ORIGINAL ARTICLE

Muscle Activation During Four Pilates Core Stability Exercises in Quadruped Position

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ABSTRACT. 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: 86-92.

Objective: To compare the activity of stabilizing trunk and hip muscles in 4 variations of Pilates stabilizing exercises in the quadruped position.

Design: Repeated-measures descriptive study.

Setting: A biomechanics laboratory at a university school of medicine.

Participants: Healthy subjects (N=19; mean age ± SD, 31±5y; mean weight ± SD, 60±11kg; mean height ± SD, 166±9cm) experienced in Pilates routines.

Interventions: Surface electromyographic signals of iliocostalis, multifidus, gluteus maximus, rectus abdominis, and external and internal oblique muscles were recorded in 4 knee stretch exercises: retroverted pelvis with flexed trunk; anteverted pelvis with extended trunk; neutral pelvis with inclined trunk; and neutral pelvis with trunk parallel to the ground.

Main Outcome Measures: Root mean square values of each muscle and exercise in both phases of hip extension and flexion, normalized by the maximal voluntary isometric contraction.

Results: The retroverted pelvis with flexed trunk position led to significantly increased external oblique and gluteus maximus muscle activation. The anteverted pelvis with trunk extension significantly increased multifidus muscle activity. The neutral pelvis position led to significantly lower activity of all muscles. Rectus abdominis muscle activation to maintain body posture was similar in all exercises and was not influenced by position of the pelvis and trunk.

Conclusions: Variations in the pelvic and trunk positions in the knee stretch exercises change the activation pattern of the multifidus, gluteus maximus, rectus abdominis, and oblique muscles. The lower level of activation of the rectus abdominis muscle suggests that pelvic stability is maintained in the 4 exercise positions.

Key Words: Electromyography; Exercise therapy; Rehabilitation.

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JOSEPH PILATES (1880–1967) developed an exercise method based on a combination of Eastern philosophical principles and movement techniques such as yoga,[1] and Western methods of body conditioning such as P. H. Ling's medical gymnastics.[2] The purpose of this method is to develop the core muscles through more than 500 stretching and strengthening exercises that can be divided into 2 broad categories: mat and apparatus exercises. The apparatus exercises require one to exercise against resistance provided by the use of springs and pulleys.[3] One of the most used apparatuses is the reformer, which consists of a sliding platform with attached springs that allow variable resistance. The reformer allows the practitioner to exercise in a sitting, reclining, or standing position. The advantages of this equipment have been described elsewhere.[4,5]

Although some authors have discussed the important role of local muscles (like the multifidus and transversus muscles), all core muscles contribute to the optimal lumbar-pelvic stabilization needed for athletic performance, daily activities, and function.[6] Diverse therapeutic exercises, called stabilization exercises, have been used to restore the dynamic control of external and internal forces over the trunk.[7-10] Other methods include alternative body conditioning techniques such as Tai Chi, yoga, and Pilates.[11] The dynamic control of trunk muscles plays an important role in preventing repetitive injury of intervertebral disks, facet joints, and related structures.[12]

Stabilization exercises can be performed in a variety of body positions. However, for the first stage of the rehabilitation process, one of the most commonly recommended in the literature are those performed in 4-point kneeling, with the trunk in a horizontal position and hands and knees touching the ground. These exercises reduce spinal loads[7,13-15] and train the recruitment pattern of specific trunk muscles.[13,14,16-18]

In the Pilates method, the exercises traditionally called knee stretch are performed exclusively in the reformer apparatus[19,20] in a quadruped position. These exercises are clinically recommended[20-22] because they intend to challenge trunk muscle stability to maintain upper trunk and pelvic postures while cyclically moving the hips backward and forward extension and flexion).[19,23]

Trunk muscle activation patterns during the performance of the 4-point kneeling exercises have been studied by several authors.[14-16,24-28] In these exercises, progression toward a greater challenge to core muscle control is achieved when subjects are asked to raise[16] one of their upper limbs or one of their contralateral lower limbs, or both.

Although knee stretch Pilates exercises may be an alternative method for developing dynamic control of the stabilizing trunk muscles, little investigation about them has been reported in the scientific literature.[21,22] These exercises are intended to bring the same benefits as traditional 4-point kneeling exercises, and

