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ORIGINAL ARTICLE

The Effects of the Use of Pilates Equipment during Pilates Hundred, Swimming Exercise on the Muscle Activation of Abdominal Muscles, Lumbar Erector Spinae, Gluteus of Lumbar Disc Disease Patients

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PURPOSE: The purpose of this study is to contribute to the academic basis for the prevention and treatment of back pain for future lumbar disc disease patients by comparing and analyzing the effect of using or not using Pilates equipment on the muscle activity of lumbar disc disease patients and ordinary persons during Pilates Hundred preb and Swimming preb.

METHODS: The subjects were 20 female with a mean age of 30-50. In order to measure muscle activity, the surface electromyography (sEMG) was used. Muscles activation were analyzed.

RESULTS: All the rectus abdominis (RA), external (EO) and internal oblique (IO) abdominal muscles showed a higher activity in Mat than in Hundred preb using equipment, and especially IO showed a higher activity in ordinary people than in lumbar disc disease patients. All the gluteus medius (Gmed), gluteus maximus (Gmax) and lumbar erector spinae (LES) showed a higher activity in Mat than in Swimming preb using equipment, but there was no significant difference between ordinary people and lumbar disc disease patients.

CONCLUSIONS: The muscle activity of all the muscles was found to be higher in ordinary people than in lumbar disc disease patients, and IO muscle showed a significant difference during Hundred, and both Hundred and Swimming preb motions showed a higher muscle activity in Mat. It is considered that abdominal (AB) muscle, RA, Gmed, Gmax and especially IO muscle and transversus abdominis (TrA) need to be strengthened in lumbar disc disease patients and education in Mat would be more effective.

Key words: Mat pilates, Equipment pilates, Clinical pilates, Lumbar disc diseases, Lumbar herniated nucleus pulposus, Herniated lumbar disc rehabilitation exercise

INTRODUCTION

The causes of back pain vary from degenerative changes of disc [1] to static lifestyle, postural abnormality, and psychological problems, of which about 45% are reported to be related to disc problems [2]. The degenerative changes of disc cause disc herniation, spinal stenosis and spondylolisthesis [3], this changes was increased the compressive forces on lumbar and pain [4], and the limitation of activity for pain avoidance leads to weakness of the lumbar muscle and atrophy of the muscles around the lumbar spine stabilizing the spine [5].

The possible causes of disc disease include fluid outflow and elastic deformation, which may lead to pain, an altered muscle response, and increased compressive forces [6]. Instability due to the weakness of the spinal stabilizing muscles causes chronic back pain [7], and weakening of the muscles around the lumbar spine leads to a vicious cycle in which back pain continues to recur [8].

Patients with low back pain (LBP) have weakened lumbar extension muscle strength [9] and show the muscle weakness in the muscles around

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the lumbar region [10]. In addition, patients with chronic back pain show a decrease in the muscle activity of the core muscle, which prevents the lumbar spine from being damaged [11,12]. For this purpose, coordinated contraction and strengthening of the stabilizing muscles of the deep part and the stabilizing muscles of the surface are required [13]. Important muscles in exercise therapy include deep stabilizing muscles with a direct influence on the vertebral segment (transversus abdominis [TrA], internal oblique [IO] muscle, multifidus [MF] muscle) and superficial stabilizing muscles contributing to the stability of the trunk (rectus abdominis [RA] muscle, external oblique abdominal [EO] muscle, lumbar erector spinae [LES]), and these muscles contribute to the stabilization of the vertebrae, and especially for patients with chronic LBP, the contractility of muscle TrA, IO muscles and EO muscles is reported to play a role as the corset of the body [7], so the increase in muscle activity of deep abdominal muscles is considered to be very important for lumbar disc disease patients. In addition to the abdominal muscle exercise, lumbar muscle exercise for patients with LBP has the effect of reducing the pressure of the disc and reliving the tense of the lumbar nerve root [14]. In addition, hip strengthening exercise has been reported to be effective in reducing pain [15]. Therefore, it is essential to evaluate lumbar extension muscle strength to prevent and treat LBP of patients with back pain [16], and it is also very important to identify the cause of back pain in patients and develop appropriate exercise therapies [17].

