Effects of a six week beginner pilates exercise programme on transversus abdominis thickness in low back pain subjects

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ABSTRACT

Purpose. Transversus abdominis has been shown to be dysfunctional in low back pain patients. Specific exercises involving contraction of core muscles of the spine have been shown to be effective in treating low back pain. Although it is widely claimed that pilates exercise develops the core muscles surrounding the spine, including transversus abdominis, there is little research to support this.

Objective. To investigate the effect of a pilates exercise programme on transversus abdominis thickness in subjects with a history of low back pain. To investigate the reliability of ultrasound measurement of transversus abdominis thickness.

Study Design. Test retest design, with subjects recruited via convenience sampling.

Method. Intra-tester reliability was investigated by measuring transversus abdominis thickness with B-mode ultrasound in eight subjects with a history of low back pain on two separate days. A further twenty-two subjects were recruited for a six week pilates matwork exercise programme with measurements of transversus abdominis thickness taken pre and post intervention.

Results. The intra-tester reliability was found to be high in supine lying for transversus abdominis measurements taken one week apart (ICC = 0.92, 95% CI 0.60 to 0.99). There was a large and varied effect of the pilates intervention on the change in thickness of transversus abdominis (effect size = 1.27, CI -2.7 to 5.5). History of respiratory dysfunction was found to be very highly correlated with a decrease in transversus abdominis thickness measured at the end of expiration (r=0.7, CI 0.3 to 0.9).

Summary. The ultrasound methodology was found to be reliable in measuring transversus abdominis thickness. It is not known why there was a wide variation observed in terms of magnitude and direction of change of transversus abdominis thickness after the pilates intervention. It is thought that changes in transversus abdominis thickness measured by ultrasound at the end of expiration (functional residual capacity) were related to respiratory function status. This relationship may have been modified by the six week beginner pilates exercise programme in subjects with a history of respiratory dysfunction. It is postulated that this relationship changed by reducing the contraction of transversus abdominis at the end of expiration. No definitive conclusions can be made, however, due to the small sample size in this preliminary study.

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LIST OF ABBREVIATIONS

95% CI	-	95% Confidence Interval
CV	-	Coefficient of Variation
EMG	-	Electromyography
ICC	-	Intraclass Correlation Coefficient
SD	-	Standard Deviation

LIST OF DEFINITIONS

B-mode ultrasound	–	Brightness mode ultrasound images are two-dimensional, produced by a linear array of transducers simultaneously scanning a plane through the body (Sternlof, 2001). In imaging the anterolateral abdominal wall, a snap shot can be taken at a point in time, giving a two-dimensional cross sectional ultrasound image. Subsequent measurements of muscle thickness between the fascial muscle boundaries can then be made.
M-mode ultrasound	–	Motion mode ultrasound images are one-dimensional, displaying changes in the position of sound-reflecting structures over time. In imaging the anterolateral abdominal wall, it gives a graph of the position of fascial muscle boundaries as they change with time (Sternlof, 2001).
Non specific low back pain	–	Non specific low back pain is pain in the low back of which the specific cause is unknown (Medline Plus, 2004). It is a ‘mechanical’ pain of musculoskeletal origin in which symptoms vary with physical activity (Waddell, 1998). It excludes by definition a specific cause (such as herniated disk), any neurological problems (such as weakness, change in sensation), neurogenic pain and low back pain caused by serious spinal pathology or serious injury (e.g. cancer, osteomyelitis, spondyloarthropathies, fracture). It is one of the three categories used in the clinical diagnostic triage for causes of low back pain outlined by Waddell (1998), with the other two categories being nerve root pain and possible serious pathology.

INTRODUCTION

Between 60 to 80 percent of the general population will suffer from low back pain at some point in their lives (Lahad, Malter, Berg & Deyo, 1994; Laslett, Crothers, Beattie, Cregten & Moses, 1991; Riihimaki, 1991). Although the natural course for most non specific low back pain is of a self-limiting nature, reoccurrence rates are high. Understanding of this vulnerability to reoccurrence is limited, and successful prevention of recurrent low back pain remains a challenge.

Spinal instability is believed to be a major cause of low back pain (Panjabi, 1992a), as well as having a major role in the high rate of reoccurrence (Nachemson, 1985). It is thought that low back pain leads to motor control deficits and dysfunction of the local stabilising muscles of the spine through long loop reflexes. Because of the inherent instability of the lumbar spine, failure of the muscular stabilisation produces an increased risk of injury to the spine (Hodges & Richardson, 1996). The deep abdominal muscle, transversus abdominis, has been shown to be a key muscle in stabilising the lumbar spine. In health, transversus abdominis functions with anticipatory or feed forward contraction to stabilise the spine prior to movement, but in subjects with low back pain transversus abdominis exhibits a timing delay or absence of activity (Hodges & Richardson, 1996; O’Sullivan, Twomey, Allison, Sinclair, Miller, 1997).

Recent studies that focussed on retraining transversus abdominis motor control through specific exercise have reported success in patients with spondylolysis and spondylolisthesis (O'Sullivan, Twomey & Allison, 1997), chronic low back pain (Johansson & Lindberg, 1995), and first episode acute low back pain (Hides et al., 1996). Despite none of these studies explicitly employing pilates exercise, it is common for proponents of pilates to claim that this research further reinforces the pilates methodology. Pilates advocates claim that the exercises are being suitable for rehabilitation of low back pain, as the pilates targets the deep postural muscles of the abdomen and spine to improve overall ‘central core stability’. The central core is the contemporary pilates terminology for what Joseph Pilates called the ‘powerhouse’ of the body (Muscolino & Cipriani, 2004). However, despite the ever-growing popularity of pilates exercise, there is a lack of research investigating the effects of pilates that might support these claims.

This project is in two parts: a reliability study and a pilates intervention study. The reliability study evaluated the intra-tester reliability of measuring transversus abdominis thickness using B-mode ultrasound in subjects with a history of low back pain. The intervention study, using this ultrasound measurement methodology, investigated the change in thickness of transversus abdominis after a six-week beginner pilates matwork programme in subjects who had a history of low back pain. The research assessed the extent to which pilates was effective in developing a change in thickness of this deep abdominal muscle. Results of this study may contribute to knowledge about how to treat back pain more effectively.

Research participants were recruited from the general public via convenience sampling. On meeting the inclusion criteria eight subjects were accepted for the reliability study and 22 for the pilates intervention study. Each intervention study subject was scheduled for measurement of transversus abdominis using ultrasound prior to and after completing the six-week, twelve session beginner pilates programme. Exercise diaries, 24-hour food recall questionnaires and injury, illness, and treatment logs were completed by subjects during the intervention study, and used to monitor variables that could potentially impact on muscle thickness. The magnitude of change in the thickness of transversus abdominis was used to determine the effectiveness of the pilates programme.

Literature Review

Low Back Pain

It is estimated that between 60 to 80 percent of any population will experience low back pain at some time in their lives (Lahad et al., 1994; Laslett et al., 1991; Riihimaki, 1991). In spite of the large number of pathological conditions that can give rise to low back pain, 85% of this population are classified as having 'non specific low back pain' (O'Sullivan, 2000). The prevalence and severity of low back pain varies by age and gender of individuals, but overall there are no significant differences for different age groups or genders (Accident Rehabilitation & Compensation Insurance Corporation, 1998).

In New Zealand, back injury claims make up a significant proportion of entitlement claims made to the Accident Rehabilitation & Compensation Insurance Corporation each year (Accident Rehabilitation & Compensation Insurance Corporation, 1998). In 1996/97 there were a total of 127,104 new entitlement claims costing NZD$193 million, and 26,735 ongoing back injury entitlements costing just under NZD$315 million. The majority of back injury entitlement claims are coded as 'low back strains'. In 1995/96 new low back strains represented 69 percent of all back injury entitlement claims by number and 70 percent by cost (Accident Rehabilitation & Compensation Insurance Corporation, 1998).

It has been widely suggested that the natural course for most low back pain is self-limiting, with the vast majority of individuals improving within six weeks or less. However, Deyo & Tsui-Wu (1987) suggest a less optimistic natural history. In their study, one-third of a population reported back pain of less than one month duration, another third reported pain lasting one to five months, and the remaining third experienced pain lasting more than six months. Studies show that the reoccurrence rate for low back pain ranges from 60 to 85 percent (Troup, Foreman, Baxter, & Brown, 1987; Troup, Martin, & Lloyd, 1981). Understanding of reasons for this apparent vulnerability to reoccurrence is limited, and successful prevention of recurrent low back pain remains a challenge for spine researchers and clinicians.

Spinal instability is considered to be an important cause of low back pain (Panjabi, 1992a). Instability of the lumbar motion segment is also considered to be one important cause of reoccurrence (Nachemson, 1985). A radiological diagnosis of spondylolisthesis in subjects with chronic low back pain attributable to this finding has been considered to be one of the most obvious manifestations of lumbar instability (Nachemson, 1991; Pope, Frymoyer & Krag, 1992), with reports of increased segmental motion occurring with this condition and spondylolysis. Lumbar segmental instability in the absence of defects of the bony architecture of the lumbar spine has also been cited as a significant cause of chronic low back pain (Long, BenDebba, Torgerson, Boyd, Dawson, Hardy, Robertson, Sypert & Watts, 1996).

The basic concept of spinal instability is that abnormally large intervertebral motions cause either compression and/or stretching of the inflamed neural elements or abnormal deformations of ligaments, joint capsules, annular fibres, and end-plates, which are all known to have a high density of nocioceptors. In both situations the abnormally large intervertebral motions may result in nocioception and a subsequent pain response (Panjabi, 1992a).

Spinal Instability

Instability Definitions

Instability is a biomechanical term. There have been three distinct definitions of instability offered by biomechanists: decreased resistance to movement, increased neutral zone, and altered ratios between translation and rotation (Bogduk, 1997). The first pertains to terminal instability (the behaviour of a system at its end-point) while the latter two refer to instability within a normal range of motion (Bogduk, 1997).

An early and simple definition maintained that instability was loss of stiffness (Pope & Panjabi, 1985). Pope et al. (1992) introduced a clinical dimension to the concept of instability, defining it as

> … loss of spinal motion segment stiffness such that force application to that motion segment produces a greater displacement than would be seen in a

> normal structure. The condition will cause pain, has the potential to result in progressive deformity, and place neurological structures at risk (p. 65).

Panjabi (1992b) then introduced the concept of the instability as an increased neutral zone. Panjabi defined instability as "a significant decrease in the capacity of the stabilising system of the spine to maintain the intervertebral neutral zones within the physiological limits so that there is no neurological dysfunction, no major deformity, and no incapacitating pain" (p. 394). To expand on Panjabi's concept of instability, first an explanation of his model of spinal stability and significance of the neutral zone will be discussed.

Stabilising System of the Spine – Panjabi (1992)

Panjabi (1992a) proposed the biomechanical concept of a spinal stabilising system of the spine that consists of three functionally interdependent subsystems: the passive, active, and neural subsystems. The passive subsystem includes vertebrae, facet articulations, intervertebral discs, spinal ligaments, and joint capsules, as well as the passive mechanical properties of the muscles. The active subsystem consists of the muscles and tendons surrounding the spinal column, through which the spinal system generates forces and provides the required stability to the spine. The neural subsystem consists of the various force and motion transducers, located in ligaments, tendons, and muscles, and the neural control centres. In normal function, the neural system receives information from transducers, determines specific requirements for spinal stability and causes the active subsystem to achieve the stability goal (Panjabi, 1992a).