List of Abbreviations

MVIC	maximal voluntary isometric contraction
SEMG	surface electromyography

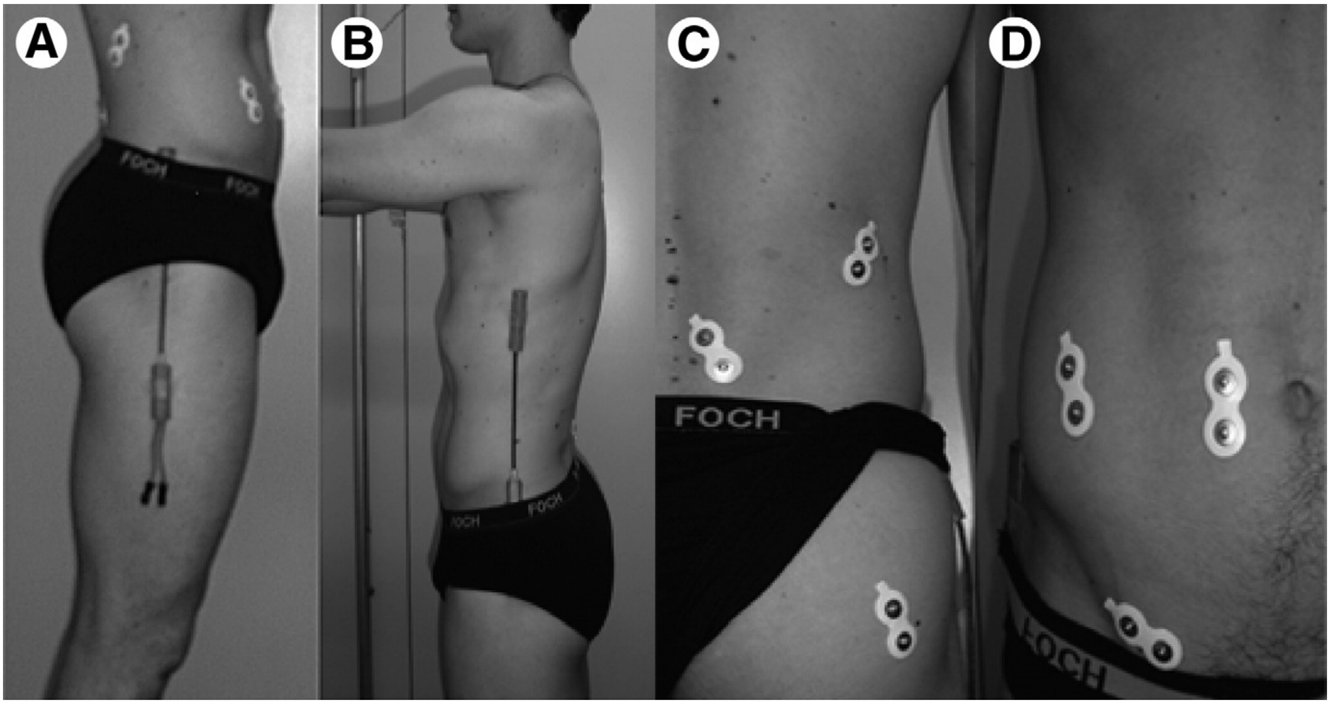

Fig 1. Hip (A) and pelvic (B) electrogoniometer positions in 1 volunteer. Bipolar surface electromyographic electrode arrangement over (C) gluteus maximus, multifidus, and iliocostalis muscles; (D) internal oblique, external oblique, and rectus abdominis muscles.

progression toward a greater challenge to core muscle control is achieved by modifying pelvic and trunk postures, not by changing the upper and lower limbs' support to the ground as the traditional exercise does. These Pilates exercises are performed pushing (in the hip extension phase) and resisting (in the hip flexion phase) the 2 springs fixed in the reformer's carriage. These springs give an extra challenge to the muscles' control of the trunk and lower limbs, which may be useful for the rehabilitative process.[5,20,21]

The purpose of this study was to evaluate and to compare the activation patterns of the trunk flexors and extensors and hip muscles in 4 variations of the Pilates knee stretch exercises: retroverted pelvis (posterior pelvic tilt) with flexed trunk; anteverted pelvis (anterior pelvic tilt) with extended trunk; neutral pelvis with trunk inclined relative to the ground; and neutral pelvis with trunk parallel to the ground. We hypothesized that the changes in pelvic and trunk positions would produce different muscle activation patterns and that these different patterns could guide the choice of exercises throughout the rehabilitation process.

METHODS

Participants

Nineteen Pilates instructors and ballet dancers who had been practicing Pilates exercises for at least 6 months with a minimum of 1 class per week (a total of 24 sessions) were evaluated (12 women, 7 men; mean age ± SD, 31±5y; mean weight ± SD, 60±11kg; mean height ± SD, 166±9cm). Their experience in Pilates was 3±2 years. Subjects were excluded if they had reported lumbar pain in the past 2 years that had lasted more than 7 days, pain or disability in the upper or lower limbs, prior lower back or abdominal surgery, or neuromuscular disorders, or if they were found to have scoliosis, lower limb discrepancy, or postural asymmetries. Informed written consent was provided by the subjects, and the research protocol was approved by the local ethics committee (Protocol: 5067/07).

Data Recording

SEMG signals of the iliocostalis, lumbar multifidus, gluteus maximus, rectus abdominis, and external and internal oblique muscles were unilaterally recorded on the right side of the body in both phases, hip extension and flexion, of the 4 exercises.

Disposable silver–silver chloride circular bipolar electrodes[a] were used with an interelectrode distance of 20mm. The signal was preamplified at the electrode location 20 times and sent to an amplifier[a] that had a gain factor of 50, achieving a gain of 1000 for the SEMG signal.

