Effect of pilates mat exercises and conventional exercise programmes on transversus abdominis and obliquus internus abdominis activity: Pilot randomised trial

Duncan J. Critchleya,*, Zoe Piersonb, Gemma Battersbya

aAcademic Department of Physiotherapy, King’s College London, London SE1 9RT, UK
bPhysiotherapy Department, Guy’s and St Thomas’ NHS Trust, London SE1 7EH, UK

Abstract

Pilates training is said to increase Transversus abdominis (TrA) and Obliquus internus (OI) activation during exercise and functional activities. 34 Pain-free health club members with no Pilates experience, mean (SD) age 30(7) years, were randomised to Pilates mat exercises or strength training. Participants exercised unsupervised twice-weekly for eight weeks. TrA and OI thickness (a proxy for muscle activity at the low-medium efforts of our exercises) were measured with ultrasound pre- and post-training during Pilates exercises ‘Imprint’ (an abdominal drawing-in manoeuvre) and ‘Hundreds A’ (lying supine, arms slightly raised, hips and knees flexed to 90°) and ‘Hundreds B’ (as A, with neck flexion) and functional postures sitting and standing.

Pilates participants had increased TrA thickness in Hundreds A [all values mean (SD) mm]: 3.7(1.3) pre-intervention, 4.7(1.1) post-intervention (P = 0.007); and decreased OI muscle thickness during Imprint: 11.7(2.8) pre-intervention, 10.8(3.5) post-intervention (P = 0.008). Strength training participants had greater OI thickness during Imprint (P = 0.014), Hundreds A (P = 0.018) and Hundreds B (P = 0.004) than Pilates participants post-intervention. There were no changes in muscle thickness at rest or during functional postures.

Pilates training appears to increase TrA activity but only when performing Pilates exercises. Further research is required into Pilates in clinical populations and how to increase deep abdominal activation during functional activities.
measured thickness change cannot be confidently used as a gauge of activity in this muscle (Hodges et al., 2003; John and Beith, 2007).

The aim of this study was to compare the effects of Pilates mat exercises and a conventional strength training programme on the activity of TrA and OI. We used ultrasound measures of muscle thickness as a proxy of muscle activity. Our hypotheses were Pilates mat exercises would result in greater voluntary (during exercises) and automatic (during functional postures) TrA activity than a conventional strength training programme.

2. Methods

See Fig. 1 for study design flow chart.

2.1. Participants

Following ethical approval by King’s College London Research Ethics Committee (ref CREC/07/08-172) and having provided written informed consent, 28 women and 6 men were recruited via posters from a health club. Potential participants were excluded if they were under eighteen years old, had had spinal or abdominal surgery at any time, low back pain in the last two years, visible scoliosis, neuromuscular disorders, were pregnant or had ever had Pilates training.

2.2. Data collection

Demographic data were recorded and height and weight measured prior to randomisation. Ultrasound measurements were made prior to randomisation and at eight weeks. Allocation was concealed from the researcher collecting data (ZP); security of concealment was evaluated by the researcher nominating which intervention she thought participants had received at reassessment. All testing took place at Fitness First health club, Balham, UK.

2.2.1. Ultrasound measurement

A portable ultrasound scanner (Aloka SSD-900, Aloka Co.Ltd., Tokyo, Japan) and 7.5 MHz linear transducer was used in B mode. The scanner was calibrated before data collection by comparing with metal phantoms of known dimensions. All measured images were from the right abdomen with transducer orientated antero-laterally, centred on the anterior axillary line midway between iliac crest and lowest rib (Fig. 2) where middle fibres of TrA and middle fibres of OI can be imaged simultaneously (Misuri et al., 1997). The transducer was placed perpendicular to the abdominal wall for optimal accuracy and image clarity. Static views were stored using the freeze facility of the scanner at end of exhalation (Ainscough-Potts et al., 2006); muscle thickness was measured in real-time using the automatic callipers software of the scanner (Fig. 3).