If any one or more of the subsystems is not functioning appropriately, the overall stability of the spinal system is affected. Compensation for dysfunction of one subsystem, within certain limits, may be provided by another subsystem. If the dysfunction is beyond these limits, then acute or chronic problems may arise (Panjabi, 1992a). For example, dysfunction of the passive subsystem may be caused by mechanical injury such as overstretching of the ligaments. This injury decreases the stabilising capacity of the passive subsystem and may require compensatory changes in the active subsystem.

Neutral Zone

Panjabi (1992b) introduced the concept of the neutral zone based on the observation of the nonlinearity of load-displacement curves of joints and spinal ligaments (see Figure 1). These load-displacement curves illustrate a high flexibility around the neutral position with little resistance to movement (neutral zone), and a stiffening effect toward the end of the range of motion (elastic zone). This nonlinear property of joints and spinal ligaments allows spinal movements near the neutral position with minimal expenditure of energy, and yet still provides significant resistance to prevent damaging motion beyond the ends of the physiological range of motion (Panjabi, 1992b).

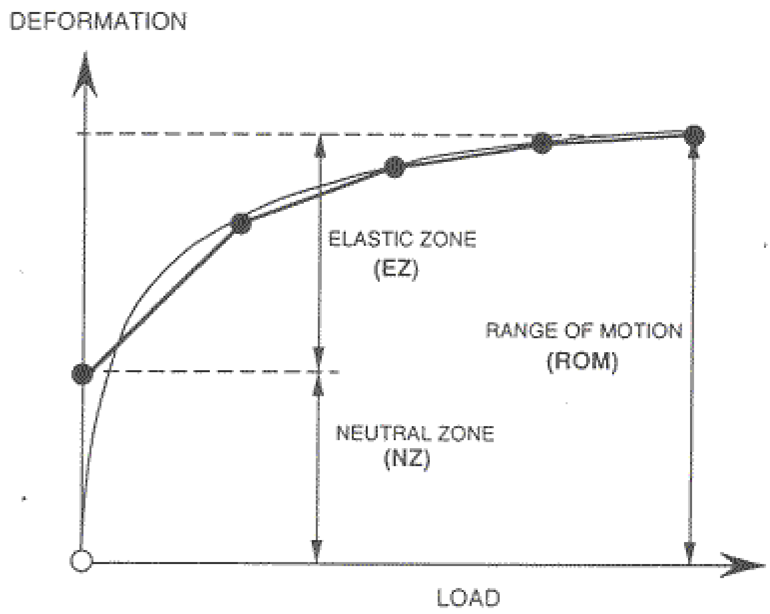

Figure 1 Load deformation curve. The load-deformation curve of a soft tissue or a body joint is highly nonlinear. The joint is highly flexible at low loads; it stiffens as the load increases. The load-displacement curve is divided into two parts: neutral zone (NZ), the region of high flexibility; and elastic zone (EZ), the region of high stiffness. The two zones together constitute the physiological range of motion (ROM) of a joint. Reproduced from Panjabi (1992b).

Panjabi (1992b) defined neutral zone, neutral position and physiological range of motion as:

> Neutral zone – that part of the range of physiological intervertebral motion, measured from the neutral position, within which the spinal motion is produced with a minimal internal resistance.

> Neutral position – the posture of the spine in which the overall internal stresses in the spinal column and the muscular effort to hold the posture are minimal.
>
> Physiological range of motion – the entire range of the physiological intervertebral motion, measured from the neutral position. It is divided into two parts: neutral and elastic zones (p. 391).

Panjabi (1992b) argues that the neutral zone is a better indicator of spinal instability than gross range of motion as it is more sensitive. The neutral zone in vitro is seen to increase with disc degeneration and to decrease with the addition (by modelling) of muscle forces and spinal instrumentation. These neutral zone changes are greater than the accompanying changes in range of motion.

The neutral zone is a function of passive and active components of the spinal stabilising system (Panjabi, 1992b). If there is damage to the passive component of the system, the passive component be compensated for by strengthening the muscle function (Panjabi, 1992b). If compensation is inadequate, the increase in the neutral zone may lead to pain through a number of mechanisms (Panjabi, 1992b) including: micro deformation of the soft tissues causing pain, stretching and compression of the neural elements due to deformation of the spinal column causing neurological deficit, excessive muscle effort (causing muscle fatigue), and spinal column stiffening caused by osteophyte formation and other degenerative effects.

Role of Muscles in Stability

Panjabi (1992a) hypothesised that if a specific group of muscles responsible for a particular directional stability can be identified, then selectively and appropriately tensioning those muscles will enhance the particular directional stability. Thus, on command from the control unit, spinal stability can be instantaneously increased. This strategy may be used in situations where the application of external load to the spinal system can be anticipated.

Throughout the last two decades there has been an increasing awareness of the importance and relevance of the specialized and integrated action of the muscle system in maintaining stability and optimal function of the movement system (Comerford & Mottram, 2001). Several models classifying muscles by function have gained increasing acceptability. Rood (as cited in Goff, 1972) was one of the first to introduce the concept of differentiating stabiliser and mobiliser muscles. Rood described stabiliser muscles as being mono-articular or segmental, deep, working eccentrically to control movement, and having static holding capacities. Mobility muscles, in contrast, are bi-articular or multi-segmental, superficial, working concentrically with the acceleration of movement and producing power.

Bergmark (1989) redefined Rood's classification of mobiliser and stabiliser muscles as the global and local muscle systems (see Figure 2). The global muscle system consists of large torque producing muscles that act on the trunk and spine without directly attaching to it. The local muscle system consists of muscles that directly attach to the lumbar vertebrae and are responsible for providing segmental stability and directly controlling the lumbar segments. The role of the local muscle system is to maintain the mechanical stiffness of the spine to control inter-segmental motion while the global muscles in conjunction with intra-abdominal pressure transfer load between the thoracic cage and the pelvis. The global system is direction and load dependent.

Specific muscles in the local muscle system have been investigated as to how they function to provide spinal segmental stability. Co-contraction of local system muscles such as transversus abdominis, diaphragm and lumbar multifidus results in a stabilising effect on the motion segments of the lumbar spine, particularly within the neutral zone, providing a stable base on which the global muscles can safely act (Allison, Kendle, Roll, Schupelius, Scott & Panizza, 1998; Hodges & Richardson, 1996; Wilke, Wolf, Claes, Arand, & Wiesend, 1995). The segmental stabilising role of lumbar multifidus, with separate segmental innervation, acts to maintain the lumbar lordosis and ensure control of individual vertebral segments particularly within the neutral zone (Goel, Kong, Han, Weinstein & Gilbertson, 1993; Kaigle, Holm & Hansson, 1995; Panjabi, Abumi, Duranceau & Oxland, 1989; Wilke et al., 1995). The deep abdominal muscles are primarily active in providing rotational and lateral stability to the spine via the thoraco-lumbar fascia, while maintaining levels of intra-abdominal pressure (Cresswell, 1993; McGill, 1991). The intra-abdominal pressure mechanism, primarily controlled by the diaphragm, transversus abdominis and pelvic diaphragm, provides a stiffening effect on the lumbar spine (Cresswell, 1993; Hodges, Butler, McKenzie & Gandevia, 1997; McGill & Norman, 1987).

Stabiliser		Mobiliser
Local	Global	
Local Stabiliser	Global Stabiliser	Global Mobiliser

Figure 2 Classification of muscle function. From Comerford & Mottram (1998).

Building on the work of Rood and Bergmark (1989), a model was developed by Comerford & Mottram (2001) which maintained the local muscle system (local stabiliser) and divided the global muscle system into two separate functional roles: global stabiliser and global mobiliser (see Figure 2). They proposed that dysfunction is specific to each of these muscle types: local stability muscle dysfunction being due to alteration of normal motor recruitment contributing to a loss of segmental control; global stability dysfunction due to an increase in functional muscle length or diminished low threshold recruitment; and dysfunction of the global mobility muscles due to a loss of functional muscle extensibility or overactive low threshold activity (see Figure 3).

LOCAL STABILISER	GLOBAL STABILISER	GLOBAL MOBILISER
Dysfunction: • Motor control deficit association with delayed timing or recruitment deficiency • Reacts to pain and pathology with inhibition • ↓ muscles stiffness and poor segmental control • Loss of control of joint neutral position Changes in motor recruitment resulting in a loss of segmental control ∴ Local Inhibition	***Dysfunction:*** • Muscle active shortening = joint passive (loss of inner range control) • If hyper-mobile – poor control of excessive range • Poor low threshold tonic recruitment • Poor rotation dissociation Changes in muscle length and recruitment resulting in <u>Under-pull</u> (long/inhibited) at a motion segment ∴ Global Imbalance	***Dysfunction:*** • Myo-fascial shortening – limits physiological and/or accessory motion (which must be compensated for elsewhere) • Overactive low threshold, low load recruitment • Reacts to pain and pathology with spasm Changes in muscle length and recruitment resulting in <u>Over-pull</u> (short/overactive) at a motion segment ∴ Global Imbalance

Figure 3 Dysfunction in the three muscle categories. Reproduced from Comerford & Mottram (1998).

Clinical Model of Movement Dysfunction

Comerford & Mottram (2001) proposed a model of movement dysfunction explaining the inter-relationships between local and global dysfunction, pain and pathology (see Figure 4). This model can be used clinically to understand the contributory factors when mechanical pain presents with an insidious onset due to suspected poor movement habits or poor postural alignment (Comerford & Mottram, 2001). The model also suggests treatment approaches for rehabilitation of each of the muscle types. In rehabilitation of the local stabiliser muscles priority is given to correcting motor control and recruitment patterns. An example of local stabiliser training is consciously activating the deep abdomen (transversus abdominis) during the abdominal drawing in manoeuvre in static, then more functional positions to retrain transversus abdominis (Comerford & Mottram, 2001). Treatment of the global stabilisers requires specific recruitment and strengthening exercise programmes to restore normal muscle function. The treatment of global mobilisers is aimed at regaining ideal physiological length with techniques such as soft tissue and myofascial release (Comerford & Mottram, 2001).

Further detail regarding the anatomy and role of transversus abdominis as a local stabiliser muscle and its dysfunction and rehabilitation in low back pain within this model of movement dysfunction will be the subject of further discussion.

