken from the middle 3 s of each exercise. EMG amplitude is expressed as a percentage of the average MVIC for each muscle (% MVIC). The %MVIC values for the three repetitions of each exercise were averaged within each participant for statistical analyses.

The kinematic data were collected at a sampling rate of 100 Hz. The pelvic segment was defined by three markers placed on the bilateral PSIS and iliac crest (Tateuchi et al., 2013). The angle of pelvic rotation was calculated as the change in angle of the transverse plane pelvic segment from start to final position during CE, relative to orientation of the global coordinate system. The mean angle of pelvic rotation was calculated in the middle 3 s of each exercise except of first and last seconds. We used the mean values of the angle of pelvic rotation across measurements of three repetitions for data analysis.

Kolmogorov–Smirnov test was used to confirm the normal distribution of the values for the EMG and kinematic data. As the data presented normal distribution (%MVIC of Gmax and IEO and the angle of pelvic rotation), a one-way repeated-measures analysis of variance (ANOVA) was used. When the data showed no normal distribution (%MVIC of IIO, CEO and CIO), Friedman ANOVA was performed for each of the three exercises (CE, CE-PBU, CE-PVF). All significance testing was set at $p < 0.05$. If a main effect was found, post hoc pair-wise comparisons with a Bonferroni correction ($p < 0.016$) were used for multiple comparisons. SPSS software (SPSS, Chicago, IL, USA) was used for the statistical analysis.

3. Results

Results showed significant differences among the three conditions in the angle of pelvic rotation ($p < 0.05$) (Table 1). The result of post hoc testing showed significantly less pelvic rotation under the CE-PVF than under the CE and CE-PBU conditions ($p < 0.016$) (Fig. 3). Furthermore, the results also showed significant differences in the EMG activity of the Gmax and IEO muscles among three conditions ($p < 0.05$) (Table 1). The post hoc results revealed significantly greater EMG activity of Gmax with the CE-PVF than with the CE and CE-PBU ($p < 0.016$). The EMG activity level of the IEO was significantly higher with the CE-PVF than with the CE ($p < 0.016$) (Fig. 4).

4. Discussion

The aim of this study was to evaluate the effect of feedback tools on the EMG activity of Gmax and abdominal muscles and the angle of pelvic rotation during CE in subjects with lower back pain. In our study, performing the CE-PVF was more effective to control the pelvic movement than CE and CE-PBU. In previous research, PBUs have been used to control pelvic movement during lower limb movement in various positions. A previous study demonstrated that the PBU was an effective feedback tool for reducing the amount of pelvic tilt in the frontal plane during hip abduction in a side-lying position (Cynn, Oh, Kwon, & Yi, 2006). In the present study, the CE-PBU was performed in a side-lying position, and it was not effective in reducing pelvic rotation compared with the CE alone. The possible cause of these conflicting results may be that the PBU

Table 1
Mean angle of pelvic rotation (degree) and EMG activation (%MVIC) of Gmax and oblique abdominal muscles during CE, CE-PBU, and CE-PVF.

Variables		CE	CE-PBU	CE-PVF	F	P
Muscle	Gmax	18.57 ± 9.84	17.29 ± 10.21	29.69 ± 12.13	11.61	0.001[a]
	IEO	12.59 ± 6.18	14.43 ± 9.16	19.37 ± 9.88	7.31	0.003[a]
	IIO	17.90 ± 12.46	17.66 ± 14.73	22.91 ± 14.33	–	0.105
	CEO	11.13 ± 8.33	12.62 ± 16.33	15.88 ± 12.06	–	0.195
	CIO	13.37 ± 8.09	14.03 ± 9.29	14.17 ± 8.82	–	0.345
Angle of pelvic rotation		10.54 ± 5.04	8.46 ± 2.56	6.98 ± 3.21	9.23	0.005[a]

Values are means ± SD.
[a] Significant differences in the angle of pelvic rotation and EMG activation in the three conditions. CE: clam exercise; PBU: pressure biofeedback unit; PVF: palpation and visual feedback; Gmax: gluteus maximus; IEO: ipsilateral external oblique; IIO: ipsilateral internal oblique; CEO: contralateral external oblique; CIO: contralateral internal oblique.

monitors pelvic motion more effectively in the frontal than in the transverse plane during hip abduction in a side-lying position. In our study, the CE induced pelvic rotation in the transverse plane, and the placement of the air bag placed below the lateral lumbopelvic region was not effective in reducing this type of pelvic rotation. We suggest that placing the air bag in a posterior lumbopelvic region against the wall in the side-lying position may be more effective than our placement for reducing the amount of pelvic rotation during the CE-PBU.