Skin at the electrode fixation sites was abraded with alcohol gauze and the electrode fixation was reinforced with transparent tape. The electrodes were placed over the following muscles (figs 1C and 1D) iliocostalis, 1 finger width medial from the line from the posterior superior iliac spine to the lowest point of the lower rib, at the level of L2[29]; lumbar multifidus, on a line from the caudal tip of the posterior superior iliac spine to the interspace between L1 and L2, at the level of the L5 spinous process[29]; gluteus maximus, on the midline between the sacral vertebrae and the greater trochanter, over the greatest prominence of the middle of the buttocks[29]; rectus abdominis, 2cm lateral to the umbilicus[30]; external oblique, above the anterior superior iliac spine at the level of the umbilicus[10]; and internal oblique, 2cm inferomedial to the anterior superior iliac spine within a triangle outlined by the inguinal ligament, the lateral border of the rectus sheath, and a line connecting the anterior superior iliac spines[10]. The ground electrode was placed over the left anterior superior iliac spine.

Two biaxial electrogoniometers instrumented with strain gauge[b] were used to monitor the hip and lumbar-pelvic angle

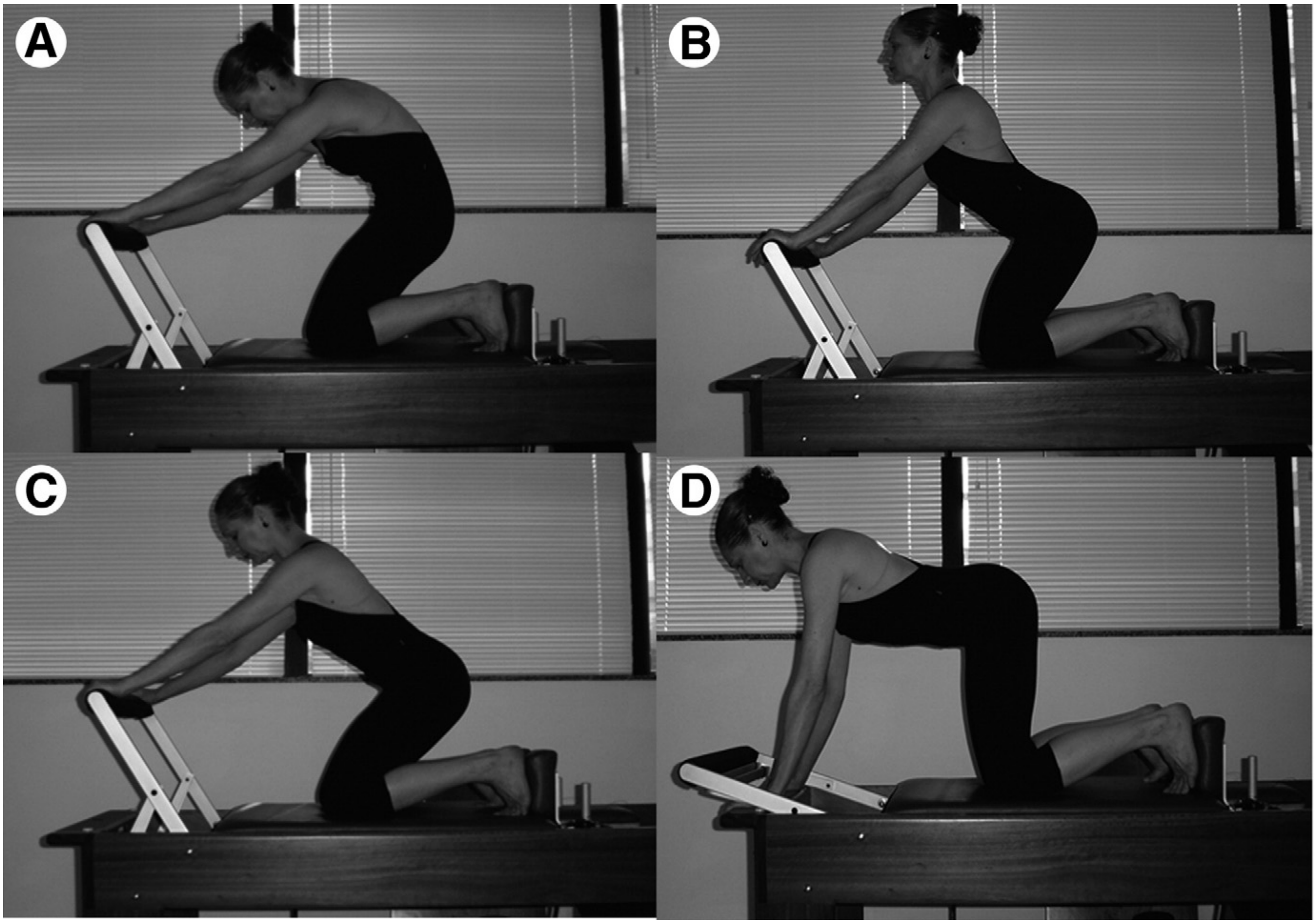

Fig 2. Knee stretch exercises. (A) Retroverted pelvis with flexed trunk. (B) Anteverted pelvis with extended trunk. (C) Neutral pelvis with trunk inclined in relation to the ground. (D) Neutral pelvis with trunk parallel to the ground.

displacement during all exercises. The hip electrogoniometer was fixed with the proximal endblock to the side of the trunk, in the pelvic region, and the distal endblock to the thigh so the axes of the thigh and the endblock coincided (fig 1A).[31] The distal endblock of the lumbar-pelvic electrogoniometer was fixed over the left iliac crest, and the proximal endblock was fixed over the midline of the floating ribs so that the axes of the endblocks and the midaxillary line coincided (fig 1B).[31]