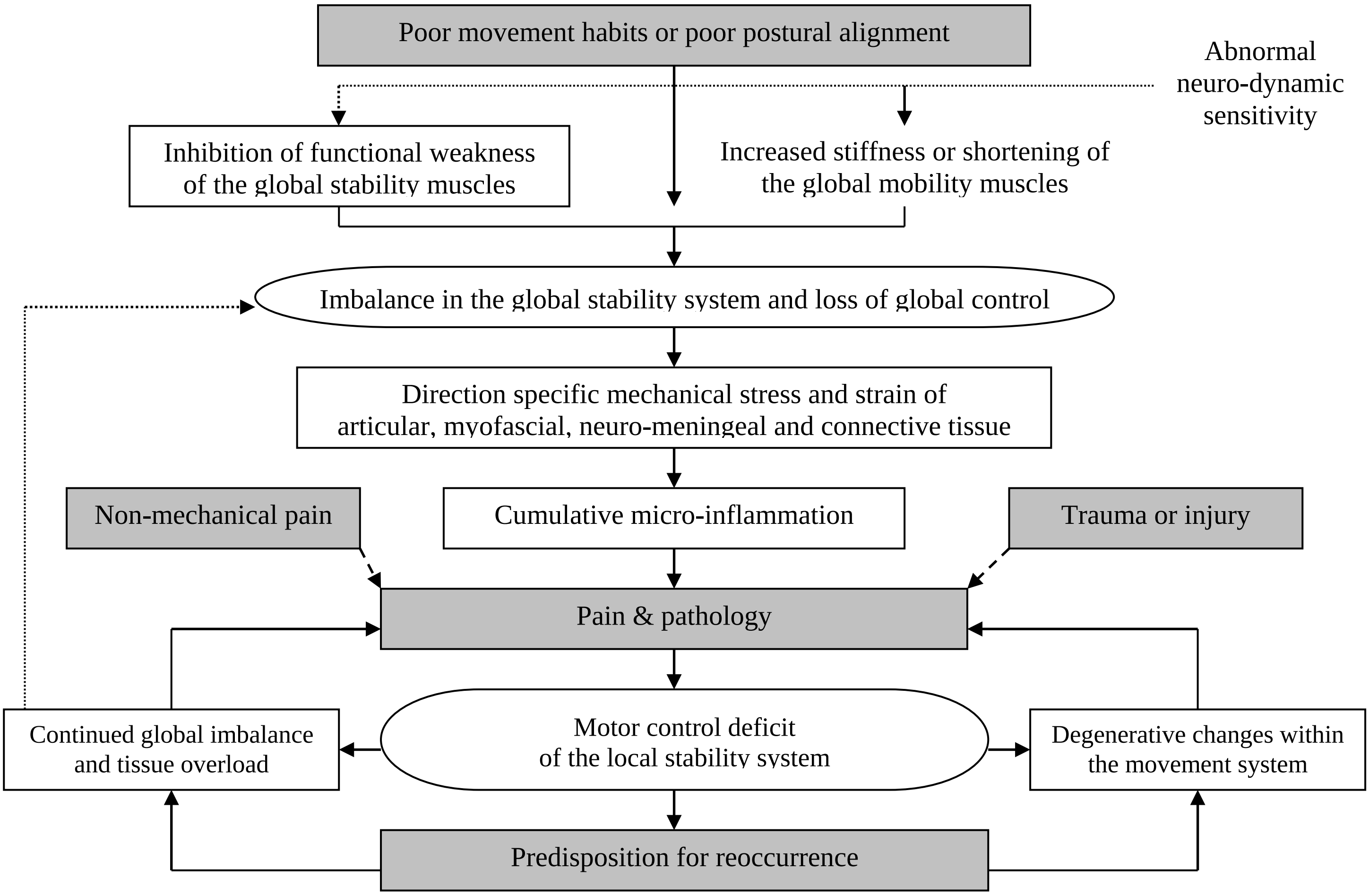

Figure 4 Model of movement dysfunction. Poor movement habits contribute to imbalance between global stabilisers and mobilisers. This then produces direction specific stress and strain on various structures that if overloaded develop pain and pathology. Pain and pathology then cause dysfunction of local stabiliser recruitment. This results in predisposition for reoccurrence, early progression of degenerative changes and maintenance of global imbalance. Reproduced from Comerford & Mottram (2001).

Transversus Abdominis

Anatomy & Function

Transversus abdominis is the innermost of the flat muscles of the abdominal wall. Its muscle fibres arise from the lateral third of the inguinal ligament, the anterior two-thirds of the inner lip of the ventral segment of the iliac crest, the thoraco-lumbar fascia between the iliac crest and the twelfth rib, and the internal aspects of the lower six costal cartilages, where it interdigitates with the diaphragm (Williams, Bannister, Berry, Collins, Dyson, Dussec & Ferguson, 1995, p. 825). Its upper fibres pass medially to form an aponeurosis blending with the linea alba, and the lower fibres curve downwards and medially together with those of the aponeurosis of internal oblique to the crest and pectin of the pubis, to form the falx inguinalis (Williams et al., 1995, p. 825) (see Figure 5).

Due to this horizontal fibre orientation, contraction of transversus abdominis results in a reduction of abdominal circumference with a resultant increase in tension in the thoraco-lumbar fascia and an increase in intra-abdominal pressure, which can induce a hoop tension (if displacement of the abdominal contents is prevented) (Hodges, 1999). Transversus abdominis is supplied by the ventral rami of the lower six thoracic and the first lumbar spinal nerves (Williams et al., 1995, p. 825).

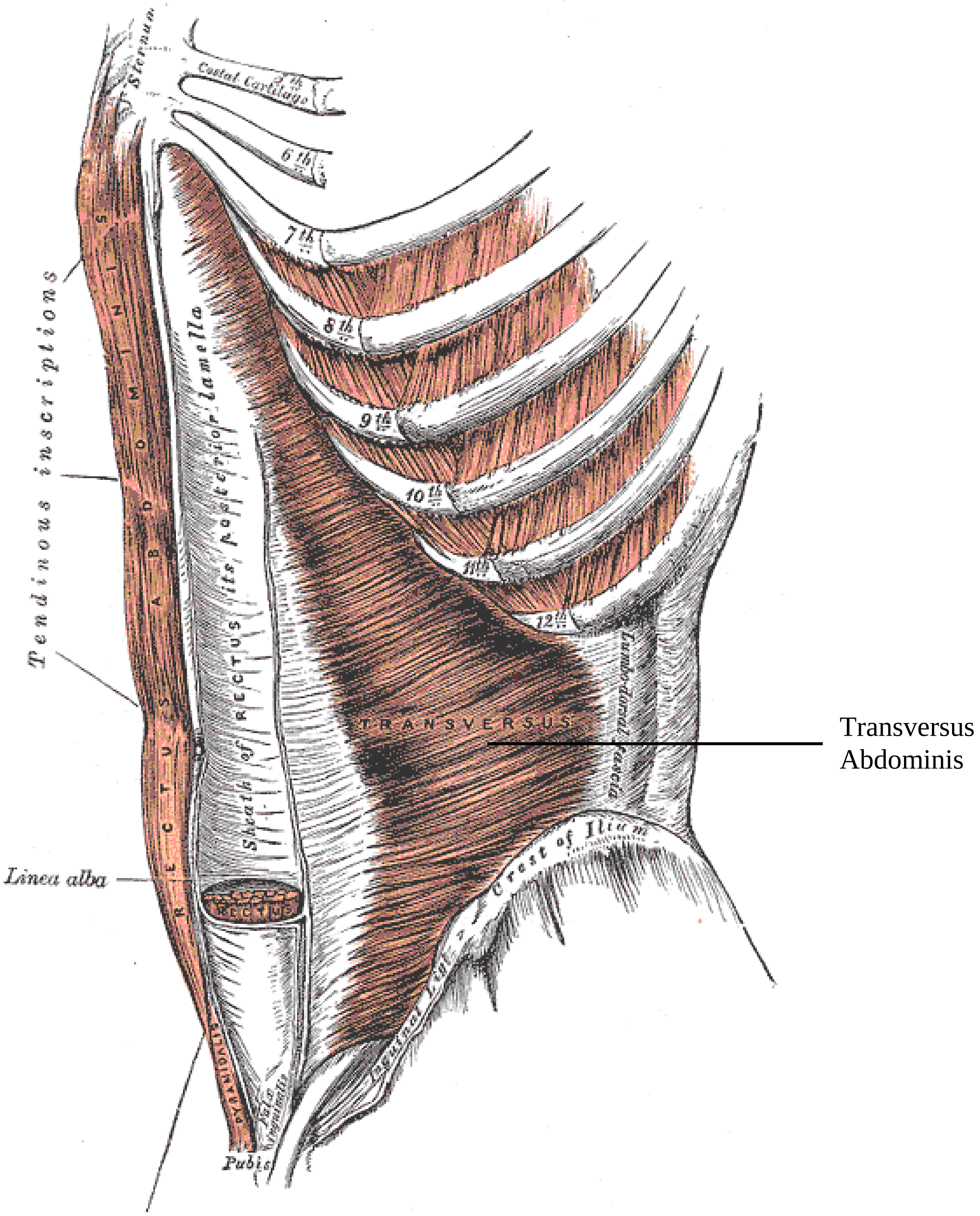

Figure 5 Transversus Abdominis. Attachments shown into the inguinal ligament, iliac crest, thoracodorsal fascia (lumbodorsal fascia), lower six costal cartilages, and linea alba. From Williams et al. (1995), p. 824.

Neuromotor Control of Transversus Abdominis

In the past decade the role of transversus abdominis in spinal stability has come under close scrutiny. An increase in the amount of research in this area was stimulated by Cresswell & Thorstensson who observed that high intra-abdominal pressure was present during isometric trunk extension, yet little activity of internal oblique, external oblique or rectus abdominis could be detected (Hodges, 1999). Transversus abdominis was postulated to be responsible for this pressure increase, which led to Cresswell, Grundstrom & Thorstensson (1992) investigating transversus abdominis as a possible contributor to spinal control. They recorded intra-muscular activity of the individual muscles of the ventrolateral abdominal wall (transversus abdominis, internal oblique, external oblique and rectus abdominis) with fine-wire electrodes during trunk movements. During trunk flexion-extension transversus abdominis was recruited continuously, whereas the other abdominal wall muscles showed phasic activity in response to trunk movement (Cresswell et al., 1992). The conclusion was that transversus abdominis was the abdominal muscle with an activity pattern that is most consistently related to changes in intra-abdominal pressure and that these changes possibly related to a general stabilising function of transversus abdominis (Cresswell et al., 1992).

Cresswell, Oddsson & Thorstensson (1994) then investigated the recruitment of the trunk muscles in response to an externally generated pertubation of the spine by adding a weight to a harness over the shoulders. These weights were added under unexpected and expected loading conditions. The transversus abdominis was always the first active muscle in both the unexpected and self-loading conditions. Cresswell et al. (1994) suggested that the increase in intra-abdominal pressure is a mechanism designed to improve the stability of the trunk through a stiffening of the whole segment prior to loading. This finding provided the first insight into the possible activation of transversus abdominis in advance of a predictable pertubation (Hodges, 1999).

