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Transversus Abdominis and Obliquus Internus Activity During Pilates Exercises: Measurement With Ultrasound Scanning

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Abstract

Endleman I, Critchley DJ. Transversus abdominis and obliquus internus activity during Pilates exercises: measurement with ultrasound scanning.

Objective

To assess activity of transversus abdominis (TrA) and obliquus internus abdominis (OI) muscles during classical Pilates exercises performed correctly and incorrectly, and with or without equipment.

Design

Repeated-measures descriptive study.

Setting

Pilates studio.

Participants

A volunteer sample of women (n=18) and men (n=8), mean age ± SD (43±14y), with more than 6 months classical Pilates training and no back pain or other condition likely to influence abdominal muscle activity.

Interventions

Participants performed Pilates imprint, hundreds A and B, roll-up, and leg-circle exercises on a mat. The hundreds exercise was also performed on a reformer (sliding platform). Mat imprint and hundreds exercises were instructed to be performed correctly (with abdominal drawing-in) or incorrectly (without drawing-in).

Main Outcome Measure

Thickness of TrA and OI middle fibers measured with ultrasound imaging.

Results

TrA thickness increased during the mat imprint, hundreds A, hundreds B, leg-circle, and roll-up exercises (all P=.001) compared with resting. OI thickness increased during the mat imprint, hundreds A, hundreds B, leg-circle (all P=.001), and roll-up exercises (P=.002) compared with resting. TrA thickness during reformer hundreds B was greater than during mat hundreds B (P=.011); OI thicknesses were not different for this comparison. During incorrect imprint, neither TrA or OI thicknesses were different to resting. TrA and OI muscle thicknesses were moderately correlated (R=.410; P=.001).

Conclusions

This study provides the first evidence that a selection of classic Pilates exercises activates TrA and OI. Use of the reformer exercise machine can result in greater TrA activation in some exercises. TrA and OI did not function independently during these exercises. Research into the training effects of Pilates or in patient populations can be undertaken using ultrasonography in submaximal exercises.

Key Words: Abdominal muscles, Exercise, Rehabilitation, Ultrasonography

List of Abbreviations: ANOVA, analysis of variance, EMG, electromyographic, ICC, intraclass correlation coefficients, MVC, maximum voluntary contraction, OI, obliquus internus abdominis, TrA, transversus abdominis

THE EXERCISE REGIMEN known as pilates, founded on the teachings of Joseph Pilates (1880–1967), has become a popular choice for people seeking conditioning and rehabilitation; devotees in the United States increased 1000-fold between 1990 and 2000.[1] Pilates advocates claim the exercises involve activation of the transversus and obliquus internus abdominal muscles thought to stabilize the lumbar spine; hence Pilates has application in lumbo-pelvic pain rehabilitation and dance, sport, or athletic conditioning. This claim has had minimal formal investigation.[2]

There has been considerable recent interest in neuromuscular control of spinal motion in rehabilitation and conditioning. Models of trunk muscle function developed from Bergmark's[3] classification of local muscles, such as TrA,[4, 5] attaching to the spine and global muscles, such as middle fibers of OI,[3] spanning the pelvis to ribs, stress the importance of TrA as a spinal stabilizer, and are influential in contemporary physical therapy and conditioning practice.[4, 6, 7, 8, 9, 10] Others, such as McGill et al,[11, 12, 13] do not employ this classification, and suggest all trunk muscles have a role in spinal stability.

Classic Pilates aims to improve health and well being with exercises that emphasize abdominal and low back muscle strengthening while maintaining good posture and body alignment.[14] Exercises are mat-based or use equipment, such as the reformer (fig 1; and see Methods: Materials), as assistive and/or resistive exercise tools.[14] It is claimed that Pilates exercises activate TrA and OI muscles[15, 16]; consequently, Pilates is advocated as a progression from spinal stabilization physical therapy (involving TrA retraining) as maintenance or preventative exercises for people with back pain.[7] To date, no published studies have evaluated TrA or OI muscle activity during Pilates exercises.

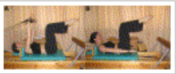

Fig 1.
(A) Reformer hundreds A and (B) reformer hundreds B.