For normalization purposes, before the performance of the exercises, 4 seconds of electromyographic data were recorded for each muscle while the subjects performed MVICs against manual resistance. The highest mean value during 500ms from the 2 central seconds window from 2 trials of each muscle was chosen as the representative MVIC. For iliocostalis and lumbar multifidus muscles, trunk extension was performed in a prone position, with the lower limbs restrained and maximum resistance applied to the upper back.[29] For the gluteus maximus muscle, in a prone position, the right lower limb was extended and lifted against maximum resistance applied to the distal leg.[29] For the rectus abdominis muscle, the upper trunk was maximally flexed (ie, curl-up position) with maximum resistance applied to the shoulders in the trunk extension direction, with knees flexed 90° and feet restrained.[10] For the external and internal oblique muscles, the trunk was maximally flexed and rotated to the left and to the right side, with maximum resistance at the shoulders in the opposite direction of rotation, in a supine position, with knees flexed 90° and feet restrained.[10]

Exercise Procedures

The exercises were performed in the reformer[c] apparatus, which consists of a sliding platform with attached resistive springs on which the subject stood in a quadruped position. Hip extension moves the carriage backwards against the spring's resistance, which offers a pull that should be resisted in the hip flexion phase. The subjects were instructed to keep breathing normally and to keep a pace of 50 beats/min, as measured by a metronome. This pace was adopted because it matched the pace in which the subjects usually performed these exercises and was the most comfortable to their expertise. Hip extension achieved by all subjects for all exercises was approximately 50°±5°, except for the exercise with the pelvis in retroversion and the trunk in flexion, in which hip extension was approximately 33°±11° for all subjects.

The knee stretch exercises were performed in 4 ways: (1) with the subject's trunk inclined to the ground, with a retroverted pelvis (posterior pelvic tilt) and flexed trunk (fig 2A); (2) with an anteverted pelvis (anterior pelvic tilt) and extended trunk (fig 2B); (3) with the pelvis in a neutral position and the trunk inclined relative to the ground (fig 2C); and (4) with the pelvis in a neutral position and the trunk parallel to the ground (fig 2D).

The anteverted pelvic position was determined when the subject was in a quadruped position in a bathing suit, and the subject was asked to perform the maximal pelvic anteversion

Table 1: Normalized Root Mean Square Values (% MVIC) of the Knee Stretch Exercises in the Hip Extension and Flexion Phases, and *P* Values From Interexercise Comparisons*

Muscle	Phase	RPFT	APET	NPTI	NPTP	*P*
Multifidus	Extension	17.92±11.60	38.85±17.70	29.55±16.05	22.70±13.93	.001
	Flexion	9.95±7.47	34.22±17.94	25.06±17.79	24.90±18.06	
Gluteus maximus	Extension	40.89±26.50	17.81±10.98	17.59±14.26	13.62±11.49	.001
	Flexion	28.34±18.83	11.05±9.74	10.74±8.76	7.93±7.66	
Rectus abdominis	Extension	10.40±9.21	7.90±4.47	8.94±7.91	6.95±4.33	.013
	Flexion	11.26±10.08	7.39±7.14	6.82±6.15	5.82±4.27	
External oblique	Extension	43.00±40.21	32.00±24.28	29.67±24.74	27.07±17.33	.004
	Flexion	47.37±45.82	23.56±17.90	26.50±23.07	21.63±13.04	
Internal oblique	Extension	33.19±14.85	32.73±21.86	24.02±16.60	25.24±14.75	.018
	Flexion	39.82±28.72	30.22±22.72	28.08±22.61	27.83±25.25	
Iliocostalis	Extension	20.23±17.64	20.53±15.57	18.30±16.37	17.01±15.84	.160
	Flexion	14.40±12.63	22.28±18.57	12.88±8.98	15.94±12.31	

NOTE. Values are mean ± SD. The *P* values represent results of testing with analysis of variance.
Abbreviations: APET, anteverted pelvis with extended trunk; NPTI, neutral pelvis with trunk inclined relative to the ground; NPTP, neutral pelvis with trunk parallel to the ground; RPFT, retroverted pelvis with flexed trunk.
*Post hoc Honestly Significant Difference Tukey.

that would be possible to maintain during the exercise. The same procedure was followed for pelvic retroversion. The neutral pelvic position was determined when the subject was in a stand-up position in a bathing suit, and, under visual inspection, the examiner aligned both anterior superior iliac spines in the same horizontal plane and aligned these spines with the pubic symphysis in the same frontal plane.[32]

During the performance of each exercise, the examiner provided verbal feedback about the pelvic position based on the online electrogoniometer angular displacement. During the anteverted pelvis and extended trunk exercise, trunk inclined relative to the ground exercise, and trunk parallel to the ground exercise, 10° of pelvic angular displacement was accepted. During the retroverted pelvis and flexed trunk exercise, 25° was accepted because the subjects could not maintain the retroverted pelvic position during hip extension. The position of posterior pelvic tilt implies that the hip is already extended in the beginning of this exercise; consequently, the exercise's range of motion is performed with the aid of the lumbar spine movement.