A series of studies then looked at how the central nervous system maintains trunk posture and intervertebral control of the inherently unstable spine during rapid limb movement. Temporal components of the response of the muscles of the trunk during rapid unilateral leg movements (Hodges & Richardson, 1997a) and arm movements (Hodges & Richardson, 1997b) in varying directions were assessed (see Figure 6). Three dimensional movement of the trunk (Hodges, Cresswell, Daggfeldt & Thorstensson, 2000) and centre of mass (Hodges, Cresswell & Thorstensson, 1999) were also assessed in relation to trunk muscle activation. Consistent with Cresswell et al. (1994), all studies revealed onset of transversus abdominis EMG activity in advance of rapid limb movement, with the timing and magnitude of activity not varying between movement directions. The onset of EMG activity of the other trunk muscles (internal oblique, external oblique, rectus abdominus, and multifidus), however, varied with the limb movement direction, being activated earliest when the prime action of the muscle opposed the reactive forces associated with the specific limb movement (Hodges & Richardson, 1997b). These muscles displayed phasic activation patterns that were found to be consistent with this pattern of preparatory motion and with the direction of motion of the centre of mass (Hodges et al., 1999). Preparatory three dimensional motion of the trunk was also found to be small but consistently in the direction opposite to the reactive moments prior to limb movement (Hodges et al., 2000). It was postulated that there were two separate preparatory central nervous system controls occurring with rapid limb movement: first the direction specific control of the centre of gravity in relation to the base of support, and second, the non-direction-specific contraction of transversus abdominis in anticipation of a predictable disturbance related to the control of trunk stability (Hodges, 1999).

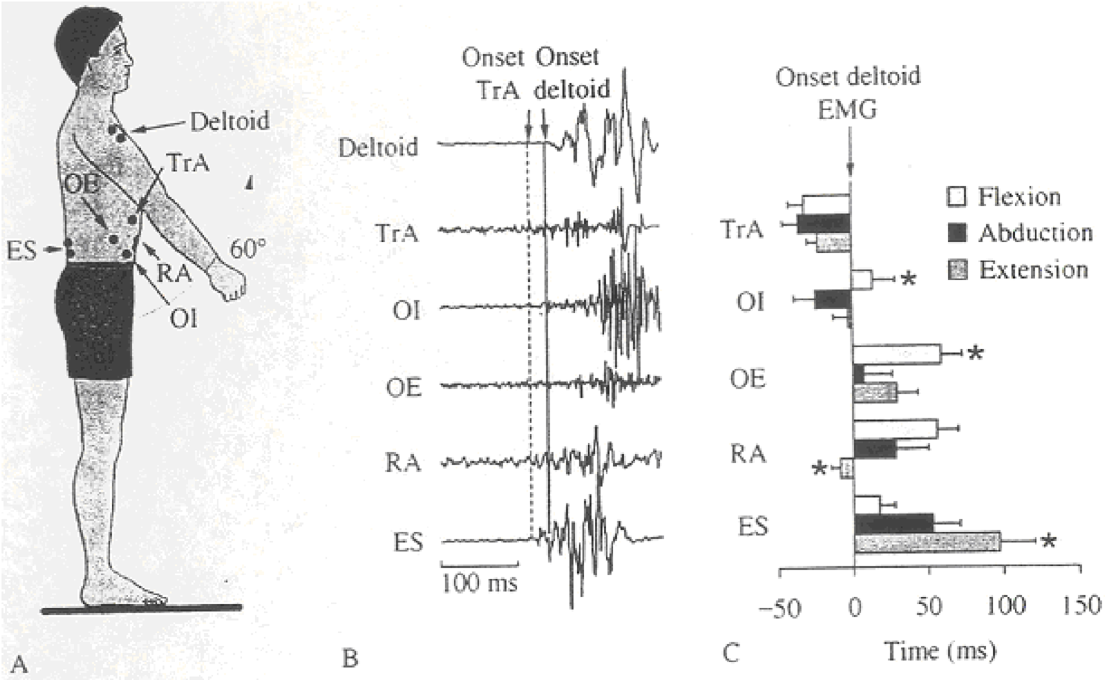

Figure 6 Recruitment of the abdominal muscles with rapid shoulder flexion. (A) Experimental setup indicating the location of the electromyography electrodes. (B) Electromyography (EMG) data of a representative subject from a single trial of shoulder flexion. Note the onset of transversus abdominis EMG prior to that of deltoid. (C) Mean times of EMG onset of each trunk muscle relative to that of deltoid for movement of the upper limb in each direction. Note the variation in limb movement direction for all muscles except transversus abdominis. Abdominal muscles: transverses abdominis (TrA), internal oblique (OI), external oblique (OE), rectus abdominis (RA) and erector spinae (ES). From Hodges & Richardson (1997b).

The relationship between force magnitude and the response of transversus abdominis has also been investigated. It was hypothesized that if the activation of transversus abdominis is related to spinal stability then it should be related to force magnitude and not be active in situations where the force is negligible and unlikely to perturb the spine (Hodges, 1999). A number of studies provide evidence of a threshold for transversus abdominis activation. Hodges & Richardson (1997c) found that feed forward activation of transversus abdominis was recorded with rapid and intermediate speed movement of the limb but no response occurred during movement performed at a slow speed, when the resulting reactive force on the spine is reduced. When comparing rapid movements of the arm and leg, the onset of transversus abdominis activity preceded that of the deltoid by 30 milliseconds during arm movement (Hodges & Richardson, 1997b), but with leg movement (which produces a greater reactive force on the spine) transversus abdominis activity preceded that of deltoid by more than 100 milliseconds (Hodges & Richardson, 1997a). The difference in timing indicated that at higher loads there is an earlier onset of transversus abdominis activation to stabilize the spine.

In summary, substantial motor control evidence exists for a contribution of transversus abdominis to spinal stability other than the control of spine orientation (Hodges, 1999). Studies have demonstrated that transversus abdominis responds in a relatively tonic manner (Cresswell et al., 1992) and is not related to the direction of trunk movement (Cresswell et al., 1992), acceleration or deceleration of the trunk (Cresswell, 1993), the direction of perturbation forces acting on the spine (Hodges & Richardson, 1997b) or the direction of displacement of the centre of mass (Hodges et al., 1999).

Proposed Mechanisms of Transversus Abdominis Contribution to Spinal Stability

It has been hypothesised that transversus abdominis contributes to spinal stability through inter-segmental control and the development of intra-abdominal pressure (Hodges, 1999; Hodges & Richardson, 1997b). The combined action of transversus abdominis contraction and intra-abdominal pressure converts the abdomen and spine into a rigid cylinder (Richardson, Jull, Hides & Hodges, 1998). With co-contraction of the pelvic floor and diaphragm, this increase in intra-abdominal pressure allows the abdominal muscles to contract without collapsing into the viscera (Richardson et al., 1998). Contraction of the transversus abdominis against the intra-abdominal pressure allows hoop tension to be developed in the thoraco-lumbar fascia, and the combined tension and intra-abdominal pressure converts the abdomen into a rigid cylinder, which may in turn stiffen the lumbar spine (Richardson et al., 1998). Intersegmental control could involve production of lateral tension by transversus abdominis in the thoraco-lumbar fascia that attaches to the lumbar vertebrae (Richardson et al., 1998). While muscles such as lumbar multifidus were found in an *in vitro* study by Wilke et al. (1995) to provide up to two thirds of the control of inter-segmental motion in certain directions, they could contribute little to the control of lumbar rotation. Bogduk, Macintosh & Pearcy (1992) also commented that the anterior shearing forces generated at the L5 level by maximal contraction of multifidus are counterproductive. Limiting translation and rotation may be where transversus abdominis is of major benefit in contributing to lumbar stability, acting through attachments to the transverse and spinous processes via the thoraco-lumbar fascia (Richardson et al., 1998). As tension is increased in the thoraco-lumbar fascia, movement of the vertebra in all directions may be decreased, resulting in a decrease in the size of the neutral zone (Richardson et al., 1998).

Transversus abdominis may also have a role in stability of the sacroiliac joints. Lee (2001) states that the transversus abdominis through its attachment to the iliac crest is ideally placed to act on the ilia to produce compression of the sacroiliac joints anteriorly, thus contributing effectively to the stability mechanism of this joint. It is also thought to contribute to compression of the sacroiliac joints secondary to its effect on the increase in thoraco-lumbar tension (Lee, 2001). This potential role of transverses abdominis is important as the sacroiliac joint is capable of being a source of nocicpetion in low back pain (Bogduk, 1997).

Transversus Abdominis Dysfunction in Low Back Pain

There is growing evidence that the deep abdominals and lumbar multifidus muscles are preferentially and adversely affected in the presence of acute low back pain (Hides, Richardson, & Jull, 1996), chronic low back pain (Hodges & Richardson, 1996; Roy, De Luca, & Casavant, 1989) and lumbar instability (Lindgren, Sihvonen, Leino, Pitkanen & Manninen, 1993; O'Sullivan, Twomey, Allison, Sinclair & Miller, 1997). It has been found that the most significant and consistent change in the anterior trunk muscles in people with low back pain is in the motor control of transversus abdominis (Richardson et al., 1998). Hodges & Richardson (1996) evaluated the temporal sequence of trunk muscle activity associated with arm movement in patients with low back pain. They found that contraction of transversus abdominis was significantly delayed and failed to occur in the pre-movement period with all arm movements in these patients failing to prepare the spine for the perturbation resulting from limb movement. The onset of transversus abdominis activity was also significantly different between movement directions and became more phasic resembling the activity of the superficial abdominal muscles (Hodges & Richardson, 1996). Further studies also showed that transversus abdominis was no longer activated independently of the superficial trunk muscles and that the threshold for activation of transversus abdominis was increased in people with low back pain

(Hodges, 1999). Richardson et al. (1998) stated that the most likely explanation for the delay in activation of the transversus abdominis in people with low back pain is changes in the motor control of this muscle. It was hypothesised that these changes in motor control would result in inefficient muscular stabilisation of the spine.

Clinical studies have investigated the ability of low back pain patients and control subjects to voluntarily perform the abdominal drawing in manoeuvre (Hodges, Richardson & Jull, 1996; Richardson & Jull, 2000). This inward displacement of the abdominal wall, which was measured by an air pressure device, is thought to be primarily the result of contraction of transversus abdominis (Hodges et al., 1996). It was found that those with low back pain were unable to consciously perform this abdominal drawing in manoeuvre adequately, while people with no history of low back pain could (Hodges et al., 1996). They were also able to predict who had low back pain based on this clinical test, and that the inability to perform the abdominal drawing in manoeuvre was related to the timing of onset of contraction of transversus abdominis associated with rapid limb movement (Hodges et al., 1996).

Theoretically, the failure of transversus abdominis activation would leave the spine unprotected from perturbation. Other structures may have to substitute for the function of transversus abdominis. In terms of muscles, lumbar multifidus could effectively take over some of the function of the transversus abdominis. Interestingly, in low back pain multifidus has been found to undergo significant wasting ipsilateral to symptoms in patients with first episode acute/subacute low back pain within 24 hours of injury (Hides, Stokes, Saide, Jull & Cooper, 1994). Furthermore, recovery of this muscle is not automatic after resolution of the painful symptoms without therapeutic intervention (Hides et al., 1996). The diaphragm and pelvic floor could also play a role in transversus abdominis dysfunction. Along with transversus abdominis, anticipatory co-activation of the diaphragm (Hodges, Butler et al., 1997; Hodges & Gandevia, 2000a) and pubococcygeus in the pelvic floor has also been reported, which is associated with an increase of intra-abdominal pressure and an increase of segmental stiffness of the spine (Comerford & Mottram, 2001). O’Sullivan (2000) reported that a failure of automatic feed forward motor control of the antero-lateral abdominal, diaphragm and pelvic floor muscles was observed in patients with lumbar segmental instability.