Some researchers have performed quantitative studies on lumbopelvic movement during lower limb movement using various feedback tools (Park, Ha, Kim, Kwon, & Oh, 2013; Scholtes et al., 2010). In a study by Scholtes et al. (2010), the therapist's verbal and tactile feedback reduced the angle of lumbopelvic rotation by 4.2° in the lower-back-pain group during hip lateral rotation in a prone position. Park et al. (2013) reported that pelvic rotation was significantly reduced, by 3.0°, during active straight leg raising (ASLR) compared with conventional ASLR using the subject's own tactile feedback. Because participants in the present study could directly observe the uncontrolled pelvic rotation in the side-lying position, we used each patient's own palpation and visual feedback as one form of feedback. We found that pelvic rotation was significantly reduced in the CE-PVF compared with the CE (mean difference = 3.6°) and CE-PBU (mean difference = 1.5°). Thus, clinicians must consider which biofeedback technique is most effective for controlling pelvic movement according to the type of exercise and the plane of pelvic movement.

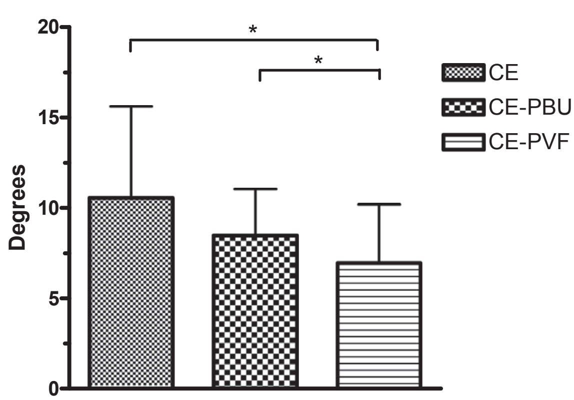

Fig. 3. Angles of pelvic rotation during CE. CE: clam exercise; PBU: pressure biofeedback unit; PVF: palpation and visual feedback. *Significant difference at p = 0.016.

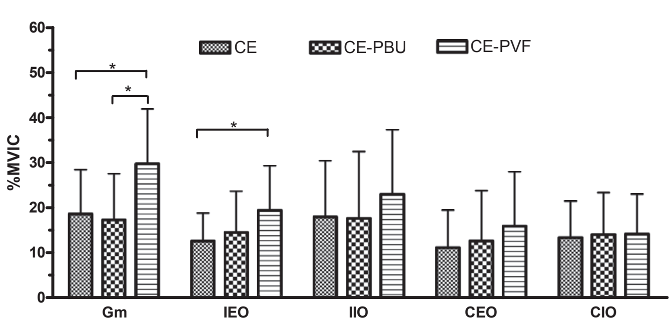

Fig. 4. Percentage MVIC of Gmax and oblique abdominal muscles during CE. CE: clam exercise; PBU: pressure biofeedback unit; PVF: palpation and visual feedback; Gmax: gluteus maximus; IEO: ipsilateral external oblique; IIO: ipsilateral internal oblique; CEO: contralateral external oblique; CIO: contralateral internal oblique. *Significant difference at p = 0.016.