Recently, Pilates has been proposed as exercise therapy for back pain in clinical practice [18], and Pilates has been reported to help improve spinal stabilization around abdominal and gluteal strengthening [19,20]. Pilates promotes increased stability of the vertebral segments, leading to fluid inflow, training the dell trunk muscles, and improving the muscle recruitment pattern [21,22]. These changes have been reported to reduce pain in dancers with Lumbar disc disease [23], and the Pilates method of exercise has been considered effective for back pain in patients with disc disease.

Hundred is a typical abdominal exercise among Pilates motions, and it is reported that Hundred affects the thickness increase of muscle TrA and IO and EO muscles as well as increase in muscle activity of EO muscle, IO muscle [24-26]. The study of muscle activity through EMG by Lee & Jeong [25] also reported that the muscle activity of RA muscle and EO muscle increased during Pilates Hundred motion. In addition, there is Swimming motion as lumbar extension exercise to strengthen the lumbar part among Pilates motions, and Swimming motion was reported to strengthen lumbar muscle strength and Gluteus muscle (GM) [26], and Lee & Jeong [25] also said that the muscle activity of LES muscle and GM increased during Beat motion and Brest stroke prep which are similar to Swimming motion. As shown above, Pilates Hundred motion and Swimming motion have been reported to be effective in the increase in abdominal (AB) muscle, LES muscle, and GM, but most of these studies studied the motions of Pilates for ordinary people without pain. In addition, da Luz et al. [27] reported that Equipment Pilates was superior to Mat Pilates was effective in improving disability and kinesiophobia of chronic nonspecific LBP patients, but there are only a few studies carried out for lumbar disc disease patients and studies that compared the difference from the motion on the mat when using Pilates equipment, so we think that it is necessary to study the effects of Pilates motion on the equipment and mat on the muscle activity of the AB muscle, LES muscle, and GM.

Therefore, the purpose of this study was to compare the muscle activity of the AB, LES, and GM in lumbar disc disease patients with chronic LBP and ordinary people and contribute to the academic basis of exercise therapy for the prevention and treatment of back pain for lumbar disc disease patients in the future.

METHODS

1. Subjects

This study divided females in their 30s and 50s who visited Kwanghye Hospital specializing in spine located in Gangnam-gu, Seoul into 10 people in the experimental group with lumbar disc disease without pilates exercise experience and 10 ordinary people without lumbar disc disease. The criteria for selecting lumbar disc disease patients are the diagnosis of lumbar disc disease, 3 or more of visual analogue scale (VAS), more than 7 of total score of oswestry disability index (ODI) [28], and the patients who agreed to the experiment before participating in the study were selected. Patients with severe myopathy, severe radicular pain, and sensory abnormalities were excluded from the study. The diagnosis names of lumbar disc disease patients include 5 cases of spinal stenosis with degenerative disc, 5 cases of lumbar nucleus swelling or herniation. The physical characteristics of the subjects are shown in (Table 1).

Table 1. Physical characteristics of the subjects

Variable	Lumbar disc Patient (N=10)	Ordinary person (N=10)	*t*	Sig
Age (yr)	47.2±8.2	42.0±2.8	1.89	0.066
Height (cm)	157.50±6.65	161.3±2.7	1.67	0.120
Weight (kg)	54.40±4.79	52.8±5.5	.69	0.497

Values are the means±standard deviations.

Table 2. Muscle activity muscle attachment sites

Attachment muscle	Attachment site
RA	5 cm above the navel, 3 cm outside
EO	15 cm outside the navel
IO	2 cm inward from upper iliac crest
Gmed	1/3 of the proximal portion of the line connecting major trochanter with the iliac crest
Gmax	Middle of the line connecting the outer angle under the sacrum with major trochanter, 3 cm above the hips wrinkles
LES	2-3 cm lateral from the lumbar spine 3 spur