Without the muscular active system, increased stress is placed on the passive support structures. Because of the inherent instability of the lumbar spine, failure of the muscular stabilisation produces an increased risk of injury to the spine with only two degrees of intersegmental rotation required to produce micro trauma of the structures of the lumbar spine (Hodges & Richardson, 1996). Repeated micro trauma of these joint structures can lead to injury and may further increase the size of the neutral zone (Panjabi, 1992b). This increased neutral zone must be compensated by the trunk musculature to maintain the mechanical stability of the lumbar spine. However, in low back pain, transversus abdominis and multifidus, which are considered the two most important stabilising muscles, are commonly found to be in dysfunction. Research investigating retraining of these muscles and their motor control through exercise rehabilitation to reduce the reoccurrence of low back pain is showing promising results.

Exercise Rehabilitation of Transversus Abdominis for Low Back Pain

Stabilisation training has been used with success in patients with spondylolysis and spondylolisthesis (O'Sullivan et al., 1997), chronic low back pain (Johansson & Lindberg, 1995), and first episode acute low back pain (Hides et al., 1996). Richardson & Jull (2000) devised a specific exercise, which is proving to provide effective pain relief for chronic and recurrent back pain sufferers with segmental instability. The exercise approach focuses on retraining a precise co-contraction pattern of the deep trunk muscles, by simultaneous isometric co-contraction of transversus abdominis and multifidus, while maintaining the spine in a static neutral position. Although there is not yet in vivo proof of the biomechanical effect of this specific exercise, it is believed to enhance stability of the lumbar spine segments, therefore giving pain relief (Richardson & Jull, 2000).

As the muscle impairments are thought to be a problem in motor control, classic motor skill learning principles are followed through the cognitive, associative and autonomous stages (Jull & Richardson, 2000). As illustrated in Figure 7, the initial focus is on retraining the co-contraction of the deep local muscles by drawing in the abdominal wall and cognitively activating these muscles independently from the global muscles (Jull & Richardson, 2000). Progression is initially through increasing the number of repetitions and duration of holding this isometric contraction during inspiration and expiration. Exercise can then be progressed from low loads with minimal body weight to more functional body positions with gradually increasing external loads. Finally, patients should be able to hold a co-contraction of the deep muscles during dynamic functional movements of the trunk (Richardson & Jull, 2000). Pain relief is usually concomitant with the patient mastering the task of holding the abdominal drawing in and correct muscle action in all exercise positions (Richardson & Jull, 2000).

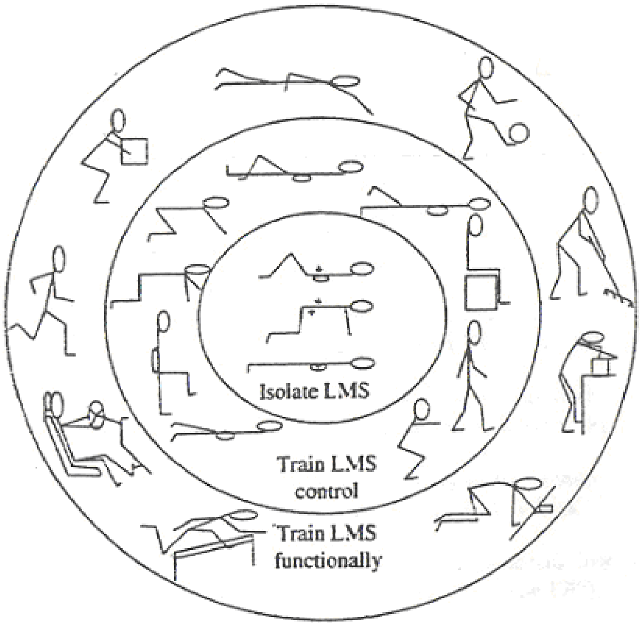

Figure 7 Stages of rehabilitation based on a motor learning model. LMS – local muscle system. From O'Sullivan (2000).

The effectiveness of this approach on pain and function in patients with low back pain was investigated by O'Sullivan et al. (1997) in the form of a randomised, controlled, clinical trial. O'Sullivan et al. (1997) took 44 patients with a radiological diagnosis of spondylolysis or spondylolisthesis and divided them into two groups. The first group followed the specific exercise programme and the control group underwent treatment as directed by their treating practitioner. The group treated with the specific motor learning exercise protocol over the ten week training period demonstrated significant reductions in pain intensity ($p<0.0001$) and pain descriptor scores ($p<0.0001$) as measured by the short form McGill pain questionnaire, and increased functional levels (p<0.0001) as measured by the Oswestry disability questionnaire (O'Sullivan et al., 1997). The control group had no significant difference in pain intensity and functional disability levels after the intervention period (O'Sullivan et al., 1997). In the 3-year follow-up of the trial, the results were maintained (Jull & Richardson, 2000).

Research into whether the specific exercise programme can reverse the muscle impairments and problems in motor control has also been investigated. Hides et al. (1996) conducted a clinical study on patients with acute, first-episode, unilateral low back pain who demonstrated unilateral, segmental inhibition of the multifidus muscle. Muscle recovery was found to be more rapid and more complete in patients who received the specific exercise therapy and medical treatment, compared to the control group who received just medical treatment. The control group still had decreased multifidus muscle cross sectional area at the ten week follow-up examination despite resuming normal levels of activity and remission of painful symptoms (Hides et al., 1996).

Further clinical trials need to be undertaken to more widely test the effectiveness of the specific motor learning exercise programme. It is unknown at this time whether this programme is the most appropriate or whether other exercise regimens (for example, pilates) are less effective, equal or superior in reversing the problems in motor control of the deep muscles (Jull & Richardson, 2000).

Pilates

Pilates (pronounced puh-LAH-teez) is an active method of balancing and strengthening, focusing on core stabilisation and postural alignment (Pilates International Training Centre, 2002). Pilates can be performed on the floor (‘matwork’) or with the use of specially designed resistance training devices. Exercises follow specific and ordered sequences and emphasise ‘core movements’ and ‘body balancing’. During the exercise session participants are encouraged to actively focus on concentration, control, movement flow, precision, body centring, and breathing. Various claims have been made about the effectiveness of pilates exercises, including enhanced motor control, enhanced physical function (strength, endurance, power, flexibility) and enhance psychological function (mood, motivational state, attentional focus) (Lange, Unnithan, Larkam & Latta, 2000).

Born in Germany in 1880, Joseph H. Pilates had a lifelong interest in body conditioning. As a sickly child plagued with asthma and rickets, he was dedicated to becoming stronger. He obsessed about the perfect body, something to combine the physique of the ancient Greeks with the meditative strength of the East. During the time he served as a nurse in World War I, he designed exercise apparatus by attaching springs to hospital beds for non-ambulatory patient exercise. This system formed the foundation for his style of body conditioning and specialised exercise apparatus. The result was 500 exercises requiring intense concentration and aimed mainly at developing a strong abdomen, as well as deep stretching. Pilates immigrated to the United States in 1923 and opened the first Pilates Studio in New York City in 1926. Initially the exercises were primarily used by dancers as a complementary form of fitness as well as in rehabilitation of injuries. After his death in 1967, numerous proponents carried on Pilates' work. Modern pilates uses the fundamentals of Joseph Pilates' work, philosophy and exercises with modifications that make it appropriate for those of any age, for the unwell, during pregnancy and after trauma as well as for the very fit elite athlete, dancer or performer (Latey, 2002).

With the publicity of celebrity appeal, and the trend toward mind-body exercises, there has been a significant increase in the popularity of pilates within the last couple of decades. There are now thousands of practitioners around the world who refer to themselves as pilates instructors. In the United States alone it is estimated that pilates based exercises have grown from 5,000 users ten years ago to five million today (Chang, 2000). Time Magazine stated that the number of pilates studios has grown from just five worldwide in 1976 to 500 in the United States alone by 1998 (Edwards, 1998). The mat portion of the pilates repertoire is also experiencing huge growth, with the Washington Post reporting that in 2001 that less than 10 percent of fitness clubs offered instruction in mat pilates, with 40 percent offering them in 2003 (Nelson, 2003).

In the 1990s, pilates techniques also began to gain popularity in the rehabilitation setting. Many rehabilitation practitioners are now using the method in multiple fields of rehabilitation, including general orthopaedic, geriatric, chronic pain, and neurologic rehabilitation (Anderson & Spector, 2000).

There has been a lack of research conducted on the effects of pilates despite its growing popularity. The majority of pilates research that has been completed has involved dancers. Fitt, Sturman & McClain-Smith (1993) demonstrated strength and flexibility gains in dancers, but data on jump-height increases was equivocal in dancers and gymnasts (Fitt et al., 1993; Hutchinson, Tremain, Christiansen & Beitzel, 1998). Static (Fitt et al., 1993) and dynamic (McMillan, Proteau & Lebe, 1998) posture improvements and various dance aesthetic qualities (Parrott, 1993) have been found but the validity of some reports has been questioned (McMillan et al., 1998). A case study by Brown & Clippinger (1996) suggests that pilates based exercise may be useful for knee rehabilitation and a case study by Blum (2002) concluded that the addition of pilates therapy can be useful in management of patients with chronic low back pain in the clinical setting.

Many other studies, however, support common movement principles found in the pilates exercises. As discussed in the literature review, recent research has highlighted the importance of transversus abdominis and multifidus in the role of lumbar instability. Abdominal hollowing techniques have been widely advocated to reduce the recurrence of low back pain and lumbar instability. The pelvic floor has been shown to activate in close association with transversus abdominis and the diaphragm in a feed forward mechanism to increase spinal stability. As mentioned above, pilates focuses on building an efficient 'central core' or ‘powerhouse of the body’ (Muscolino & Cipriani, 2004). In pilates, 'central core' is usually defined as extending from the pelvic floor inferiorly to the ribcage superiorly (Muscolino & Cipriani, 2004) with the strengthening of key muscles of the central core: transversus abdominis, multifidus, pelvic floor and diaphragm, being of importance. Siler (2000) states that all of the pilates exercises constantly work the powerhouse. Muscolino & Cipriani (2004) support this supposition in their statement that pilates exercises fit into two broad categories: category one exercises solely aimed at working the muscles of the powerhouse using mainly concentric and eccentric contractions, and category two exercises that seem to be focusing on another part of the body where motion is being directed to occur, but, the underlying focus and intent is directed toward stabilising (isometric) contractions of the muscles of the powerhouse. Neither of these authors, however, gives any experimental data to support these statements.

Initially when learning pilates there is a predominance of category one exercises often starting with abdominal hollowing and pelvic floor contraction techniques coordinated with breathing taught in static positions so the participant learns to activate the central core. The load and demand on the central core is then increased by introducing graduated arm and leg movements and stretches (category two exercises) in more dynamic movements and postures to improve functional ability.

Methodology Literature Review

Muscle Size as a Measure of Training

Repeated overloading of a muscle, as well as chronic stretch of either a normal or denervated muscle, are factors that can increase the muscle mass, whereas disuse of a skeletal muscle will result in muscle atrophy, and a reduced cross-sectional area of both type I and type II fibres is noticed (Åstrand, 1986). In order to achieve a training effect, it is necessary to expose the organism to an overload, that is, to a stress that is greater than that regularly encountered during everyday life (Åstrand, 1986).