Twelve valid repetitions of each exercise variation were performed to reduce variability. The exercises were performed in the following order: the neutral pelvic exercises initiated the sequence in a random order (trunk inclined relative to the ground exercise and trunk parallel to the ground exercise); after that, the retroverted pelvis and flexed trunk exercise and the anteverted pelvis and extended trunk exercise were performed in a random order.

Data Analysis

The SEMG and electrogoniometer signals were acquired and synchronized by a 12 bits analog-to-digital converter[d] at a sampling rate of 2kHz.

In a custom-written Matlab[e] function, hip angular displacement was used to determine the hip extension and flexion phases in the electromyographic signal. The raw electromyographic signal for each phase of each exercise was digitally band-pass filtered (10–500Hz), full-wave rectified, and normalized by the MVIC. From each one of these intervals, the root mean square value was calculated and expressed as a percentage of an MVIC. Each exercise and muscle was represented by the mean value of 12 cycles per subject.

Statistical Analysis

After confirming the normal distribution of data (Kolmogorov-Smirnov test) and homogeneity of variances (Levene's test), the exercises and phases were compared using a 2-way analysis of variance for repeated measures (2 × 4), for 2 phases, hip extension and flexion, and for the 4 exercise variations, followed by the Honestly Significant Difference Tukey post hoc test (α=.05).

RESULTS

There was significant interaction between exercise variations and movement phases for the activity of the lumbar multifidus (P=.001), gluteus maximus (P=.001), rectus abdominis (P=.013), and external (P=.004) and internal oblique (P=.018) muscles (table 1). There was no significant effect between either exercises or phases for the iliocostalis (see table 1).

The multifidus muscle presented significantly higher activity (P<.001) in the anteverted pelvis and extended trunk exercise compared with the other exercises during both extension and flexion phases. This muscle also showed significantly higher activity (P<.001) in the neutral pelvis with trunk inclined relative to the ground exercise compared with the exercise with retroverted pelvis and flexed trunk in both phases, and compared with the exercise with neutral pelvis with trunk parallel to the ground (P<.05) in the hip extension phase. During the retroverted pelvis and flexed trunk exercise, multifidus activity was higher during the hip extension phase compared with the flexion phase (P<.05).

Gluteus maximus activity was significantly higher (P<.001) in the retroverted pelvis and flexed trunk exercise compared with the other exercises during both phases. Activity was higher in this muscle in the hip extension phase when compared with the flexion phase during all exercises (retroverted pelvis and flexed trunk, P<.001; anteverted pelvis and extended trunk, P<.001; neutral pelvis with trunk inclined relative to the ground, P<.05; and neutral pelvis with trunk parallel to the ground, P<.05).

Rectus abdominis activity was significantly higher in the retroverted pelvis with flexed trunk exercise when compared with the anteverted pelvis and extended trunk exercise (P<.05) and the neutral pelvis and trunk parallel to the ground exercise

($P<.001$) during both phases. In the retroverted pelvis with flexed trunk exercise, the rectus abdominis activity was also significantly higher ($P<.001$) when compared with the neutral pelvis and trunk inclined relative to the ground exercise during the hip flexion phase. There was no significant difference between both phases during all exercises.

Compared with the other exercises during both phases, the external oblique muscle showed significantly higher activity ($P<.001$) in the retroverted pelvis with flexed trunk exercise. Its activity was higher in the anteverted pelvis and extended trunk exercise during the hip extension phase compared with the flexion phase ($P<.05$).

The internal oblique demonstrated significantly higher activity ($P<.001$) in the retroverted pelvis and flexed trunk exercise when compared with the neutral pelvis exercises (trunk inclined relative to the ground exercise and trunk parallel to the ground exercise) during both phases and compared with the anteverted pelvis and extended trunk in the flexion phase. Activity in this muscle was also significantly higher ($P<.001$) in the anteverted pelvis with extended trunk exercise compared with both exercises in neutral pelvis in the extension phase. Internal oblique muscle activity was higher in the exercise with retroverted pelvis and flexed trunk during the flexion phase compared with the extension phase ($P<.001$).

DISCUSSION

The purpose of this study was to compare the activation patterns of the trunk flexors and extensors and hip muscles during 4 different Pilates knee stretch exercises with pelvic and trunk posture variations. The results showed evidence to support our initial hypotheses that the proposed trunk and pelvic position variations would alter the activation of the multifidus, gluteus maximus, rectus abdominis, and oblique muscles, although our results did not confirm the positions' influence on the iliocostalis muscle. Pelvic retroversion and trunk flexion consistently increased external oblique and gluteus maximus muscle activity but, in comparison with the other trunk and pelvis positions, decreased multifidus muscle activity. Also, rectus abdominis muscle activity was generally higher in this position of pelvis retroversion and trunk flexed. Multifidus activity increased substantially during trunk extension and pelvis anteversion. Particularly, the neutral pelvis posture with trunk parallel to the ground promoted activity of the gluteus maximus, rectus abdominis, and oblique muscles to a lesser degree compared with the other pelvis and trunk positions.