2. Experimental procedure and measurement method

In order to measure the muscle activity of RA, EO, IO, LES, Gmed, Gmax during Pilates Hundred and Swimming motion, we trained Pilates Hundred preb on the mat, Hundred preb on the Reformer, Swimming preb on the mat and Swimming preb on the Cadillac before examination to all 20 participants and measured and compared the muscle activity of muscles while performing these four motions. The muscle activity was measured using sEMG (TeleMyo 2400, Noraxon, USA), and the measured sEMG signals were processed by the Root Mean Square (RMS) and were analyzed with a measured value for 10 seconds except for the beginning of the action and the last one second. According to the report that when the muscle activity of patients with back pain was measured, Maximum Voluntary Isomeric Contraction (MVIC) is unreliable [10] and it is not used for patients who may have limited maximum contraction [29], the MVIC was not performed because there may be a problem due to the nature of the subjects.

1) Muscle attachment site during EMG muscle activity test

The surface electrodes were attached after wiping them with alcohol swabs to eliminate the signal resistance and attached to the muscles according to the previous studies of Cram et al. [30] and Queiroz et al. [31]. Table 2 shows the muscle activity muscle attachment sites.

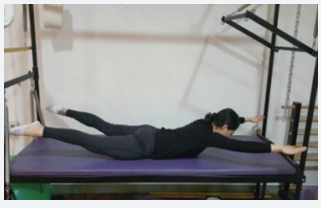
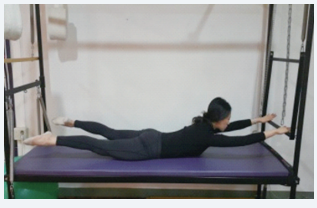
2) Muscle activity measurement during Pilates Hundred preb, Swimming prep

Mat Hundred preb and Reformer Hundred preb were carried out in order to find out the muscle activity of RA, EO, IO, and Mat Swimming preb and Cadillac Swimming prep conducted to measure the muscle activity of LES and GM. The motions for measuring the muscle activity are shown in (Table 3).

3. Statistical analysis

In the experiment, the mean and standard deviation of the measured values were obtained using SPSS 18.0 (Statistcal Package for Social Sciences, IBM Inc., USA) Two-way ANOVA was carried out to compare and analyze differences depending on the group and exercise types. Statistical significance of all results was set to $\alpha = .05$.

Table 3. Motions for measuring the muscle activity

Mat hundred prep	Reformer hundred prep
	
Place the two legs at the table top position and raise the upper body. At this time, lift both hands to shoulder height and rock the arms up and down 30 times with small movement	Climb up the Reformer carriage and put a strab on the hand and shake it 30 times like the above mat motion
Mat swimming preb	**Cadillac swimming preb**
	
Lift both arms and legs at the same time and hold and then come back. Repeat 5 times	Put both hands on the push thru bar. Push both arms upwards like hurraying. At this time, life both legs simultaneously. Repeat 5 times

RESULTS

1. A comparison of the muscle activity of AB muscle of lumbar disc disease patients and ordinary people during Pilates Hundred preb on the Mat and Reformer

During Pilates Hundred preb on the Mat and Reformer, the activity of

Table 4. Comparison of the muscle activity during Hundred preb on the Mat and Reformer

Variable		Lumbar disc patient	Ordinary person		F	Sig
RA (%)	Mat	50.45±27.32	73.99±44.69	Group	2.291	0.147
				Exercise	4.987	0.038*
	Reformer	38.88±21.55	53.18±31.12	G×E	0.407	0.532
EO (%)	Mat	23.87±6.55	30.36±10.09	Group	1.361	0.259
				Exercise	2.840	0.109
	Reformer	22.60±8.27	23.81±10.58	G×E	1.302	0.269
IO (%)	Mat	21.22±7.84	45.79±24.29	Group	8.155	0.011*
				Exercise	8.208	0.010*
	Reformer	17.36±5.55	33.60±22.25	G×E	2.208	0.155

Values are the means±standard deviations.
*p<.05.