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All classic Pilates exercises involve the imprint action, pulling the navel toward the spine. Pilates believed pulling in the abdomen in this way protected the spine.[14] The imprint action appears to be similar to the low abdominal drawing-in exercise used to activate TrA in spinal stabilization training.[10] It is recognized that many patients find low abdominal drawing-in difficult to learn even when taught by expert physical therapists.[10] With the widespread popularity of Pilates, there is variation in teaching standards, and there are differences in emphasis of the importance of the imprint action.[14, 15, 16] It is not known whether it is necessary to maintain the imprint action during exercises, according to classic Pilates principles, in order to activate TrA and OI muscles most effectively.

Ultrasound imaging has been used as a noninvasive tool for measuring abdominal muscle thickness change during respiration, abdominal muscle exercises, and gait.[17, 18, 19, 20, 21] Thickness change in TrA and OI has been shown to have good correlation with EMG activity up to 30% to 50% MVC,[22, 23] suggesting that thickness change is a valid measure of activity in these muscles at these levels of effort. Unfortunately, the relationship in obliquus externus abdominis is much weaker, and ultrasound-measured thickness change cannot be confidently used as a gauge of activity in this muscle.[22, 24]

The aims of the investigation were to evaluate the following hypotheses with ultrasound measurements of muscle thickness: (1) Pilates exercises performed by Pilates-trained healthy persons would result in greater activity in TrA and OI muscles than at rest. (2) Performing the exercises correctly, following classic Pilates principles of maintaining the imprint action, or drawn-in abdominal wall, would result in greater TrA and OI muscle activity than performing the same exercises incorrectly. (3) Using the Pilates reformer[a] equipment would result in greater TrA and OI muscle activity than when performing the same exercise on mats.

In addition, we evaluated the correlation of TrA and middle fibers of OI muscle activity during a range of exercises aimed at promoting trunk stability in order to investigate the degree of functional independence of these muscles.

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Methods

Participants

After we obtained ethical approval from the University College London Research Ethics Committee and written informed consent, 8 men and 18 women who had attended supervised classical Pilates sessions at least once a week for the previous 6 months were recruited from a Pilates studio. Potential participants were excluded if they were under 18 years old, had spinal or abdominal surgery at any time, had low back pain in the last 2 years, had visible scoliosis, had neuromuscular disorders, or were pregnant.

Materials

A portable ultrasound scanner[b] was used in B mode with a 7.5-MHz linear head. A Pilates reformer, a sliding platform on tracks set in a frame, was used for the equipment-based exercise (see fig 1). Participants can lie, sit, or stand on the sliding platform, which is free to move, thus providing a unidirectionally unstable base of support. Exercises are performed by moving the platform against spring resistance.

Procedures

Each participant's demographic data, height, and weight were recorded. All exercises were initially demonstrated by the researcher, a physical therapist who is also an experienced Pilates instructor. Exercises were conducted in random order over a 50-minute period to minimize possible fatigue effects. All testing took place in the studio of Pilates International, Highgate, London, UK.

Ultrasonography

The ultrasound machine was calibrated prior to data collection by comparing with metal phantoms of known dimensions. All subjects had their antero-lateral abdominal muscles imaged in a supine position initially, to familiarize the researcher with the participant's muscle topography and fascial landmarks that could be used to improve measurement reliability (fig 2). All stored images for measurement purposes were made with the transducer orientated antero-laterally with the midpoint of the transducer positioned midway between the iliac crest and the lowest rib along the anterior axillary line of the left abdomen. At this point, the middle fibers of TrA can be imaged simultaneously with the middle fibers of OI.[21] Care was taken to position the transducer perpendicularly to the abdominal wall at all times for optimal image clarity and increased accuracy of readings. Static views were stored using the freeze facility of the scanner timed to the end of exhalation[17]; the thickness of muscles was measured using the automatic calipers software of the scanner. All ultrasound scans were taken with the scanner head in the same position, using skin landmarks or an indelible pen to minimize repositioning error. Thicknesses of TrA and OI muscles were measured in resting supine position, during the following exercises, then repeated in resting supine position to assess short-term intratester reliability.