The high correlation between the cross-sectional area of a muscle and its potential to produce strength was first documented by Ikai & Fukunaga (1970). The authors noted that three maximal ten second isometric contractions repeated daily for about 100 days increased the isometric strength approximately 90 percent with about a 25 percent increase in the thickness of the muscles involved (Åstrand, 1986). The gradually increasing muscle hypertrophy is achieved by an increase in the thickness of individual muscle fibres (Timson, Bowlin, Dudenhoeffer & George, 1985) by the formation of more myofibrils. The number of muscle fibres remains constant (Åstrand, 1986). At the beginning of a strength training programme, an increase in strength may be observed without any change in the cross-sectional area of the muscles involved. One explanation for this finding is a more efficient activation of the motor units illustrated by an increase in the electromyographic activity during a maximal effort (Åstrand, 1986).

Factors That Could Affect Muscle Size

As well as training and disuse, age, stress, medication and nutrition are all factors that can affect muscle thickness. Sarcopenia (loss of skeletal muscle mass with age) is common in adults over the age of 65 years and increases with age (Iannuzzi-Sucich, Prestwood & Kenny, 2002). The influence of sarcopenia will be reduced in this study by restricting the maximum age of participants to 55 years.

During physical and mental stress, cortisol is produced which has a profound influence on carbohydrate metabolism. Cortisol increases the catabolic breakdown of proteins and the formation of carbohydrates from protein, a major source of protein being muscle. It has been found that the result of prolonged cortisol administration was muscular wastage, causing reduced muscle strength and endurance (Åstrand, 1986). The level of stress that subjects are under is not anticipated to have a major influence on the outcome of this study and will not be controlled for. However, a list of any medication taken and any medical conditions subjects are suffering will be noted, with its potential effect on muscle thickness being taken into account when analysing the results.

Muscle size is influenced by nutrition. Nutritional deprivation has been shown in rats to result in a significant decrease in diaphragm fibre cross-sectional area (both type I and II), with type II fibres showing greater atrophy (Sieck, Lewis & Blanco, 1989). McLoughlin, Spargo, Wassif, Newham, Peters, Lantos & Russell (1998) also demonstrated severe type II muscle fibre atrophy in young adult female patients with severe anorexia nervosa (40% self-induced weight loss).

In an attempt to assess nutritional status in this study, 24-hour food recall questionnaires will be administered randomly to subjects during the pilates intervention study. The 24-hour recall is a retrospective method of collecting dietary information. This method is preferred to other methods as it does not influence the individuals eating habits. Johansson, Solvoll, Opdahl, Bjorneboe & Drevon (1997) showed that having the interviewer personally contact the participants by either giving out the surveys or collecting them back in increased the response rate. The questionnaire requires the subject to remember and report all the food and beverages consumed in the preceding 24-hours.

Subject total energy intake and protein levels will be compared to levels stated in the New Zealand Food and Nutrition Guidelines (Ministry of Health, 2003). The recommended daily intake of protein for healthy adults is set at 45 grams for women and 55 grams for men per day (Ministry of Health, 2003). The usual daily median energy intake is 11,631 KJ/day (2769 Kcal/day) for males and 7,701 KJ/day (1834 Kcal/day) for females (Ministry of Health, 2003).

Implications for Osteopathy

The discovery of the important role played by the deep abdominal muscles in back pain rehabilitation and prevention has lead to a sharp rise in the popularity of the clinical use of specific exercises in the rehabilitation of back pain patients. Despite the research recommending the inclusion of these specific exercises, along with manual therapy and education in treating patients with low back pain, to the author's knowledge, osteopaths are not trained to a satisfactory clinical level in exercise rehabilitation or in teaching these specific exercises to patients.

As these specific exercises require a high level of participant concentration in order to correctly involve the desired muscles, a supervised environment is optimal to learn and perform these exercises in to gain maximal benefit and prevent further injury. Pilates classes offer a supervised environment in which the participant rehabilitating from low back pain can be cued to correctly activate the appropriate muscles to perform the specific exercises in the correct way.

If claims can be substantiated that pilates trains the deep abdominal muscles, pilates offers an alternative for osteopaths in referring patients for exercise rehabilitation of low back pain. This project is, therefore, of direct relevance to all practitioners, including osteopaths, prescribing specific exercise therapy in the rehabilitation of patients with low back pain.

Research Aims & Objectives

The aim of the pilates intervention study was to investigate the extent to which pilates was effective in altering muscle thickness in the deep abdominal muscle, transversus abdominis, which has been identified as being important in protecting the spine and in rehabilitation of low back problems. The methodology used to measure transversus abdominis thickness with B-mode ultrasound was evaluated in the reliability study.

Pilates instructors claim the exercise methodology trains these deep abdominal muscles and is effective in the rehabilitation of low back pain. Results of this study will also contribute to knowledge about how to treat back pain more effectively.

METHOD

RELIABILITY STUDY
Intra-tester Reliability of Transversus Abdominis Thickness Measurement Using B-mode Ultrasound in Subjects with a History of Low Back Pain.

Introduction

Function of transversus abdominis has been studied in people with and without low back pain using EMG, pressure biofeedback and ultrasound (Critchley & Coutts, 2002; De Troyer, Estenne, Ninane, van Gansbeke & Gorini, 1990; Ferreira, Ferreira & Hodges, 2004; Hodges & Richardson, 1997a; O'Sullivan et al., 1997). Ultrasound imaging is a non-invasive tool that can be used to generate measurements of muscle size, thus providing a method of direct assessment of muscle atrophy and hypertrophy (Hides, Richardson, Jull et al., 1995). It has been suggested that serial measurements could be used to assess the effects of muscle rehabilitation (Hides, Richardson, Jull et al., 1995).

Validity of ultrasound measurements of muscle size of the quadriceps has been demonstrated when comparing with measurements obtained by computer tomography scanning (Sipila & Suominen, 1993). Ultrasound and magnetic resonance imaging measurements of lumbar multifidus cross sectional area were compared by Hides, Richardson & Jull (1995) who found no significant differences between the two imaging modalities.

Reliability of transversus abdominis thickness measurement by ultrasound has been demonstrated in healthy subjects. Bunce, Moore & Hough (2002) measured 22 subjects on three separate occasions using M-mode ultrasound, taking 20 measures at half-second intervals from each M-mode image. In measurements taken with subjects positioned supine, reliability was relatively high for consecutive measures shown by the mean (standard deviation) coefficient of variation of 7% (2), and for measurements on separate days an intraclass correlation coefficient of 0.94. Misuri, Colagrande, Gorini, Iandelli, Mancini, Duranti & Scano (1997) also concluded that measurement of transversus abdominis thickness was repeatable (coefficients of variation ranging from 0 to 15.6%) after measuring thickness using B-mode ultrasound at functional residual capacity in six normal male subjects.

McMeeken, Beith, Newham, Milligan & Critchley (2004) used real time ultrasound in B-mode and M-mode and with 7.5 MHz linear or 5 MHz curvilinear transducers to measure transversus abdominis thickness at the end of quiet inspiration. Intra-tester reliability for B-mode ultrasound with 7.5 MHz linear transducer was very high with ICC of 0.99 (95% CI 0.96 to 0.99) for measurement of transversus abdominis thickness in 13 healthy subjects on two separate days. Intra-tester reliability for M-mode ultrasound measurements on two separate days was also found to be very high with ICC of 0.98 (95% CI 0.94 to 0.99). Results from the concurrent measurements of transversus abdominis with both B-mode and M-mode ultrasound were analysed by McMeeken et al. (2004) using Bland and Altman plots and maximum difference between measures (0.2 mm). McMeeken et al. (2004) concluded that results from B-mode and M-mode ultrasound may be validly compared.

De Troyer et al. (1990) and Abe, Kusuhara, Yoshimura, Tomita & Easton (1996) observed variable firing of transversus abdominis in the later part of expiration during quiet breathing in "healthy subjects" while seated. In the supine position, however, De Troyer et al. (1990) commented that abdominal muscle use during breathing is in general minimised or delayed compared with the seated posture. Hodges, Gandevia et al. (1997) did not observe transversus abdominis contraction during quiet breathing in the standing posture, although they explained that during the study they reminded subjects to relax their abdominal muscles when tonic activity was occasionally observed, this being enough to cease contraction in transversus abdominis.

Ultrasound imaging is widely regarded as being a safe procedure, and unlike many other forms of medical imaging, there is no exposure to any ionising radiation (Chhem, Kaplan & Dussault, 1994). However, limitations of ultrasound do include an inability to measure large muscles in their entirety in cross-section and the possible effects of pathology, such as fatty infiltration on muscle size (Hides, Richardson, Jull et al., 1995). The quality of the ultrasound image is also very dependent on the expertise of the operator (Hides, Richardson, Jull et al., 1995).

Haberkorn, Layer, Rudat, Zuna, Lorenz & van Kaick (1993) investigated the effect on ultrasound B-scan image brightness, microtexture and macrotexture (image sharpness), with different simulations of abdominal wall composition and thickness. Haberkorn et al. (1993) found that an increasing fat path caused a decrease in ultrasound image brightness and microtexture, and concluded that an increase in the fat layer of the abdominal wall caused a darker, less sharp image. A potential source of error could, therefore, be introduced in subjects with increased abdominal wall adipose tissue if fascial boundaries of transversus abdominis when scanning with ultrasound are not well defined.

At the time of undertaking the study, there were no published studies investigating the reliability of transversus abdominis thickness measurement using B-mode ultrasound in subjects with a history of low back pain. Also, as the techniques are operator dependent in carrying out the ultrasound measurement procedure, reliability specific to the operator needed to be shown before an intervention study using this methodology could be conducted.

Method

The study was approved by the Unitec Research Ethics Committee (Unitec, New Zealand) and all subjects gave their written informed consent to participate prior to testing.

Reliability of Transversus Abdominis Measurement on Separate Days

Study Population

Subjects in the reliability group were recruited from the general public via convenience sampling, and consisted of eight subjects (four male and four female) aged from 21 to 45 years with a mean (SD) of 29.9 (7.6) years. All subjects reported having experienced low back pain at some point in the past. None of the subjects had had surgery for low back pain or abdominal surgery. At the time of testing, all subjects were asymptomatic and not receiving treatment for low back pain.

Study Design

The reliability study for measurement of transversus abdominis on two separate days was a within subject repeated measures design using a single operator to conduct ultrasound imaging of transversus abdominis in subjects with a history of non-specific low back pain. Transversus abdominis thickness was measured five times for each subject at each of the measurement sessions held at the same time of the day one week apart.

Reliability of Transversus Abdominis Measurement over Five Consecutive Trials

Study Population

Thirty subjects, eight from reliability group and the 22 from the pilates intervention group were tested during this study. The participants consisted of nine males and 21 females, aged 21 to 55 years with a mean of 37.7 (10.4) years. Further information on the subject selection for the pilates intervention group subjects can be found under the heading Study Population, page 44.

Study Design

The reliability study of five consecutive measurements of transversus abdominis thickness was a within subject repeated measures study using a single operator to conduct ultrasound imaging of transversus abdominis in subjects with a history of non-specific low back pain. Data were used from the measurement sessions for the reliability group (trial one and trial two) and the measurement sessions for the pilates intervention group (pre pilates and post pilates).