Based on anatomic architectural analysis and intraoperative measurements, Ward,[33] Rosatelli,[34] and Bojadsen[35] and colleagues proposed that the multifidus muscle is an important lumbar extensor and a key muscle for lumbar stability. Arokoski et al[25] reported that the lumbar multifidus is activated for 34% of the MVIC during dynamic Roman chair–type extension exercise. We also observed high extensor activity of the multifidus muscle of about 39% of the MVIC in the anteverted pelvis with extended trunk exercise. In the Roman chair–type exercise, one's pelvis and lower limbs are supported although the trunk is not. On the other hand, in the knee stretch exercises, one's limbs are symmetrically supported, which may be an advantage to therapeutic intervention strategies.

Changes in pelvic position from retroversion (retroverted pelvis and flexed trunk) to neutral (with trunk inclined relative to the ground), and changes from neutral pelvis to anteverted pelvis with trunk extended promoted a significant increase in multifidus activity, from 18% to 39% of the MVIC, particularly in the hip extension phase. From all these results, we suggest that the multifidus activity is related to the increased trunk extension and to movement from retroverted to neutral, and from neutral to anteverted pelvis, consistent with its role as a local muscle (ie, responsible for the control of the curvature and sagittal stiffness of the lumbar spine) in Bergmark's theory.[36] In the retroverted pelvis and flexed trunk exercise, the multifidus muscle is elongated because of the trunk flexion and retroverted pelvis, which may be responsible for its lower activity.

Concerns about the association between gluteus maximus muscle dysfunction and chronic low back pain led Rydeard et al[22] to propose therapeutic use of the Pilates exercises in a neutral pelvis position, including the knee stretch exercise in the reformer apparatus. These authors suggested the addition of exercises out of the neutral pelvis for treatment progression. The knee stretch exercise in the neutral pelvis position and trunk parallel to the ground may be recommended for a gluteus maximus activation between 7% and 17% of the MVIC. The knee stretch exercise in the retroverted pelvis position and flexed trunk could increase gluteus maximus activity up to 40% of the MVIC. However, animal studies support the notion that disk herniation may be caused by repeated flexion motions,[37,38] and the range of motion of this exercise is performed through a greater pelvic movement (25°) than in the other knee stretch variations (10°). Therefore, in the Pilates method, other exercises than the retroverted pelvis and flexed trunk exercise should be studied for an increase in gluteus maximus activity from a therapeutic point of view.

The knee stretch variations with neutral pelvis and the exercise with anteverted pelvis and extended trunk did not promote significant changes in rectus abdominis muscle activity, which was below 9% of the MVIC. Similarly, Stevens et al[14] found a constant level of activity of the rectus abdominis muscles, below 5% of the MVIC, during changes in position of the upper and lower limbs during a traditional quadruped exercise. According to McGill,[7,39] the rectus abdominis muscle is the main trunk flexor. In addition, the rectus abdominis fascial sheath is an important force transmitter from the lateral obliques and an "anchor" to these muscles. The exercise with retroverted pelvis and extended trunk indeed demonstrated a significantly higher activity of the rectus abdominis muscle, although it was not of a high intensity (11% of the MVIC).

The results of the present study suggest that the multifidus and oblique muscles are more involved with changes in the position of the pelvis and trunk (with maximum activity of 39% of the MVIC in the anteverted pelvis exercise and 47% of the MVIC in the retroverted pelvis exercise, respectively), while the rectus abdominis muscle is mainly responsible for pelvic stability in all knee stretch exercises and for control of the extensor torque generated by hip extension on the sliding platform of the reformer.

Urquhart et al[40] demonstrated that, compared with the contraction effort of the abdominal muscles in a neutral pelvis position, abdominal exercises with a posterior pelvic tilt, similar to the retroverted pelvis and flexed trunk exercises, promoted predominant activity of the external oblique muscles. In the same way, in the results of the present study, we observed increased external oblique muscle activity with the position change from neutral to retroverted pelvis (27% to 43% of the MVIC in the extension phase). However, a simultaneous increase in internal oblique muscle activity was also observed (25% to 33% of the MVIC in the extension phase). This fact suggests that these 2 muscles perform in a synergistic way to keep the retroverted pelvis with flexed trunk.

We, however, observed high internal oblique muscle activity both in the knee stretch exercises with anterior and posterior pelvic tilt (32% and 33% of the MVIC, respectively) in comparison with the exercises with neutral pelvis, in the extension phase. The external oblique muscle is more active with the exercise with posterior pelvic tilt and flexed trunk solely. A possible explanation for this difference in oblique muscles activity is that the internal oblique activity could be more active to restrain pelvic position against the hip extensor momentum in the anteverted pelvis with extended trunk exercise. Therefore, the internal oblique muscle could have a greater role in controlling pelvic position than the external oblique muscle.

According to McGill,[7] activation of about 10% of MVIC or even less of the trunk muscles is sufficient for stability purposes, considering activities of daily living. The knee stretch exercises promoted activity well above this value for most of the muscles studied, except for the rectus abdominis muscle. It should also be observed that muscle activities during these exercises are above the intensities reported in several quadruped exercise studies[14,27,41] where the rectus abdominis muscle intensity was below 5% of the MVIC.