2.2.2. Test exercises and positions for all participants

Following standardised instructions, muscle thickness measurements were taken first in resting supine, then (in random order) standing, sitting and during Pilates exercises known as Imprint (Fig. 4), Hundreds A and Hundreds B (Fig. 5). For Pilates exercise Imprint, participants were instructed to lie supine with their head resting on one pillow. Before Imprint, participants were

---

**Fig. 1.** Study design flow chart.

**Fig. 2.** Ultrasound scanning point.

**Fig. 3.** Example ultrasound image of the antro-lateral abdominal wall. The lighter shade fascia planes separate obliquus externus (OE), obliquus internus (OI) and transversus abdominis (TrA).
instructed to palpate their abdominal muscles just antero-medial to their anterior superior iliac spines, identify the muscle contraction when coughing, and contract this muscle during Imprint. They were then instructed to draw-in their abdomen using command “scoop the belly, navel to spine”. For Pilates exercise Hundreds A, participants were instructed to flex their knees and hips to 90° and lift their arms just off the plinth by flexing their shoulders slightly with the command: “Bring your knees and hips up to 90°. Hover your hands just above the bed”. For Pilates exercise Hundreds B, participants were instructed to assume Hundreds A then lift their head slightly above the pillow by flexing their neck. In standing, participants were instructed to weight-bear equally; in sitting, to sit upright without back support. Participants were not instructed to contract their abdominal muscles other than during Imprint.

Measurements were spaced over 40 min to minimise fatigue. Resting supine measurements were repeated at the end of assessment to evaluate short-term intra-tester reliability. This procedure was repeated after the eight-week training period.

2.3. Randomisation

Following baseline data collection, participants were allocated to conventional strength exercise or Pilates exercise groups using sealed, sequentially numbered envelopes containing allocations randomly generated by a computer programme, prepared by a second researcher (DC) prior to the start of the study.

2.4. Interventions

Following randomisation, participants received individual assessment and teaching of their exercise programme for 1 h by a third researcher (GB), a student physiotherapist, member of the UK Register of Exercise Professionals, and qualified Pilates instructor with The Australian Physiotherapy Pilates Institute. All participants were instructed to follow a 45-min programme, twice a week, for eight weeks. Exercises were not individually supervised but instruction included photographic and written descriptions. Additionally, participants were encouraged to contact GB at any point during the eight week intervention if they required guidance. Compliance was encouraged through telephone contact every two weeks and was self-monitored using an exercise diary but not recorded by investigators. No restrictions were placed on continuing with usual training regimes if desired.

2.4.1. Pilates

In the teaching session, Pilates participants were shown how to recruit their deep abdominal muscles using a variety of facilitation strategies including visual imagery, verbal cueing, and demonstration. They were then taught a programme of 10 mat exercises and encouraged to perform each exercise 10 times for two sets. Conscious recruitment of the deep abdominal muscles, the incorporation of the Pilates principles of breathing control and neutral spinal alignment was taught and encouraged during all exercises. Progressions were described for each exercise whereby load was increased by changing limb movements or positions. Participants were encouraged to progress the exercises as they were able over the eight weeks.

Fig. 4. Testing positions: relaxed (above), ‘Imprint’ (below).