Ultrasound Measurement of Transversus Abdominis

Ultrasound services including venue, use of equipment and clinical sonographer to conduct measurements were provided by Mercy Radiology Group. Ultrasound measurements were conducted at Mercy Radiology, Mercy Hospital, Epsom, Auckland.

The thickness of the right transversus abdominis of each subject was measured with the subject in the supine position and knees bent to 90 degrees (see Figure 8). Ultrasound images were obtained using B-mode diagnostic ultrasound on a LOGIQ 700 Expert Series (General Electrics, Milwaukee, WI) with a 7 Mhz 739L linear array transducer.

The ultrasound transducer was applied to the skin, with gel intervening, in an area between the twelfth rib and the iliac crest, and held perpendicular to the anterolateral abdominal wall to obtain the highest level of clarity of the fascia. The placement of the transducer is consistent with positioning described in studies by Critchley & Coutts (2002), Bunce et al. (2004) and Misuri et al. (1997). Skin blemishes were noted by the sonographer for each subject to allow a more accurate re-location of the imaging site at the second ultrasound measurement session. Where skin blemishes were not present, an ink mark was placed on the subject with an indelible skin marker.

Figure 8 Patient and ultrasound transducer position for measurement of transversus abdominis. Reproduced from Hides et al. (1998).

Images were displayed in grey scale on a video monitor. With the subject breathing quietly at rest, an image of the anterolateral abdominal wall was captured at the end of expiration (functional residual capacity). The sonographer then scanned frame by frame forward and backward to choose the frame that showed transversus abdominis at its greatest thickness. The sonographer then measured the thickness of transversus abdominis in the middle of the image at the thickest point, by placing the cursor on the fascia either side of transversus abdominis, with the distance being calculated between the two points (see Figure 9 and Figure 10). This process was repeated until five images and measurements had been captured for each subject.

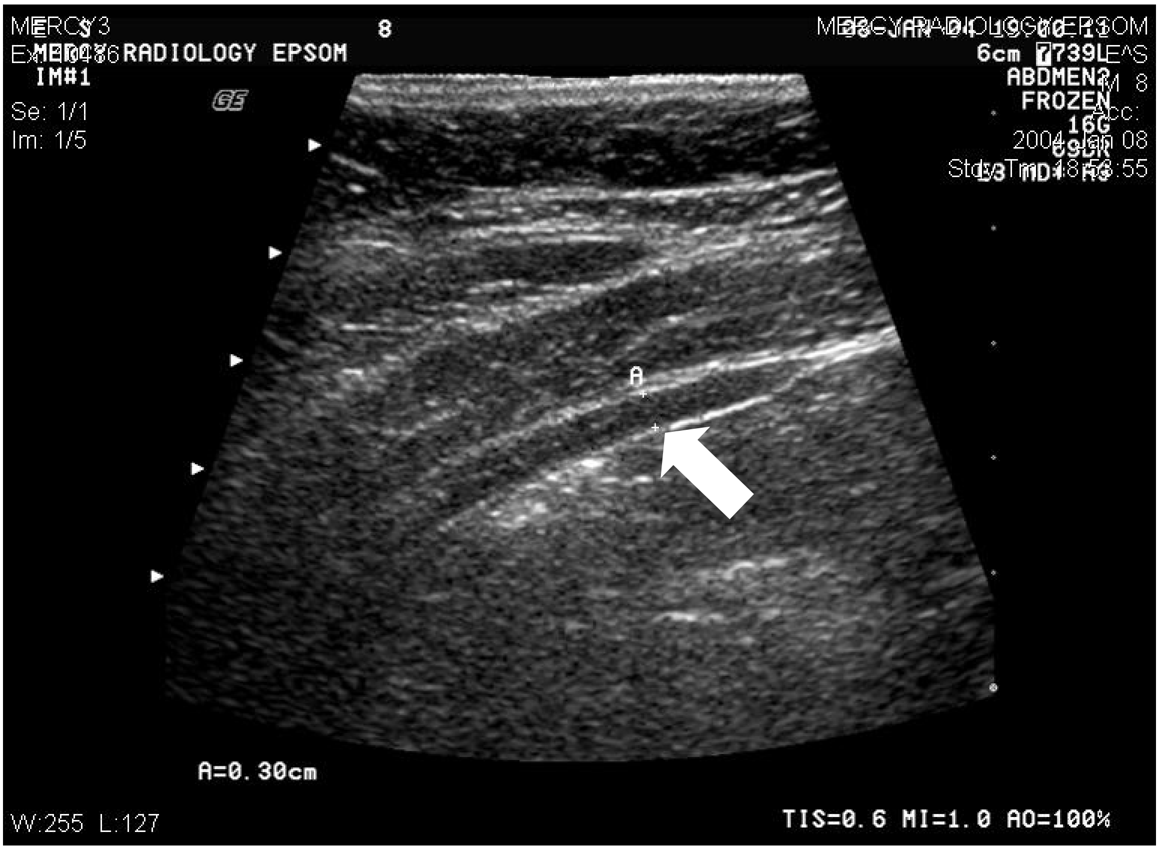

Figure 9 A typical example of a pre pilates ultrasound digital image of the anterolateral abdominal wall in transverse section (subject 8). Arrow pointing to the markers (small white + marker) (label = A) placed on the fascia bordering transversus abdominis (thickness measurement shown A=0.30 cm).

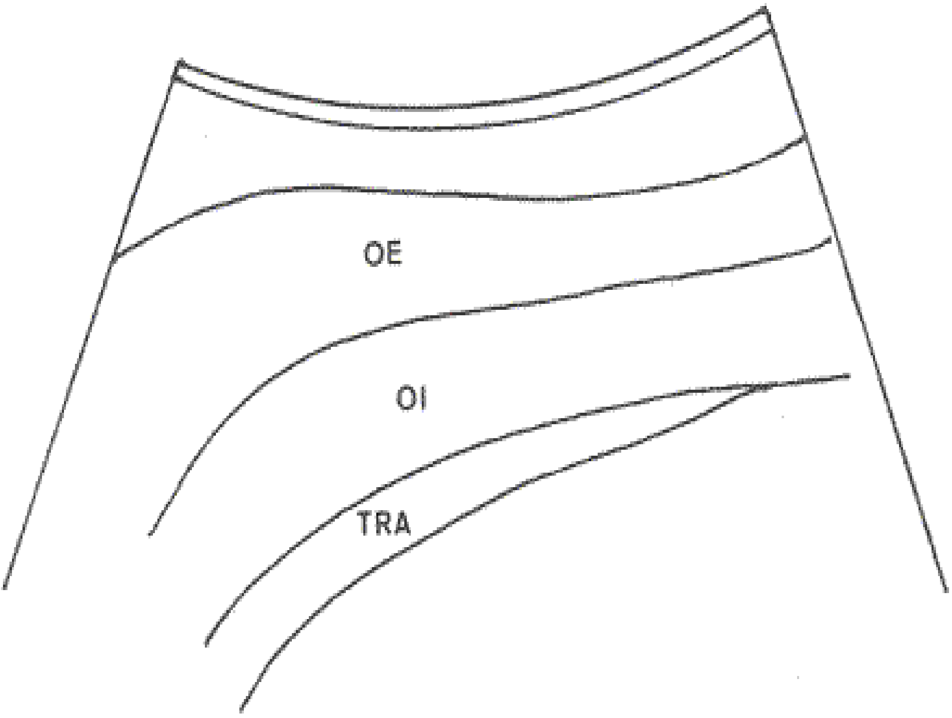

Figure 10 Diagram representing sonographic appearance of muscles of anterolateral abdominal wall in transverse section. From Hides et al. (1998).

As a control for bias, the sonographer was blind to the values of measurements taken. Also, the subjects were not instructed on breathing and were blind to the timing of thickness measurement with respiration. Positioning the subject, identifying ultrasound transducer position, waiting until the subjects breathing had reached a quiet relaxed rate and rhythm, and performing the measurements at the end of expiration on five consecutive occasions, took approximately five minutes per subject.

Data

The captured images and measurements were stored electronically against each subject's unique identifier code. The images and measurements for each subject were then printed out on laser x-ray film and stored digitally on compact disc. The five measurements for each subject at each session were copied manually from the printed images onto an excel spreadsheet for statistical analysis.

Statistical Analysis

Reliability analysis was performed using Hopkins (2000b) excel spreadsheet. The reliability of the transversus abdominis thickness measurements one week apart, and the reliability of the five consecutive trials of measurements of transversus abdominis thickness, was analysed using intraclass correlation coefficients (ICC). 95% confidence intervals were also constructed for each coefficient. These calculations were repeated using log transformed data to check for heteroscedasticity. Descriptors were obtained from Cohen (1988) and Hopkins (2002a) for the magnitude of the confidence intervals. Typical error as a coefficient of variation (%) using log transformed data was also calculated for the reliability of the five consecutive measurements. All descriptive data are reported in the format mean (standard deviation).

Results

Reliability of Transversus Abdominis Measurement on Separate Days

The mean thickness of the transversus abdominis measurements taken at the first (trial 1) and second (trial 2) sessions were 0.37 cm (0.11), and 0.38 cm (0.09) respectively (see Table 1). There was a high level of correlation found between the repeated ultrasound measurements taken in supine position in the eight individuals one week apart using the same sonographer (Intraclass Correlation Coefficient = 0.92, 95% confidence intervals 0.60 to 0.99) (see Table 1). Similar figures were obtained with log transformed data when checking for heteroscedasticity. Typical error calculated as a coefficient of variation using log transformed data was 8.1% (CI 5.5 to 18.0).

Table 1 Intra-tester reliability for ultrasound measurements of transversus abdominis thickness on separate days one week apart (n=8).

Thickness of Transversus Abdominis (cm) Mean (standard deviation)		Intraclass Correlation Coefficient (r)	Confidence Intervals (95%)	Magnitude of Correlation
Trial 1	Trial 2			
0.37 (0.11)	0.38 (0.09)	0.92	0.60 - 0.99	High to nearly perfect

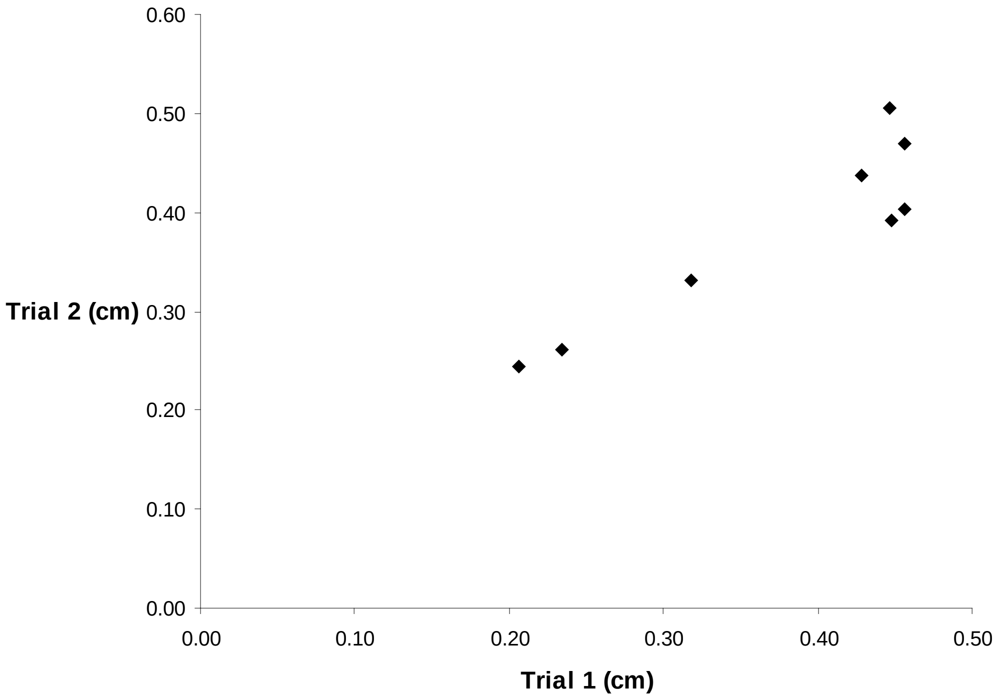

Figure 11 Transversus abdominis thickness (mean) for each subject measured by ultrasound on separate days one week apart (n=8).