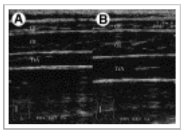

Fig 2.
Example ultrasound image of antero-lateral abdominal wall (A) at rest and (B) during imprint. OE, obliquus externus abdominis; OI, obliquus internus abdominis; TrA, transversus abdominis.

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Exercises

Muscle thickness ultrasound measurements were taken during the imprint (fig 3) abdominal draw-in action, the starting posture for all other classic Pilates exercises. After consultation with experienced classic Pilates instructors, a representative set of 3 classic Pilates mat exercises was chosen: the hundreds (fig 4), roll-up (fig 5), and leg-circle (fig 6). The exercises chosen employ the Pilates principles of breathing control and abdominal muscle control. They are included in every classical Pilates class and can be modified and progressed. The 3 exercises provided a variety of different ways of loading the abdominal muscles, such as through a raised leg (leg-circle), raised legs (hundreds A), raised legs and head (hundreds B), raised arms (roll-up A), and raised arms and trunk (roll-up B). Roll-up and hundreds are dynamic exercises, so measurements were taken at 2 stages of each of these exercises, described, for example, as hundreds A and hundreds B (see fig 4). The imprint action and hundreds exercises were performed with both correct and incorrect instructions (fig 7). The hundreds exercises were performed on the reformer (see fig 1) as well as on a mat.

Fig 3.
Mat imprint.

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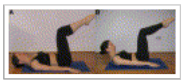

Fig 4.
(A) Mat hundreds A and (B) mat hundreds B.

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Fig 5.
(A) Roll-up A and (B) roll-up B.

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Fig 6.
Leg-circle.

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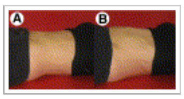

Fig 7.
(A) Correct imprint and (B) incorrect imprint.

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Although all participants were experienced students of classic Pilates and might be expected to know how to perform the exercises correctly, a standardized teaching protocol was followed for each exercise. Teaching correctly performed exercises emphasized imprinting, or maintaining a drawn-in abdomen during exercises, while breathing freely with a mobile rib cage. The phrases *scoop the belly* or *navel to spine* are used during exercises to reinforce this teaching. When teaching the incorrect exercises, participants were not corrected if their antero-lateral abdomen rose away from their spine. Participants who drew in their abdomen during incorrect exercises were instructed to push the abdominal muscles out and allow them to rise (see fig 7).

This was also demonstrated to them by the examiner. All teaching was conducted by a single Pilates instructor to ensure consistency.

Data Analysis

Repeated resting thickness measurements were compared with the methods described by Rankin and Stokes[25] using Bland and Altman plots and ICC. The correlation coefficient (R^2) indicates the extent to which the pairs of numbers for these 2 variables lie on a straight line. Distributions were checked to ensure that parametric assumptions were met. Muscle thicknesses of TrA and OI in all conditions were compared separately with repeated-measures 1-way ANOVAs in order to compare the effect of the 4 exercises with rest, between correctly and incorrectly performed exercises, and between exercise with and without equipment. In order to assess whether TrA and OI thicknesses were related, Pearson's correlation between the 2 muscle thicknesses was tested, and lines of best fit for 8 possible relationships were compared. Statistical significance was accepted at $P<.05$. Data were analyzed using SPSS 12.0.[c] All data are presented as means ± SDs unless otherwise stated.

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Results

Demographic Data

Participants had a mean ± SD age of 43±14 year old, weight of 62.3±9.1kg, 1.70±0.74m tall, 21.7±2.8kg/m^2 body mass index and had practiced Pilates for 8.2±7.2 years, ranging from 6 months to 25 years.

Repeatability

Visual inspection of Bland and Altman plots suggested no systematic differences between the 2 ultrasound measurements for either resting muscle. ICCs were .82 and .91 for TrA and OI, respectively. These results suggest that there is good short-term intraoperator repeatability for either resting muscle thickness measurement using ultrasound imaging.