Table 5. Comparison of the muscle activity during swimming preb on the Mat and Cadillac

Variable		Lumbar disc patient	Ordinary person		F	Sig
Gmed (%)	Mat	14.00±8.96	20.69±23.10	Group	1.113	0.305
				Exercise	12.591	0.002**
	Reformer	9.12±4.11	17.57±20.64	G×E	0.611	0.444
Gmax (%)	Mat	23.17±10.59	30.51±17.78	Group	20.169	0.158
				Exercise	14.004	0.001**
	Reformer	14.12±7.13	20.28±8.55	G×E	0.053	0.821
LES (%)	Mat	47.10±22.22	62.74±27.63	Group	0.999	0.331
				Exercise	4.890	0.040*
	Reformer	42.72±21.29	46.28±24.03	G×E	1.643	0.216

Values are the means±standard deviations.
*p<.05, **p<.01.

RA muscle (p<.05) and IO muscle showed differences depending on the types of exercise (p<.05), and Hundred preb on the mat showed a higher activity than Hundred preb on the Reformer in all the RA, EO and IO muscle. The muscle activity of the IO muscle was found to be higher in ordinary people than in lumbar disc disease patients (p<.05) (Table 4).

2. A comparison of the muscle activity of GM and LES of lumbar disc disease patients and ordinary people during Pilates Swimming preb on the Mat and Cadillac

During Pilates Swimming preb on the Mat and Cadillac, the muscle activity of Gmed (p<.05) and Gmax, LES showed differences depending on the types of exercise (p<.05), and Swimming preb on the mat showed a higher activity than Swimming preb on the Cadillac in all the muscles. However, the muscle activity of Gmed, Gmax, and LES did not show significant differences between ordinary people and lumbar disc disease patients (Table 5).

DISCUSSION

In this study, we applied Prep, the easy and stable transformation of Hundred, which is the typical motion of Pilates and Swimming preb reported to strengthen lumbar muscular strength and GM to compare the muscle activity of lumbar disc disease patients and ordinary people, and there was a significant difference in the IO muscle between the two groups during Hundred preb on the Mat and Reformer, and ordinary people showed a higher muscle activity of IO muscle than lumbar disc disease patients. There was also a significant difference in muscle activity depending on the types of exercise, and Hundred preb on the mat showed a higher muscle activity of RA muscle and IO muscle than Hundred preb on the Reformer.

In terms of exercise therapy, weakened muscular strength is considered to be a major factor of low back pain [32], and it is said that patients with low back pain have delayed muscle control of deep muscles compared to normal people [33] and show the dysfunction of deep AB muscles such as IO muscle and TrA [34,35]. This means that AB muscle exercise of the deep part is required for lumbar disc disease patients. RA

muscle plays a role in providing the stability of the spine for patients with back pain [36], and IO and EO muscles are muscles that help to prevent rotation of the lumbar part and pelvis during motion and to maintain the stability of the spine, so the increase in the muscle activity of deep AB muscles during motion means to contribute to the stability of the vertebrae [37]. In this study, ordinary people showed a higher muscle activity of IO muscle in Hundred prep on the Mat and Reformer than lumbar disc disease patients. These results are consistent with the report of Marques et al. [38] that the muscle activity of spinal deep muscle was higher in ordinary people than in patients with LBP. The practice of Pilates could enable IO muscle contraction, owing to increased muscle activation, generated movements, and force [39,40]. However, low back pain (LBP) causes alteration in muscular recruitment, force generation capacity, and endurance potential of deep abdominal muscles [41,42]. Therefore, for this reason, patients with LBP show lower muscle activity during the Hundred Prep on the mat and reformer.

When comparing the muscle activity of ordinary people and patients with LBP, however, there was no significant difference except IO muscle. Given that there is no difference in the muscle activity of RA muscle, EO muscle, LES muscle and Gmax, which are superficial muscles, the weakness and dysfunction of a AB muscles in the deep part is more remarkable than superficial muscles in patients with LBP than in ordinary people [43,44].

In this study, the TrA was not measured using sEMG. In the study by Marshall and Murphy [45], the portion of the sEMG electrode in the IO was located 2 cm below the anterior aspect of the anterior superior iliac spine (ASIS), where the IO and TrA muscles coexist. Mannion et al. [46] also reported that increased activity of the IO muscle influences the activity of the TrA muscle, which suggests that the overlap in muscle coactivation and function may be due to the parallel position of the IO and TrA below the anterior aspect of the ASIS.