The CE is commonly employed as an open-chain exercise during the early stages of strengthening the hip abductors and external rotators. In previous studies, the muscle activity of the Gmax and hip abductor was examined during the performance of this exercise by healthy subjects (Boren, Conrey, Le Coguic, Paprocki, Voight, & Robinson, 2011; Distefano, Blackburn, Marshall, & Padua, 2009; McBeth, et al., 2012; Willcox & Burden, 2013). Willcox and Burden (2013) demonstrated that a neutral pelvic position is more effective for recruitment of the Gmax (17.8%MVIC) than is a 35°-reclined pelvic position (10.1%MVIC). Similar to the results of a previous study, our study revealed higher levels of Gmax activation during the CE-PVF (29.7%MVIC) than during the CE (18.6%MVIC). Pelvic rotation was 7.0° during the CE-PVF and 10.5° during the CE, suggesting that the pelvic position was closer to a neutral position during the CE-PVF than it was during the CE. Similar to a previous study, a more neutral pelvic position was associated with greater recruitment of the Gmax during the CE (Willcox & Burden, 2013). Patients with lower back pain tend to exhibit pelvic rotation during hip external rotation; thus, maintaining a neutral pelvic position with less rotation is important during exercise for lower back pain. Considering these findings, we suggest that PVF is effective for controlling pelvic rotation and activating the Gmax during the CE in patients with lower back pain.

The unilateral hip rotation of the CE transfers movement to the lumbopelvic region asymmetrically, and this rotation stress at the lumbopelvic region should be controlled by the stabilizer muscles. Comerford and Mottram (2012) reported that uncontrolled lumbopelvic rotation during the top leg turn-out exercise in a side-lying position was associated with inefficacy in the trunk stabilizing muscles, especially the abdominal oblique muscles. They suggested that selective contraction of the CEO and IIO by verbal instructions could control uncontrolled lumbopelvic rotation during CE. However, in our study, the EMG activity level of the IEO, not CEO and IIO, was significantly higher during the CE-PVF than during the CE. This result indicates that feedback can selectively activate only the IEO during the CE. Further research is needed to confirm whether feedback can selectively recruit the CEO and IIO to reduce uncontrolled lumbopelvic movement and increase Gmax EMG activity during the CE.

This study has several limitations. The first limitation is that subjects with lower back pain were only participated without control group in this study. We did not compare the effectiveness of feedback techniques on EMG activities and pelvic rotation between lower back pain group and healthy group. Second, we did not measure the activation of deep trunk muscles such as the transverse abdominis, pelvic floor muscles, and multifidus. We speculate that the deep trunk muscles, as well as the oblique muscles, can contribute to reduced pelvic rotation during the CE. Third, we did not measure the initiation point of pelvic movement during the CE exercise. To prevent and treat lower back pain, it may be important to assess the starting point as well as the degree of lumbopelvic rotation. Further study is needed to determine the effect of visual and palpation feedback on the activation of deep trunk muscles and the onset of pelvic rotation during the CE.

5. Conclusion

The muscle activity of Gmax increased more and the angle of pelvis rotation decreased more in the CE-VPF than those in the CE and CE-PBU. We suggest that the visual and tactile feedback training is more effective than training using a pressure biofeedback unit during the CE in patients with lower back pain. Clinicians should select an optimal feedback technique that effectively controls pelvic rotation during hip rotation exercises.

Conflict of interest

None declared.

Ethical statement

The investigation obtained the approval of Institutional Review Board (IRB) at Joongbu University.

Funding

None declared.

Acknowledgements

The authors would like to acknowledge Dong-jun, Choi and Geun-su, Kim for their contributions to this work.

References

Boren, K., Conrey, C., Le Coguic, J., Paprocki, L., Voight, M., & Robinson, T. K. (2011). Electromyographic analysis of gluteus medius and gluteus maximus during rehabilitation exercises. *International Journal of Sports Physical Therapy, 6*(3), 206–223.

Comerford, M., & Mottram, S. (2012). *Kinetic control: The management of uncontrolled movement*. New York: Elsevier Churchill Livingstone.

Cram, J., & Kasman, G. (1998). *Introduction to surface electromyography*. Gaithersburg, MD: Aspen.

Cynn, H. S., Oh, J. S., Kwon, O. Y., & Yi, C. H. (2006). Effects of lumbar stabilization using a pressure biofeedback unit on muscle activity and lateral pelvic tilt during hip abduction in sidelying. *Archives of Physical Medicine and Rehabilitation, 87*(11), 1454–1458.

Distefano, L. J., Blackburn, J. T., Marshall, S. W., & Padua, D. A. (2009). Gluteal muscle activation during common therapeutic exercises. *The Journal of Orthopaedic and Sports Physical Therapy, 39*(7), 532–540.