Fig. 5. Test positions: Hundreds A (above) and B (below).
Pilates exercises

1. ‘Hundreds’: in crook lying, arms by side, draw-in abdominal muscles then raise head and shoulders, raise arms slightly and circle arms. Progress to lifting legs to 90° hip and knee flexion.
2. ‘Bridge’: in crook lying, arms by side, draw-in abdominal muscles then lift pelvis. Progress to crossing arms across chest.
3. ‘Scissors’: in crook lying, arms by side, draw-in abdominal muscles then lift alternate legs to 90° hip and knee flexion.
4. ‘Hip Twist’: in crook lying, arms by side, draw-in abdominal muscles then roll knees to alternate sides. Progress to rolling knees in 90° hip and knee flexion.
5. ‘One Leg Stretch’: in crook lying, arms by side, draw-in abdominal muscles then lift straighten alternate legs to full knee extension. Progress to starting with both legs in 90° hip and knee flexion.
6. ‘One leg circle’: start as for one leg stretch. Describe 5 small circles with raised leg. Progress to starting with both legs in 90° hip and knee flexion, circle one leg.
7. ‘Counter balance’: in four point kneeling, draw-in abdominal muscles, raise alternate arms to 150° shoulder abduction. Progress to lifting opposite leg to full hip extension.
8. ‘Swan Dive’: in prone lying, arms elevated, draw-in abdominal muscles and raise arms slightly.
9. ‘Clam’: in side lying, hips and knees flexed to 60°, draw-in abdominal muscles and lift upper knee to 45° external hip rotation, keeping heels together. Progress to starting with both heels raised 20 cm.
10. ‘Side kick’: in side lying, hips and knees flexed to 60°, draw-in abdominal muscles and lift upper leg slightly. Flex hip to 90°. Progress to starting exercise with straight leg, flex hip to 60°.

2.4.2. Strength training

In the teaching session, participants were shown a programme of strengthening exercises using free weights and machines. Safe exercise techniques were taught, such as avoiding extremes of spinal motion, but abdominal muscles were not mentioned. The conventional strength exercise programme consisted of seven exercises, incorporating major muscle group of the chest, shoulders, back, upper arm and legs. No abdominal muscle exercises were described. Four sets of each exercise were performed incorporating a pyramid-style training regime, decreasing the number of repetitions from 12 repetitions in the first set to 4 repetitions in the 4th set and increasing the weight with each subsequent set. Participants were encouraged to increase weights as they felt able over the course of the programme.

Strength training exercises

1. Chest press
2. Bent over row
3. Shoulder press
4. Biceps curl in standing
5. Triceps extension in standing
6. Squat
7. Lunge

2.5. Data analysis

Prior to recruitment, a sample size calculation was performed based on results from Endleman and Critchley (2008) who reported mean (standard deviation) difference of 0.67 (0.42) mm in TrA thickness between correctly and incorrectly performed Pilates exercises. In a two-group design, 32 total participants are required to detect such difference at 5% level of significance with 99% power.

Bland and Altman plots and single measures intra-class correlation coefficients (ICC2,1) were used to compare repeated resting thickness measurements (Rankin and Stokes, 1998). Fisher’s test was performed to assess reliability of blinding. Attrition rates were compared with Pearson’s Chi-square test. Distribution analysis by Shapiro–Wilk and Kolmogorov–Smirnov tests revealed that parametric assumptions were not met. Consequently two-tailed Mann-Whitney U tests were used to compare mean differences between Pilates and strength training groups and one-tailed Wilcoxon tests were used to compare mean differences pre and post-intervention or between the same muscle during different exercises. All analyses were per protocol on participants that provided both baseline and follow-up data. Statistical significance was accepted at $P < 0.05$. Data was analysed using SPSS 14.0 (SPSS Inc., Chicago, IL). All data are presented as means (standard deviations) unless otherwise stated.

3. Results

3.1. Baseline demographic data

The 28 completing participants had mean (SD) age of 30 (7) years old, weighed 66.9 (10.7) kg, were 1.67 (0.09) m tall, had a body mass index of 23.8 (2.4) kg/m² and exercised 3.0 (1.1) times a week at the start of the study. Participant characteristics were similar between groups at baseline, suggesting successful randomisation (Table 1).

3.2. Attrition

Following interventions, 28 participants were reassessed. One Pilates and four strength exercise participants were not reassessed, attrition was not significantly different between groups: Chi-square = 1.8, $P = 0.18$. One strength participant withdrew because they became pregnant; four completed the interventions but could not attend reassessment for logistic reasons. No adverse events were reported. Results were analysed using the 17 complete data sets from the Pilates group and 11 from the strength group.