In addition, the AB exercise on the unstable side increases the AB muscle activity more than that on the stable ground [47]. In this study, Hundred preb on the mat showed a higher muscle activity of IO muscles than Reformer Hundred preb with a spring on a moving carrier although carried out on the unstable side. Greater activation of muscles when using the reformer and significant activation of the trunk extensors when exercising in the prone position have been reported. Exercise on the reformer imposes resistance through the spring on the equipment, and the resistance is changed by controlling the force of spring compression [48]. Therefore, in patients with LBP, control of the trunk and stability is difficult [49]. This result is also presumed to be due to the fact that the subjects are not accustomed to pilates motions and patients with back pain do not use more muscles due to back pain when exercising on the unstable side, and when training Pilates Hundred preb later, Hundred preb on the mat in early training seems to be more effective in improving the muscle activity of IO muscle than Reformer Hundred preb.

In addition, patients with LBP showed weakening of the Gmed compared to normal people, and this weakening of the Gmed may cause lower extremity dysfunction as well as LBP, so in addition to evaluating the muscular strength of the Gmed, evaluating the instability of the lumbar region is important for the diagnosis of back pain. In other words, it was reported that the higher the instability of the lumbar region, the lower the muscular strength of the Gmed [50]. In addition, the study of Kwon & Koh [50] reported that patients with back pain showed a more decline of muscle contraction of the Gmax than normal people in the motion of extending the hip joints in the lying down posture. It was also reported that problems with the mobilization of the Gmax cause excessive muscle tone of thoracolumbar spine in a compensatory manner [51]. This suggests that the muscle strengthening of the Gmax is necessary for patients with low back pain.

Pilates is a lumbar stabilization exercise that strengthens the muscles around the vertebra while balancing the flexion of the lumbar part and the extension muscles [25]. It is reported that the superman motion like Pilates Swimming prep performed in this study is the representative exercise of the core stabilization exercise [52] and is the exercise developing the back muscles of the whole body including the lumbar part and hips, and especially, this motion was reported to increase the muscle activity of the Gmed [26]. The Gmed and Gmax are important muscles for the pelvic stability, and weakened gluteus is closely related to back pain [53]. Therefore, the muscular strength improvement of Gmed and Gmax can be said to be very important for decreasing back pain [54]. The study of Lee & Seo [55] reported that Swimming prep increased the muscle activity of LES muscle and Gmed, and the activity of the LES muscle was effective in relieving pain and fatigue of the lumbar part.

This study showed that ordinary people showed a higher muscle activity of Gmed, Gmax and LES muscle than lumbar disc disease patients during Swimming preb on the mat and Cadillac, but there was no significant difference. Despite the report that Swimming prep is effective for stimulation of lumbar extensor muscles and Gmed, there was no statistical difference between ordinary people and lumbar disc disease patients

because even though ordinary people have no back pain, the automation of modern life and the increase of sedentary life reduce the physical activity [56] and the use of muscles related to the lumbar extension is less.

In addition, Swimming preb on the mat showed a higher muscle activity than Swimming preb on the cadillac, and the motion on the cadillac has the advantage of stretching the upper body more easily and stably by supporting the push-thru bar, but this study showed that Swimming preb on the cadillac did not have the effect of further increasing the muscle mobilization of the LES, Gmed and Gmax in lumbar disc disease patients than motion on the mat. The limitations of this study are that only the LES was measured using surface electrodes and the deep stabilizing muscle, multifidus muscle could not be measured.

We analyzed the muscle activity of lumbar disc disease patients and ordinary people by applying Pilates Hundred Prep and Swimming preb. As a result, Hundred preb showed a meaningful difference of IO muscle between the two groups, and this study reported that lumbar disc disease patients show further weakening of AB muscle, LES, GM than ordinary people, especially causing the weakening of the IO muscle. In the future, it is considered that AB muscle exercise of the deep part is necessary for lumbar disc disease patients.