Comparisons of Muscle Thickness During Exercise and Rest

Both muscles increased in thickness during all correctly performed exercises compared with at rest (hypothesis 1). There were significant differences between all exercises in both TrA ($P<.001$) and OI ($P<.001$) thickness, assessed with measures repeated 1-way ANOVAs (Table 1, Table 2; fig 8).

Table 1. Pairwise Comparisons of Transversus Abdominis Thickness (mm) Between Different Pilates Exercises

		Mean Difference ± SE									
		Rest	Imprint	Imprint Incorrect	Hundreds A	Hundreds A Incorrect	Hundreds B	Hundreds B Incorrect	Roll-Up A	Roll-Up B	L C
	Rest		2.66±0.25 *	0.38±0.22 *	4.90±0.54 *	5.57±0.61 *	4.05±0.41 *	4.78±0.69 *	2.68±0.39 *	4.72±0.49 *	4. *
P	Imprint	.000 *		2.28±0.26 *	2.24±0.57	2.91±0.64	1.39±0.50	2.12±0.71	0.02±0.49	2.06±0 .57	1.
	Imprint incorrect	.096	.000*		4.52±0.54	5.19±0.56	3.67±0.40	4.40±0.64	2.30±0.41	4.34±0 .46	4.
	Hundreds A	.000 *	.001	.000		0.67±0.42 *	0.85±0.35	0.12±0.58	2.22±0.41	0.18±0.46	0.
	Hundreds A incorrect	.000	.000	.000	.124*		1.52±0.41	0.79±0.34	2.88±0.55	0.85±0.47	1.
	Hundreds B	.000 *	.010	.000	.022	.001		0.73±0.59 *	1.37±0.41	0.67±0.40	0.
	Hundreds B incorrect	.000	.006	.000	.838	.030	.225*		2.10±0.68	0.06±0.62	0.
	Roll-up A	.000 *	.962	.000	.000	.000	.003	.005		2.03±0.44	1.
	Roll-up B	.000 *	.001	.000	.699	.080	.103	.922	.000		0.
	Leg-circle	.000 *	.005	.000	.150	.016	.253	.527	.001	.440	
	Hundreds A reformer	.000 *	.000	.000	.299*	.675	.002	.313	.000	.211	.0
	Hundreds B reformer	.000 *	.000	.000	.491	.592	.011*	.452	.000	.390	.1

NOTE. Upper right, means ± SEs of differences between thickness; lower left, their associated *P* values.

*Test of a priori hypothesis.

Table 2. Pairwise Comparisons of Obliquus Internus Abdominis Thickness (mm) Between Different Pilates Exercises

		Mean Difference ± SE									
		Rest	Imprint	Imprint Incorrect	Hundreds A	Hundreds A Incorrect	Hundreds B	Hundreds B Incorrect	Roll-up A	Roll-up B	L C
	Rest		2.00±0.31 *	0.71±0.53	2.07±0.44 *	1.08±0.52 *	4.00±0.53 *	1.82±0.75	1.11±0.32 *	5.80±0.75 *	1. *
P	Imprint	.000 *		1.29±0.52 *	0.07±0.52	0.92±0.55	2.00±0.55	0.18±0.82	0.89±0.30	3.80±0 .74	0.
	Imprint incorrect	.192	.019*		1.35±0.65	−0.37±0.67	3.29±0.73	1.11±0.69	0.40±0.52	5.09± 0.84	−(
	Hundreds A	.000 *	.901	.048		0.98±0.48 *	1.93±0.54	0.24±0.63	0.95±0.49	3.75±0.60	0.
	Hundreds A incorrect	.047	.106	.587	.510*		2.92±0.66	0.74±0.56	0.03±0.54	4.72±0.58	0.
	Hundreds B	.000 *	.001	.000	.001	.000		2.18±0.89 *	2.89±0.44	1.80±0.69	2.
	Hundreds B incorrect	.022	.831	.117	.706	.196	.022*		0.71±0.81	3.98±0.86	0.
	Roll-up A	.002 *	.007	.453	.065	.955	.000	.388		4.69±0.65	0.
	Roll-up B	.000 *	.000	.000	.000	.000	.015	.000	.000		4.
	Leg-circle	.001 *	.311	.106	.201	.172	.000	.698	.253	.000	
	Hundreds A reformer	.000 *	.071	.002	.056*	.004	.119	.140	.001	.001	.C
	Hundreds B reformer	.000 *	.000	.000	.000	.000	.135*	.002	.000	.297	.C

NOTE. Upper right, means ± SEs of differences between thickness; lower left, their associated *P* values.