Table 1

<table>
<thead>
<tr>
<th>Demographic characteristic</th>
<th>Pilates (n = 18)</th>
<th>Strength (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>31 (5)</td>
<td>30 (8)</td>
</tr>
<tr>
<td>Female*</td>
<td>78% (14/18)</td>
<td>75% (12/16)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>65.2 (9.8)</td>
<td>68.9 (11.7)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.67 (0.07)</td>
<td>1.67 (0.11)</td>
</tr>
<tr>
<td>BMI (m²/kg)</td>
<td>23.2 (2.0)</td>
<td>24.5 (2.8)</td>
</tr>
<tr>
<td>Type of exercise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiovascular*</td>
<td>78% (14/18)</td>
<td>75% (12/16)</td>
</tr>
<tr>
<td>Resistance*</td>
<td>56% (10/18)</td>
<td>56% (9/16)</td>
</tr>
<tr>
<td>Classes*</td>
<td>67% (12/18)</td>
<td>63% (10/16)</td>
</tr>
<tr>
<td>Pelvic floor*</td>
<td>28% (5/18)</td>
<td>31% (5/16)</td>
</tr>
<tr>
<td>Exercise frequency (days/week)</td>
<td>3.1 (1.2)</td>
<td>3.0 (1.2)</td>
</tr>
</tbody>
</table>

Summary measures are means (SD) or *percentage of participants.
3.3. Reliability of ultrasound thickness measurements
Muscle thickness (mm) in different test positions pre and post-intervention.

<table>
<thead>
<tr>
<th>Position</th>
<th>Transversus abdominis</th>
<th>Obliquus internus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Resting supine</td>
<td>3.49 (0.95)</td>
<td>3.83 (1.06)</td>
</tr>
<tr>
<td>Strength</td>
<td>4.65 (1.70)</td>
<td>4.51 (1.26)</td>
</tr>
<tr>
<td>Imprint</td>
<td>5.75 (1.65)</td>
<td>5.72 (1.98)</td>
</tr>
<tr>
<td>Strength</td>
<td>7.36 (2.51)</td>
<td>6.84 (2.30)</td>
</tr>
<tr>
<td>Hundreds A Pilates</td>
<td>3.72 (1.35)</td>
<td>4.74 (1.11)</td>
</tr>
<tr>
<td>Strength</td>
<td>4.84 (1.62)</td>
<td>5.05 (1.90)</td>
</tr>
<tr>
<td>Hundreds B Pilates</td>
<td>4.02 (1.24)</td>
<td>4.49 (1.19)</td>
</tr>
<tr>
<td>Strength</td>
<td>4.28 (1.32)</td>
<td>4.83 (1.45)</td>
</tr>
<tr>
<td>Standing Pilates</td>
<td>4.93 (1.48)</td>
<td>4.74 (0.97)</td>
</tr>
<tr>
<td>Strength</td>
<td>6.03 (1.71)</td>
<td>5.91 (2.19)</td>
</tr>
<tr>
<td>Sitting Pilates</td>
<td>5.05 (1.48)</td>
<td>5.71 (1.80)</td>
</tr>
<tr>
<td>Strength</td>
<td>5.89 (2.56)</td>
<td>6.32 (2.31)</td>
</tr>
</tbody>
</table>

Summary measures are means (SD).

3.4. Within groups pre- and post-intervention comparisons of muscle thickness
Pilates participants’ transversus abdominis thickness increased during Hundreds A from 3.72 (1.35) [all values mean (SD) mm] pre-intervention to 4.74 (1.11) post-intervention (P = 0.007) (Table 2).