In two motions performed in this study, the motion on the mat showed a higher muscle activity of RA, IO, Gmed, Gmax, LES muscle than motion using equipment, suggesting that the exercise on the mat will be more effective in increasing muscle activity when teaching these two motions to lumbar disc disease patients in the future. In this study, we compared and analyzed the muscle activity of RA, EO, IO, LES, Gmed, Gmax during Pilates Hunrdred preb and Swimming preb of lumbar disc disease patients and ordinary people. As a result, the muscle activity of all muscles was found to be higher in ordinary people than in lumbar disc disease patients and IO muscle showed a significant difference during Hundred preb on the mat and Reformer ($p>.05$), and Hundred preb on the mat and Swimming preb on the mat showed a higher muscle activity than motion on the equipment.

CONCLUSION

It is considered that the AB muscle, LES, and gluteal muscle exercise is necessary when applying the Pilates exercise program to lumbar disc disease patients, and especially strengthening of the IO muscle and TrA may be necessary and the education on the mat will be more effective.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

1. Adams MA, Roughley PJ. What is intervertebral disc degeneration, and what causes it? Spine. (Phila Pa 1976) 2006;31(18):2151-61.
2. Kallewaard JW, Terheggen MA, Groen GJ, Sluijter ME, Derby R, et al. Disco-genic low back pain. Pain Pract. 2010;10(6):560-79.
3. Adams MA, Stefanakis M, Dolan P. Healing of a painful intervertebral disc should not be confused with reversing disc degeneration: Implications for physical therapies for discogenic back pain. Clin Biomech. (Bristol, Avon). 2010;32(2):123-31.
4. Adams MA, Dolan P, Hutton WC, Porter RW. Dirunal changes in spinal mechanics and their clinical significance. J Bone Joint Surg Br. 1990; 42:660-9.
5. Kalichman L, Hodges P, Li L, Guermazi A, Hunter DJ. Changes in paraspinal muscles and their association with low back pain and spinal degeneration: CT study. Eur Spine J. 2009;19(7):1136-44.
6. Healsy EL, Flower NE, Burden A, McEwan IM. Raised paraspinal muscle activity reduces rate of stature recovery after loaded exercise in individuals with chronic low back pain. Arch Phys Med Rehab. 2005;86: 710-5.
7. Panjabi MM. Clinical spinal instability and low back pain. J Electromyogr Kinesiol. 2003;13(4):371-9.
8. Lee SH, Kim SJ. Isokinetic evaluation of the trunk flexors and extersors in chronic low back pain. J Kor Acad Rehabil Medi. 1994;18(2): 248-55.
9. Addison R, Schultz A. Trunk strengths in patients seeking hospitalization for chronic low-back disorders. Spine. 1980;5(6):539-44.
10. Beimborn DS, Morrissey MC. A review of the literature related to trunk muscle performance. Spine. 1988;13(6):655-60.
11. da Fonseca JL, Magini M, de Freitas TH. Laboratory gait analysis in patients with low back oaun before and after a pilates intervention. J Sport Rehabil. 2009;18:269-82.
12. O'Sullivan PB, Twomey L, Allison GT. Altered abdominal muscle recruitment patients with chronic back pain following a specific exercise intervention. J Orthop Sports Phys Ther. 1998;27(2):114-24.
13. McGill SM, Grenier S, Kavcic N, Cholewicki J. Coordination of muscle activity to assure stability of the lumbar spine. J Electromyogr Kine-

siol. 2003;13(4):353-9.