The knee stretch exercises with neutral pelvis could be indicated for stabilization purposes in the initial phase of the rehabilitation process and also from the point of view of motor control, maintenance of pelvic position, and dissociation between pelvic position and hip movement. The knee stretch exercise with anteverted pelvis and extended trunk could also be recommended for stabilization purposes, to challenge the multifidus and internal oblique muscles' training action, in addition to the dissociation between pelvic position and hip movement.

Repeated extension has been used by manual therapists to assist in returning displaced portions of a herniated disk back to its center, following the McKenzie approach.[42] Based on an animal model, Scannel and McGill[38] found scientific basis to support this practice. It may open the possibility that the knee stretch exercise with anteverted pelvis and extended trunk could help with the centralization of prolapsed disks in addition to its function as a stabilization and multifidus muscle strengthening exercise.

Further studies conducted with patients with lumbar dysfunctions should be done to determine whether the present results would be the same and contribute to a further discussion about the rehabilitation implications of the muscle patterns of activation.

In the traditional 4-point kneeling exercise, extending one lower limb and raising the contralateral upper limb challenge the ability of the extensor muscle to maintain control and produce force, although in an asymmetric way.[16,24-27,43-45] This modification also increases the compressive and shear forces over L4 to L5,[24,28] which may not be recommended for some stages of the rehabilitative process. Knee stretch exercises may increase extensor action in a more symmetric way because of the symmetrical support of the limbs on the ground. In addition, it may be possible to better control the intensity of the compression and shear forces in the lumbar vertebrae as a result of controlled hip extension movements when the subject resists the sliding platform in the reformer. However, confirming these hypotheses will be possible only with studies that evaluate bilateral muscle activity and the lumbar compression and shear forces.

CONCLUSIONS

Variations in the pelvic and trunk positions in the knee stretch exercises change the activation pattern of the multifidus, gluteus maximus, rectus abdominis, and oblique muscles. The lower level of activation of the rectus abdominis muscle suggests that pelvic stability is maintained in the 4 exercise positions.

The neutral pelvis position with the trunk parallel to the ground promotes multifidus, gluteus maximus, and oblique muscle activity from 8% to 28% of the MVIC.

In the anteverted pelvic position with extended trunk, multifidus muscle activity was increased, consistent with this muscle's role as an important lumbar extensor.

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References

1. Pilates JH. The complete writings of Joseph H. Pilates. Philadelphia: BainBridge Books; 2000.
2. Latey P. The Pilates method: history and philosophy. J Bodyw Mov Ther 2001;5:275-82.
3. Muscolino JE, Cipriani C. Pilates and the "powerhouse"-I. J Bodyw Mov Ther 2004;8:15-24.
4. Hutchinson MR, Tremain L, Christiansen J, Beitzel J. Improving leaping ability in elite rhythmic gymnasts. Med Sci Sports Exerc 1998;30:1543-7.
5. Self BP, Bagley AM, Triplett TL, Paulos LE. Functional biomechanical analysis of the Pilates-based reformer during demi-plie movements. J Appl Biomech 1996;12:326-37.
6. McGill SM, Cholewicki J. Biomechanical basis for stability: an explanation to enhance clinical utility. J Orthop Sports Phys Ther 2001;31:96-100.
7. McGill SM. Low back disorders: evidence-based prevention and rehabilitation. 2nd ed. Champaign: Human Kinetics; 2007.
8. McGill SM, Karpowicz A. Exercises for spine stabilization: motion/motor patterns, stability progressions, and clinical technique. Arch Phys Med Rehabil 2009;90:118-26.
9. Axler CT, McGill SM. Low back loads over a variety of abdominal exercises: searching for the safest abdominal challenge. Med Sci Sports Exerc 1997;29:804-11.
10. Escamilla RF, Babb E, DeWitt R, et al. Electromyographic analysis of traditional and nontraditional abdominal exercises: implications for rehabilitation and training. Phys Ther 2006; 86:656-71.
11. Akuthota V, Nadler SF. Core strengthening. Arch Phys Med Rehabil 2004;85:S86-92.
12. Saal JA, Saal JS. Nonoperative treatment of herniated lumbar intervertebral disc with radiculopathy. An outcome study. Spine 1989;14:431-7.
13. Richardson CA, Jull GA. Muscle control–pain control. What exercises would you prescribe? Man Ther 1995;1:2-10.
14. Stevens VK, Vleeming A, Bouche KG, Mahieu NN, Vanderstraeten GG, Danneels LA. Electromyographic activity of trunk and hip muscles during stabilization exercises in four-point kneeling in healthy volunteers. Eur Spine J 2007;16:711-8.
15. Gill KP, Callaghan MJ. The measurement of lumbar proprioception in individuals with and without low back pain. Spine 1998; 23:371-7.
16. Stevens VK, Coorevits PL, Bouche KG, Mahieu NN, Vanderstraeten GG, Danneels LA. The influence of specific training on trunk muscle recruitment patterns in healthy subjects during stabilization exercises. Man Ther 2007;12:271-9.
17. Lee D. The pelvic girdle. 3rd ed. Edinburgh: Churchill Livingstone; 2005.
18. Beith ID, Synnott RE, Newman SA. Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone positions. Man Ther 2001;6:82-7.
19. Liekens B. The Pilates studio teacher training manual: part I. New York: The Pilates Studio; 1997.
20. Anderson B, editor. Polestar Pilates advanced spine. Salvador: Polestar Education; 2004.