*Test of a priori hypothesis.

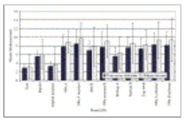

Fig 8.
TrA and OI thickness measurement (mm) during different Pilates exercises.

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Comparisons of Muscle Thickness During Exercises Performed Correctly and Incorrectly

The effects of performing the exercises incorrectly varied between the 2 muscles and between different exercises. The imprint exercise performed correctly resulted in significantly greater thickness than when the exercise was performed incorrectly in both TrA and OI. During the imprint exercise performed incorrectly, neither TrA nor OI was thicker than at rest (hypothesis 2) (see Table 1, Table 2; see fig 8).

There were no differences in TrA thickness between correctly and incorrectly performed mat hundreds A or mat hundreds B exercises, and both correctly and incorrectly performed mat hundreds A and mat hundreds B exercises resulted in significantly greater TrA thickness than at rest. During the mat hundreds A exercise, there was no difference in OI thickness between correctly and incorrectly performed exercises; during the mat hundreds B exercise, OI muscle thickness was greater when this exercise was performed incorrectly (hypothesis 2) (see Table 1, Table 2; see fig 8).

Comparisons of Muscle Thickness During Exercises With and Without Equipment

During the hundreds A exercise, TrA muscle thickness was the same regardless of whether the exercise took place on a mat or on the reformer. During the hundreds B exercise, TrA was thicker when exercising with the reformer. Performing the hundreds A and hundreds B exercises on the reformer made no difference to OI muscle thickness compared with the same exercises performed on a mat, although the muscle was close to being significantly thicker during the hundreds A exercise on the reformer (*P*=.56; hypothesis 3) (see Table 1, Table 2; see fig 8).

It was observed post hoc that the more demanding exercises—the mat hundreds A, the mat hundreds B, the leg-circle, and the roll-up B exercises—were associated with greater muscle thickness compared with the imprint or roll-up A exercises (see Table 1, Table 2; see fig 8).

Pearson's correlation between all TrA and OI muscle thicknesses R^2 was equal to .410 (*P*=.001). A power relationship provided the closest line of best fit (F=66.73; *P*=0.001), but was only a little better than a linear relationship (F=62.58; *P*=0.001) (fig 9).

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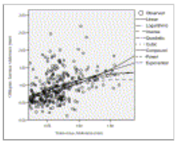

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Fig 9.

Correlation of TrA and OI thickness with lines of best fit.

Discussion

The main finding was that both TrA and OI muscles were significantly thicker during all correctly performed Pilates exercises investigated compared with resting supine. TrA and OI muscle thickness change has been shown to correlate with EMG muscular activity up to moderate levels of effort,[22, 23] suggesting that this thickness increase indicates muscle activity, possibly in order to help stabilize or protect the spine.[10] The 3 Pilates exercises investigated therefore activate the deeper abdominal muscles. This has been frequently claimed but not clearly demonstrated prior to this study.

The imprint action, taught when first learning Pilates and the basis of all other classic Pilates exercises, showed a difference in muscle thickness according to whether the exercise was performed correctly or not. During higher effort exercises, such as hundreds A and B, there were no significant differences between exercises performed correctly and incorrectly. However, participants were all experienced Pilates practitioners, and it may have been hard for them to unlearn the exercises, particularly in complex movements such as the hundreds or leg-circle exercises, components of which may have been performed unconsciously. Some participants reported finding it difficult to perform the exercises incorrectly because they were so accustomed to drawing in their abdomens. Further studies could investigate the activity of the abdominal muscles during Pilates exercises among naive or patient populations.

Using the reformer equipment resulted in thicker TrA during the higher effort hundreds B exercise, but no difference during the lower effort hundreds A, and no differences in OI. The hundreds exercise involves lying supine on the sliding board of the reformer, which may provide external lumbo-pelvic stabilization and thus minimize the effects of the extra resistance and challenge to balance provided by the equipment.