14. Lee WH, Lee YM, Gong WT. The effects of lumbar strengthening exercise on pain and the cross-sectional area change of lumbar muscles. J Phys Ther. 2011;23(2):209-12.
15. Akuthota V, Ferreiro A, Moore T, Fredericson M. Core stability exercise principles. Curr Sports Med Rep. 2008;7(1):39-44.
16. Seidel H, Beyer H, Brauer D. Electromyographic evaluation of back muscle fatigue with repeated sustained contractions of different strengths. Eur J Appl Physiol Occup Physiol. 1987;56(5):592-602.
17. Sohn MK, Yoon YS, Jun KH. EMG power spectrum of lumbar back muscle in chronic low back pain patients. J Kor Acad Rehabil Medi. 1998;22(1):68-76.
18. Blum CL. Chiropractic and pilates therapy for the treatment of adult scoliosis. J Manipulative physiol Ther. 2002;25(4):E3.
19. Bernard LM. The effectiveness of Pilates training in healthy adults: An appraisal of the research literature. J Body Mov Ther. 2006;11(2):106-10.
20. Curnow D, Cobin D, Wyndham J, Choy ST. Altered motor control, posture and the pilates method of exercise prescription. J Body Mov Ther. 2008;13(2):104-11.
21. Muscolino JE, Cipriani S. Pilates and the "power house" II. Journal of Bodywork and Movement Therapies. 2004:8:122-30.
22. Bryan M, Hawson S. The benefits of Pilates exercise in orthopedic rehabilitation. Techniques in Orthopaedics. 2003:18(1):126-9.
23. Lee SR. Effect of Pilates exercise on dancer pain- Focused on lumbar disc. 2005; Master's Thesis, Graduate School, Chungnam National University.
24. Moon JH, Hong SM, Kim CW, Shin YA. Comparison of deep and superficial abdominal muscle activity between experienced Pilates and resistance exercise instructor and controls during stabilization exercise. J Exercis Rehabil. 2015;11(3):161-8.
25. Lee J, Jeong IS. Effects of pilates-based core-strengthening exercise on muscle activities in middle-aged women. Kor J Sport Sci. 2017;26(3): 1377-88.
26. Son NJ, Yi KO. The analysis of EMG according to surface type and elastic band usage during the Pilates superman movement. Kor J Sport Biomec. 2015;25(2):219-29.
27. da Luz MA Jr, Costa LO, Fuhro FF, Manzoni AC, Oliveira NT, et al. Effectiveness of mat pilates or equipment-based pilates exercises in patients with chronic nonspecific low back pain: a randomized controlled trial. Phys Ther. 2014;94:623-31.
28. Claeys K, Brumagne S, Dankaerts W, Kiers H, Janssens L. Decreased variablility in postural control strategies in young people with non-specific low back pain is associated with altered proprioceptive reweighting. Eur J Appl Physiol. 2011;111(1):115-23.
29. Bolgla LA, Uhl TL. Reliability of electromyographic normalization methods for evaluating the hip musculature. J Electromyogr Kinesiol. 2007;17(1):102-11.
30. Cram JR, Kasman GS, Holtz J. Introduction to surface electromyography. J Athl Train. 1998;34(1):69.
31. Queiroz BC, Cagliari MF, Amorim CF, Sacco IC. Muscle activation during four pilates core stability exercises in quadruped position. Arch Phys Med Rehabil. 2010;91(1):86-92.
32. Koumantakis GA, Watson PJ, Oldham JA. Trunk muscle stabilization training plus general exercise versus general exercise only: randomized controlled trial of patients with recurrent low back pain. Phys Ther. 2005;85(3):209-25.
33. Arendt-Nielsen L, Graven-Nielsen T, Svarrer H, Svensson P. The influence of low back pain on muscle activity and coordination during gait: a clinical and experimental study. Pain. 1996;64(2):231-40.
34. Hodges PW. Is there a role for transversus abdominis in lumbo-pelvic stability? Man Ther. 1999;4(2):74-86.
35. Kumar S, Negi MPS, Sharma VP, Shukla R. The spinal column and abdominal pressure changes and their relationship with pain severity in patients with low back pain. Niger J Med Rehabil. 2008;13(1):1-6.
36. Richardson CA, Hodges PW, Hides JA. Therapeutic exercise for lumbopelvic stabilization. A motor control approach for the treatment and prevention of low back pain (2nd ed.). 2004 London: Churchill Livingstone.
37. Sauza GM, backer LL, Powers CM. Electro myograpic activity of selected trunk muscles during dynamic spine stabilization exercises. Arch Phys Med Rehabil. 2001;82(11):1551-7.
38. Marques NR, Morcelli MH, Hallal CZ, Gonçalves M. EMG activity of trunk stabilizer muscles during Centering Principle of Pilates Method. J Bodyw Mov Ther. 2013;17(2):185-91.
39. Andersen LL, Magnusson SP, Nielsen M, Haleem J, Poulsen K, et al. Neuromuscular activation in conventional therapeutic exercises and heavy resistance exercises: implications for rehabilitation. Phys Ther. 2006;86(5):683-97.
40. Fry AC. The role of resistance exercise intensity on muscle fibre adaptations. Sports Med. 2004;34(10):663-79.
41. van Dieën JH, Selen LP, Cholewicki J. Trunk muscle activation in low-back painpatients, an analysis of the literature. J Electromyogr Kinesiol.