Pilates participants’ obliquus internus muscle thickness decreased during Imprint from 11.69 (2.84) pre-intervention to 10.80 (3.53) post-intervention (P = 0.008) (Table 2).

There were no within-group changes in TrA or OI thickness following strength training.

3.5. Between groups pre- and post-intervention comparison of muscle thickness
At baseline, there were no differences in OI thickness between the two groups.

Following interventions, the strength group had greater OI muscle thickness compared to the Pilates group during Imprint (10.8 mm compared to 14.1 mm; P = 0.014), Hundreds A (9.6 mm compared to 12.36 mm; P = 0.018) and Hundreds B (10.34 mm compared to 14.27 mm; P = 0.004) (Table 2).

There were no differences in TrA thickness between Pilates and strength training groups pre- or post-intervention (Table 2).

3.6. Comparison of muscle thickness in different test positions
Prior to interventions for all participants, TrA was thicker during Imprint (P < 0.001), sitting (P < 0.001) and standing (P < 0.001) compared to resting supine. Obliquis internus was thicker during Imprint (P = 0.001) and Hundreds B (P = 0.002) (Table 3).

3.7. Assessment of security of masking
At reassessment, the assessor guessed 17 participants’ treatment correctly and 11 incorrectly compared with 14 each expected by chance (P = 0.059; Fisher’s test, two-tailed).

4. Discussion
This is the first prospective study into the effects of Pilates exercises on abdominal muscles. Following 8 weeks of Pilates mat training, TrA increased in thickness during Pilates exercise Hundreds and OI decreased in thickness during Pilates exercise Imprint. There were no changes in muscle thickness in functional postures and no changes following strength training. If thickness change of TrA and OI represent muscular activity, these findings suggest Pilates caused an increase in TrA relative to OI activity during abdominal muscle exercises but this does not carry over into everyday postures.

4.1. Effects of interventions
Following Pilates training, Imprint, the basis to all Pilates exercises (Latey, 2002), showed a decrease in OI thickness whilst maintaining TrA thickness, suggesting an increase in ratio of local to global (Bergmark, 1989) muscle activation or greater isolation of TrA contraction. Teyhen et al. (2005) found no change in TrA and OI muscle thickness in subjects with low back pain during abdominal drawing-in [similar to Imprint (Endleman and Critchley, 2008)] after 4 days of abdominal drawing-in training. Their exercise dosage may have been inadequate to change muscle activity in subjects where pain may have inhibited TrA (Critchley and Coutts, 2002). The ratio of local to global abdominal muscle EMG activity increased following 10 weeks spinal stability training in low back pain patients (O’Sullivan et al., 1998) and 3 months training in pain-free subjects (Stevens et al., 2007), findings similar to the present. Both studies measured muscle activity during abdominal exercises and did not evaluate functional postures or activities.

Surprisingly, there was no increase in thickness of TrA following training during Imprint. This may represents a ceiling effect, with test instructions sufficient to produce ‘good’ TrA activation; both Critchley and Coutts (2002) and Teyhen et al. (2005) found pain-free subjects able to perform a good TrA contraction after brief instruction. Unlike Hundreds, where load is approximately constant, the level of effort can vary during Imprint. Participants were instructed to perform Imprint “gently” but the degree of effort was not measured. TrA to OI ratio is perhaps a more valid measure for this exercise if increased TrA activity relative to OI is a desired outcome, as suggested by spinal stability models deriving from Bergmark’s local-global muscle classification (Richardson et al., 2004).

Hundreds A is similar to double-leg raise that O’Sullivan et al. (1998) suggested tests automatic abdominal muscle activity. If this suggestion is correct, increased TrA thickness in Hundreds A following Pilates represents modified automatic abdominal muscle activity. Changes in muscle activity were not seen in functional...
postures and, as Hundreds A is similar to exercises performed by Pilates participants, it is more likely our findings are examples of training specificity. In order to change abdominal muscle activity during function, it may be necessary to perform exercises that more closely resemble the function than the Pilates mat exercises investigated here.