21. Anderson B, Spector A. Introduction to Pilates-based rehabilitation. Orthop Phys Ther Clin N Am 2000;9:395-410.
22. Rydeard R, Leger A, Smith D. Pilates-based therapeutic exercise: effect on subjects with nonspecific chronic low back pain and functional disability: a randomized controlled trial. J Orthop Sports Phys Ther 2006;36:472-84.
23. King B, Gentry E. Physicalmind encyclopedia: the universal reformer. Santa Fe: Physicalmind Institute; 1992.
24. Kavcic N, Grenier S, McGill SM. Quantifying tissue loads and spine stability while performing commonly prescribed low back stabilization exercises. Spine 2004;29:2319-29.
25. Arokoski JP, Kankaanpaa M, Valta T, et al. Back and hip extensor muscle function during therapeutic exercises. Arch Phys Med Rehabil 1999;80:842-50.
26. Koumantakis GA, Oldham JA, Winstanley J. Intermittent isometric fatigue study of the lumbar multifidus muscle in four-point kneeling: an intra-rater reliability investigation. Man Ther 2001; 6:97-105.
27. Souza GM, Baker LL, Powers CM. Electromyographic activity of selected trunk muscles during dynamic spine stabilization exercises. Arch Phys Med Rehabil 2001;82:1551-7.
28. Drake JD, Fischer SL, Brown SH, Callaghan JP. Do exercise balls provide a training advantage for trunk extensor exercises? A biomechanical evaluation. J Manipulative Physiol Ther 2006;29: 354-62.
29. SENIAM. Project 2005. Available at: http://www.seniam.org. Accessed April 3, 2009.
30. Grenier SG, McGill SM. Quantification of lumbar stability by using 2 different abdominal activation strategies. Arch Phys Med Rehabil 2007;88:54-62.
31. Goniometer and torsiometer operating manual. Gwent: Biometrics Ltd; 2002.
32. Kendall FP, McCreary EK, Provance PG. Músculos provas e funções. 4th ed. São Paulo: Editora Manole; 1995.
33. Ward SR, Kim CW, Eng CM, et al. Architectural analysis and intraoperative measurements demonstrate the unique design of the multifidus muscle for lumbar spine stability. J Bone Joint Surg Am 2009;91:176-85.
34. Rosatelli AL, Ravichandiran K, Agur AM. Three-dimensional study of the musculotendinous architecture of lumbar multifidus and its functional implications. Clin Anat 2008;21:539-46.
35. Bojadsen TW, Silva ES, Rodrigues AJ, Amadio AC. Comparative study of Mm. multifidi in lumbar and thoracic spine. J Electromyogr Kinesiol 2000;10:143-9.
36. Bergmark A. Stability of the lumbar spine. A study in mechanical engineering. Acta Orthop Scand Suppl 1989;230:1-54.
37. Callaghan JP, McGill SM. Intervertebral disc herniation: studies on a porcine model exposed to highly repetitive flexion/extension motion with compressive force. Clin Biomech (Bristol, Avon) 2001;16:28-37.
38. Scannell JP, McGill SM. Disc prolapse: evidence of reversal with repeated extension. Spine (Phila PA 1976) 2009;34:344-50.
39. McGill SM. A revised anatomical model of the abdominal musculature for torso flexion efforts. J Biomech 1996;29:973-7.
40. Urquhart DM, Hodges PW, Allen TJ, Story IH. Abdominal muscle recruitment during a range of voluntary exercises. Man Ther 2005;10:144-53.
41. Marshall PW, Murphy BA. Core stability exercises on and off a Swiss ball. Arch Phys Med Rehabil 2005;86:242-9.
42. Clare HA, Adams R, Maher CG. Construct validity of lumbar extension measures in McKenzie's derangement syndrome. Man Ther 2007;12:328-34.
43. Callaghan JP, Gunning JL, McGill SM. The relationship between lumbar spine load and muscle activity during extensor exercises. Phys Ther 1998;78:8-18.
44. McGill SM. Low back exercises: evidence for improving exercise regimens. Phys Ther 1998;78:754-65.
45. Kavcic N, Grenier S, McGill SM. Determining the stabilizing role of individual torso muscles during rehabilitation exercises. Spine 2004;29:1254-65.

Suppliers

a. EMG800C model; EMG System do Brasil Ltda, Rua Porto Príncipe, 50, São José dos Campos, 12245-572, SP, Brazil.
b. Electrogoniometers model SG 150; Biometrics Ltd, Cwmfelinfach, Gwent, NP11, 7HZ, UK.
c. Equipment reformer from Physio Pilates; Physioaligned Indústria e Comércio Ltda, Av Barros Reis, 1703, Retiro, Salvador 40330-620, BA, Brazil.
d. Card A/D DT3002; AMTI—Advanced Mechanical Technology, Inc, 176 Waltham St, Watertown, MA 02172.
e. Matlab software version 7.6; MathWorks, 3 Apple Hill Dr, Natick, MA 01760.