2003;13(4):333-51.
42. van Dieën JH, Kingma I, van der Bug P. Evidence for a role of antagonisticcocontraction in controlling trunk stiffness during lifting. J Biomech. 2003;36(12):1829-36.
43. Danneels LA, Coorevits PL, Cools AM, Vanderstraeten GG, Cambier DC, et al. Differences in electromyographic activity in the multifidus muscle andthe iliocostalis lumborum between healthy subjects and patients with sub-acuteand chronic low back pain. Eur Spine J. 2002;11(1):13-9.
44. Vleeming A, Schuenke MD, Danneels L, Willard FH. The functional coupling of thedeep abdominal and paraspinal muscles: the effects of simulated paraspinalmuscle contraction on force transfer to the middle and posterior layer of thethoracolumbar fascia. J Anat. 2014;225(4):447-62.
45. Marshall PW, Murphy BA. Core stability exercises on and off Swiss ball. Arch Phys Med Rehabil. 2005;86(2):242-9.
46. Mannion AF, Pullkovski N, Gubler D. Muscle thickness changes during abdominal hollowing an assessment of between day measurment error in conrols and patients with chronic low back pain. Eur spine J. 2008;17(4):494-501.
47. Vera Garcia FJ, Grenier SG, McGill SM. Abdominal muscle response during curl-ups on both stable and labile surfaces. J America Phys Ther. 2000;80(6):564-9.
48. Mayer JM, Graves JE, Robertson VL, Pierra EA, Verna JL, et al. Electromyographic activity of the lumbar extensor muscles: effect of angle andhand position during Roman chair exercise. Arch Phys Med Rehabil. 1999;80(7):751-5.
49. Ward SR, Kim CW, Eng CM, Gottschalk LJ 4th, Tomiya A, et al. Architectural analysis and intraoperative measurements demonstrate the uniquedesign of the multifidus muscle for lumbar spine stability. J Bone Joint Surg Am. 2009;91(1):176-85.
50. Kwon OY, Koh Ek. The comparison of the Onset Tunes of hamstring, gluteus maximus, and lumbar erector spinae muscle activity during hip extension between subjects with low back pain and healthy subjects. Kor Res Soc Phys Ther. 2002;9(2):33-42.
51. Jull GA, Janda V. Muscles and motor controls in low back pain: Assessment and management. Physical therapy of the low back. Newyork, Churchill Livingstone. 1987;253-78.
52. Behm DG, Leonard AM, Young WB, Bonsey WA, Mackinnon SN. Trunk muscle electromyographic activity with unstable and unilateral exercises. J Strength Cond Res. 2005;19(1):193-201.
53. Akuthota V, Nadler SF. Core strength. Arch Phys Med and Rehabil. 2004;85(1):86-92.
54. Kang SY, Jeon HS, Kwon OY, Cynn HS, Choi B. activation of the gluteus maximus and hamstring muscles during prone hip extension with knee flexion in three hip abducttion positions. Man Ther. 2013;18(4):303-7.
55. Lee J, Seo SJ. A study of middle aged women, on their muscle activity and subjective analysis of the body according to pilates positions, J Kor Soc Dance Sci. 2016;33(4):109-23.
56. Baek CY, Seo JH. The effet of pilates traning on the lumbar mobility, stability and pain level of clerical worker. Kor J Grow Deve. 2016;24(1):53-8.