There were no changes in abdominal muscle thickness in the strengthening group. The strength programme did not include conventional abdominal exercises, although participants were free to continue with any pre-existing abdominal exercise programme. Additionally, as members of a health club, all participants were exercising when the trial started which may have reduced potential for further improvement with conventional exercises.

4.2. Ultrasonography

Ultrasound has several advantages as a tool for evaluating morphology and activation of the abdominal muscles including safety, non-invasive nature, speed of use, usability in many postures, and in eliminating the cross-talk from surrounding muscles associated with surface EMG (Teyhen et al., 2007; Koppenhaver et al., 2009). Short-term reliability of measures in relaxed supine was excellent, similar to conclusions of a recent review (Costa et al., 2009). Reliability of measurements during abdominal exercises is typically less good (Costa et al., 2009) and was not tested, a study weakness. Reliability can be further improved with multiple measurement (Springer et al., 2006) but this needs more time and so may have been unacceptable to paying health club clients.

The validity of static measurement of muscle morphology is excellent for TrA and OI (Pretorius and Keating, 2008; Koppenhaver et al., 2009). The thickness changes observed were similar to investigations of low abdominal drawing-in (e.g. Mannion et al., 2008). Hodges et al. (2003) suggested contractions up to 20% of maximal voluntary contraction (MVC) had a good correlation between EMG and muscle thickness whereas McMeeken et al. (2004) found a linear relationship up to 80% MVC. Ultrasound provides a valid measure of muscle activity for moderate levels of contraction but should not be used to measure highest levels of abdominal muscle effort. The use of Pilates exercise as test positions potentially favoured the Pilates intervention. Other test exercises could have been used in addition to Pilates exercises to overcome this possible bias.

This study measured muscle thickness at a single point. Middle fibres of the TrA modulate intra-abdominal pressure and attach to the lumbar vertebrae, whereas the lower fibres support the abdominal viscera in upright postures and compress the sacroiliac joints (Urquhart et al., 2005). Further investigations could measure thickness in different locations of the TrA muscle to identify whether Pilates exercises have different effects upon possible functional subdivisions of this muscle.

The 28 participants fell short of the 32 suggested by sample size calculations; differences between means were also smaller than anticipated. Some tendencies towards thickness difference came close to significance so may represent type-II errors due to under-powering. Attrition tended to be greater from strength training participants but this did not reach significance and appeared to be unrelated to the nature of the programmes.

4.4. Clinical implications

The mat exercises required minimal equipment and could be accomplished in non-gym or clinical settings. Many Pilates exercises are similar to those employed in motor control and spinal stabilization training programmes (McGill, 2001; Richardson et al., 2004). These findings suggest Pilates exercises can be incorporated into spinal stabilization training with the caveats that it is not known if the muscle thickness (activation) changes seen are clinically important and carry over into functional activities remains unproven.

4.5. Further research

Further research could investigate Pilates in clinical populations and in other functional postures or activities. Low back pain and disability improved following Pilates (Rydeard et al., 2006) but abdominal muscle activity was not measured and it is not known if benefits were related to muscle changes. Ultrasound is well-suited to evaluating abdominal muscle changes in such populations.

5. Conclusions

Transversus abdominis activation increased following a programme of unsupervised Pilates mat exercises that is practical and requires no special equipment. There was no change in abdominal muscle activation during functional postures. Supervision of exercises and progression to more functional exercises may be required to increase functional abdominal activation. Further research could investigate Pilates in clinical populations.

Acknowledgements

The authors thank all the participants, the staff of Fitness First health club, Balham, UK for loan of facilities and equipment, and John Nugus for helpful comments on an early draft of the manuscript. This project received no external funding support.

Gemma Battersby died during the preparation of this manuscript (24.12.2008) and the other authors would like to dedicate this paper to her memory.
References