Some models of spinal stability propose independent functions for TrA and OI.[3, 10] The moderate correlation between these 2 muscles found in the present study does not support this view. There is controversy regarding whether isolated TrA muscle exercises are desirable or practical in programs aimed at enhancing muscular stabilization of the spine.[10, 11, 13, 26, 27] In the present study, there was an increase in thickness of OI in 23 of 26 participants during the imprint action correctly performed (according to an experienced classic Pilates instructor and physical therapist), suggesting that an isolated TrA contraction is hard to achieve even in a highly trained population. Beith and Harrison[28] argue that because of the anatomy of the combined aponeurosis and their reflex connections, the abdominal muscles cannot function independently. These results support that view.

The use of ultrasound to measure abdominal muscle thickness as a proxy of muscle activity is becoming increasingly popular.[17, 18, 19, 20, 21, 29, 30] Non-Pilates exercises designed to activate the stabilizing abdominal muscles have been demonstrated to increase the thickness of TrA and OI,[9, 19, 29, 31] findings similar to those of this study. Repeated measurement of the thickness from the same portion of abdominal muscle requires accurate identification of muscle architecture and careful repositioning between scans to ensure that the same portion of the abdominal wall is measured each time; however, reliability was investigated and demonstrated to be very good. Similar very good-to-excellent intrarater reliability (ICC) has been reported in other studies.[9, 23, 32] Thickness change and EMG signal have been demonstrated to correlate well in both TrA and OI at low to moderate levels of effort.[22, 23] Hodges et al[22] concluded that the relationship was weaker during efforts greater than 20% to 30% MVC from results of a small sample (n=3), whereas McMeeken et al[23] demonstrated a good relationship to 50% MVC in a larger group (n=9). Data from both these studies[22, 23] suggest muscle thickness increase tends to be smaller for the same increase in EMG signal during higher efforts. Ultrasound measurement of thickness may therefore have underestimated differences between more strenuous exercises so that differences may exist but were not detected between, for example, correct and incorrect hundreds B. The percentage of MVC of transversus and OI muscles during these exercises is unknown, but comparison with similar exercises from other studies suggests that most were less than 30% and unlikely to have exceeded 50%; during the dying bug exercise (crook lying, both arms and both legs raised from plinth), similar to the hundreds B exercise, oblique abdominal muscle EMG activity was never greater than 25% MVC[33]; in a curl-up exercise, similar to the present roll-up B, OI EMG activity was reported as 42% of MVC.[34] In the present study, during more strenuous exercises such as hundreds A and B and roll-up B, muscles were thicker than during lower effort exercises such as the imprint action or roll-up A, increasing confidence in the validity of this method of measuring of muscle activity. However, further studies should investigate the relationship of abdominal muscle thickness and EMG activity during different exercises and with larger sample sizes.[21]

The present study measured muscle thickness during 3 of 34 possible classic Pilates exercises. The exercises were chosen after consultation with experienced instructors and are believed to be representative of the conditioning system. Further research could compare other exercises. Exercises such as leg-circle and roll-up are dynamic but were measured in a stationary position in the present study. Video recording real-time ultrasound can be used to measure muscle thickness during dynamic exercises,[20, 23] which may give more valid findings. Ultrasound scanning is a safe, reliable, and practical tool that could be used to evaluate change in both the TrA and OI muscle thickness after Pilates or other training programs if submaximal exercises are investigated.

Study Limitations

Because of the weaker relationship between muscle thickness and EMG activity at higher percentages of MVC, less confidence can be placed in the results of more strenuous exercises.

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Conclusions

A significant increase in thickness, representing muscle activity, was demonstrated in both TrA and OI during 3 Pilates exercises performed according to classic Pilates principles. Muscle thicknesses during the imprint action performed incorrectly are no greater than at rest. Further research is needed to investigate other exercises, the longer-term effects of performing Pilates exercises, and patient populations such as those with low back or pelvic pain.

Suppliers

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Acknowledgments

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