Gombatto, S. P., Collins, D. R., Sahrmann, S. A., Engsberg, J. R., & Van Dillen, L. R. (2006). Gender differences in pattern of hip and lumbopelvic rotation in people with low back pain. *Clinical Biomechanics (Bristol, Avon), 21*(3), 263–271.

Hislop, H. J., & Montgomery, J. (2007). *Daniels and Worthingham's muscle testing: Techniques of manual examination* (8th ed.). St. Louis: Elsevier.

Hodges, P. W. (2011). Pain and motor control: from the laboratory to rehabilitation. *Journal of Electromyography and Kinesiology, 21*(2), 220–228.

Hoffman, S. L., Johnson, M. B., Zou, D., & Van Dillen, L. R. (2012). Gender differences in modifying lumbopelvic motion during hip medial rotation in people with low back pain. *Rehabilitation Research and Practice [Electronic Resource], 2012*, 635312.

Kisner, C., & Colby, L. A. (2012). *Therapeutic exercise: Foundations and techniques* (6th ed.). Philadelphia: F.A. Davis.

Lawrence, R. C., Helmick, C. G., Arnett, F. C., Deyo, R. A., Felson, D. T., Giannini, E. H., et al. (1998). Estimates of the prevalence of arthritis and selected musculoskeletal disorders in the United States. *Arthritis and Rheumatism, 41*(5), 778–799.

McBeth, J. M., Earl Boehm, J. E., Cobb, S. C., & Huddleston, W. E. (2012). Hip muscle activity during 3 side-lying hip-strengthening exercises in distance runners. *Journal of Athletic Training, 47*(1), 15–23.

McGill, S. M. (1997). The biomechanics of low back injury: implications on current practice in industry and the clinic. *Journal of Biomechanics, 30*(5), 465–475.

O'Sullivan, P. (2005). Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. *Manual Therapy, 10*(4), 242–255.

Panjabi, M. M. (2003). Clinical spinal instability and low back pain. *Journal of Electromyography and Kinesiology, 13*(4), 371–379.

Park, K., Ha, S., Kim, S., Kwon, O., & Oh, J. (2013). Effects of the pelvic rotatory control method on abdominal muscle activity and the pelvic rotation during active straight leg raising. *Manual Therapy, 18*(3), 220–224.

Sahrmann, S. (2002). *Diagnosis and treatment of movement impairment syndromes*. St. Louis, Mo: Mosby.

Scholtes, S. A., Norton, B. J., Lang, C. E., & Van Dillen, L. R. (2010). The effect of within-session instruction on lumbopelvic motion during a lower limb movement in people with and people without low back pain. *Manual Therapy, 15*(5), 496–501.

Scholtes, S. A., & Van Dillen, L. R. (2007). Gender-related differences in prevalence of lumbopelvic region movement impairments in people with low back pain. *The Journal of Orthopaedic and Sports Physical Therapy, 37*(12), 744–753.

Tateuchi, H., Tsukagoshi, R., Fukumoto, Y., Akiyama, H., So, K., Kuroda, Y., et al. (2013). Pelvic instability and trunk and hip muscle recruitment patterns in patients with total hip arthroplasty. *Journal of Electromyography and Kinesiology, 23*(1), 151–158.

Van Dillen, L. R., Maluf, K. S., & Sahrmann, S. A. (2009). Further examination of modifying patient-preferred movement and alignment strategies in patients with low back pain during symptomatic tests. *Manual Therapy, 14*(1), 52–60.

Van Dillen, L. R., Sahrmann, S. A., Norton, B. J., Caldwell, C. A., McDonnell, M. K., & Bloom, N. (2003). The effect of modifying patient-preferred spinal movement and alignment during symptom testing in patients with low back pain: a preliminary report. *Archives of Physical Medicine and Rehabilitation, 84*, 313–322.

Willcox, E. L., & Burden, A. M. (2013). The influence of varying hip angle and pelvis position on muscle recruitment patterns of the hip abductor muscles during the clam exercise. *The Journal of Orthopaedic and Sports Physical Therapy, 43*(5), 325–331.