Reliability of Transversus Abdominis Measurement over Five Consecutive Trials

Fifty-seven sets of data consisting of five consecutive trials of measurements from 30 subjects were recorded. Three subjects from the pilates intervention group withdrew from the study, one due to family reasons, one due to health reasons, and one failed to turn up for the post pilates measurement session. The mean thickness of transversus abdominis in subjects ranged from 0.20 cm (0.03) to 0.59 cm (0.04). The mean thickness of the five trials of measurements of transversus abdominis ranged from 0.35 cm (0.10) to 0.37 cm (0.09) (see Table 2).

Table 2 Transversus abdominis thickness for the five consecutive trials of ultrasound measurements taken on the same day (n=30, with 57 sets of data).

Trial	Mean (cm)	Standard Deviation (cm)
Trial 1	0.37	0.09
Trial 2	0.36	0.11
Trial 3	0.36	0.10
Trial 4	0.35	0.10
Trial 5	0.35	0.10

The results of the analysis suggested there was a high level of correlation between the consecutive trials of ultrasound measurements using the same sonographer. Typical error calculated as a coefficient of variation using log transformed data ranged from 5.4% (CI 4.7% to 6.9%) to 8.8% (CI 7.7% to 11.4%) (see Table 3). Intraclass correlation coefficients ranged from 0.89 (95% CI 0.82 to 0.94) to 0.97 (95% CI 0.95 to 0.98) (see Table 3 and Figure 12), with coefficients of similar magnitude obtained with log transformed data when checking for heteroscedasticity.

Table 3 Intra-tester reliability of five consecutive trials of ultrasound measurements of transversus abdominis on the same day.

Trial	Coefficient of Variation (%) (95% CI)	Intraclass Correlation Coefficient	95% Confidence Intervals	Magnitude of Confidence Intervals
Trial 2v1	8.8 (7.7 to 11.4)	0.89	0.82 to 0.94	Very high to nearly perfect
Trial 3v2	7.1 (6.2 to 9.1)	0.95	0.91 to 0.97	Nearly perfect
Trial 4v3	5.4 (4.7 to 6.9)	0.97	0.94 to 0.98	Nearly perfect
Trial 5v4	5.6 (4.8 to 7.1)	0.97	0.95 to 0.98	Nearly perfect

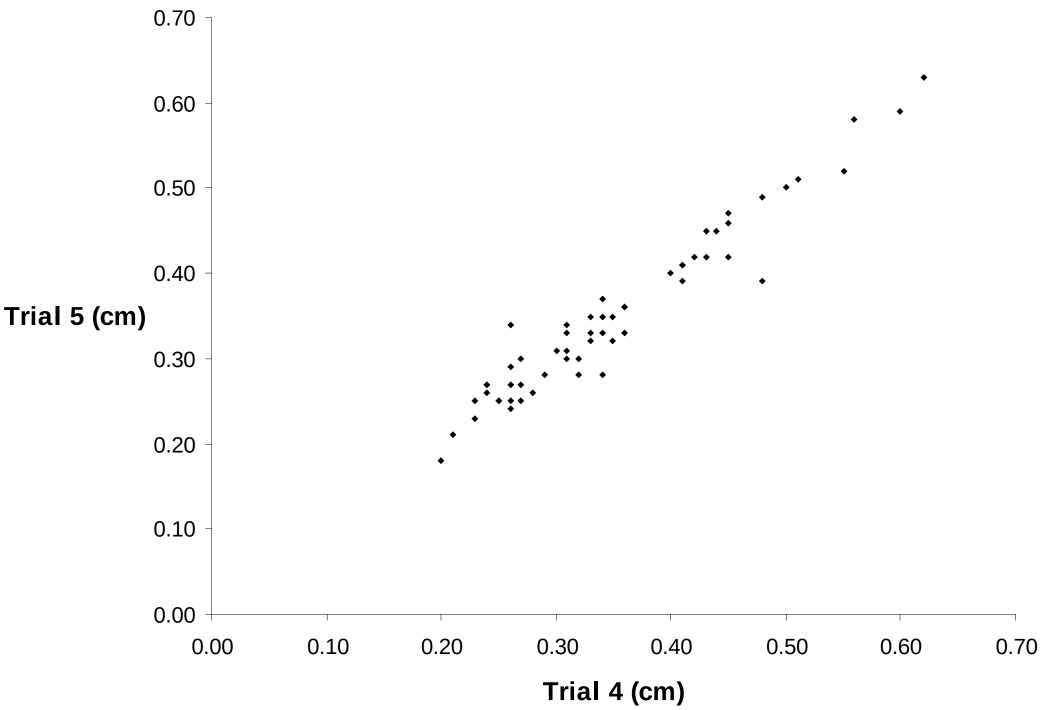

Figure 12 Typical plot of the mean thickness of transversus abdominis for two consecutive trials of ultrasound measurements on the same day (trial 5 versus trial 4).

Discussion

Reliability of Ultrasound Measurement of Transversus Abdominis

The results of the study showed that there was high intra-tester reliability for the ultrasound protocol used in measuring the thickness of transversus abdominis in subjects with a history of low back pain. Ultrasound measurements of subjects were found to have high intra-tester reliability in measuring transversus abdominis thickness one week apart. Intra-tester reliability was found to be very high for the five consecutive trials of transversus abdominis thickness measurements when analysing all data from the reliability and pilates intervention group subjects.

Reliability of Transversus Abdominis Thickness Measurement on Separate Days

The results from this study are consistent with previous findings of intra-tester reliability in measurement of transversus abdominis thickness by ultrasound on separate days (Bunce et al., 2002; McMeeken et al., 2004). The intraclass correlation coefficient and confidence intervals were comparable with, but slightly lower than that found by Bunce et al. (2002) (ICC = 0.94) and McMeeken et al. (2004) (ICC = 0.99, 95% CI 0.96 to 0.99) measured in subjects supine.

When comparing the present study and studies conducted by Bunce et al. (2002) and McMeeken et al. (2004) it was noted that there was a variation in the timing of the measurement of transversus abdominis during the respiratory cycle. The timing of measurements could potentially contribute to the slight variation in correlation coefficients observed. Bunce et al. (2002) measured transversus abdominis thicknesses at half-second intervals, with timing of measurements during the respiratory cycle not being mentioned in the study. McMeeken et al. (2004) measured the thickness of transversus abdominis at the end of quiet inspiration using B-mode ultrasound, with the timing during respiration being to avoid detectable contractile activity in transversus abdominis. In the present study measures of transversus abdominis thickness were taken at the end of quiet expiration.

Variable electrical activity in transversus abdominis has been observed in seated subjects breathing at rest only in the latter part of expiration (De Troyer et al., 1990;

Abe et al., 1996). McMeeken et al. (2004) found that EMG activity is linearly related to increase in transversus abdominis thickness ($p<0.0005$; $R^2 = 0.87$). Measuring transversus abdominis at the end of quiet expiration when there is potential for variably increased thickness could explain the variation of measurements recorded by ultrasound, especially on the subjects with higher average readings (see Figure 11). It would also fit as an explanation for why the ICC (0.92) in this present reliability study was slightly lower than reported by Bunce et al. (2002) (ICC 0.94) who took measurements throughout respiratory cycle, this ICC again being slightly lower than McMeeken et al. (2004) (ICC 0.99) who took measurements only at the end of inspiration.

In McMeeken et al. (2004), Bunce et al. (2002) and this current study, transversus abdominis EMG activity was not monitored at the time of thickness measurement. Therefore, any increase in thickness from resting levels due to muscle contraction of transversus abdominis (conscious or unconscious) at the point of ultrasound measurement and its subsequent influence on the magnitude of the reliability calculation is unknown.

Although these results show high intra-tester reliability in measurement of transversus abdominis thickness by B-mode ultrasound on separate days, further investigation into the relationship between transversus abdominis electrical activity at functional residual capacity and transversus abdominis thickness is required to refine this measurement technique.

Reliability of Transversus Abdominis Measurement over Five Consecutive Trials

Establishing transversus abdominis muscle thickness via ultrasound was found to have very high to nearly perfect intra-tester reliability for the five consecutive measures. The coefficient of variation found in this study ranged from 5.4% to 8.8% and compares to the findings of Bunce et al. (2002) who reported a mean (SD) coefficient of variation of 7% (2). Misuri et al. (1997) found the coefficient of variation ranged from 0 to 15.6% across six subjects, with four subjects showing no variation in measurement taken at functional residual capacity. Further investigation is required to assess why some individuals have a large variation in transversus abdominis thickness at functional residual capacity when others have virtually no variation.

Reliability Study Limitations

The intra-tester reliability for the ultrasound scanning protocol used in this study was found to be acceptable for measuring transversus abdominis thickness. However, there are several stages in the ultrasound protocol where there is potential for error. Improvements in reliability may be made with modifications to the ultrasound scanning methodology and measurement protocol.

Positioning the ultrasound transducer to optimally show defined fascial lines and ability to maintain this position was dependent on the skill of the sonographer. To minimise the change in position the transducer could have been fixed in a device and attached to the subject. For example, Ferreira et al. (2004) placed the transducer in a dense foam cube to minimise changes in angulation or pressure when imaging the anterolateral wall.

The judgement of the sonographer was used when timing the ultrasound image capture at the end of quiet expiration and in choosing by eye from the images the frame that had the greatest thickness of transversus abdominis. A more technical approach was used by Ferreira et al. (2004) who placed an inductance plethysmograph around the chest of subjects to indicate timing of end of expiration when muscle thickness images were captured for measurement. Misuri et al. (1997) found that the thickness of transversus abdominis increased significantly from functional residual capacity to residual volume ($p<0.005$) when measuring six normal male subjects using B-mode ultrasound. Any increase in breathing volume to below functional residual capacity could, therefore, potentially influence the thickness of transversus abdominis.

Muscle measurement in the present study was made at the point in the middle of the image that appeared to have the largest transversus abdominis thickness, with the image being marked with a cursor on the fascial boundaries of transversus abdominis on screen to calculate the distance. Measurement of thickness was carried out at the time of making the recordings, adding time pressure to a process relying on the skill of the sonographer. Time pressure could have been removed by just capturing the image of the anterolateral wall and storing it for post hoc measurement. The digital images of the anterolateral wall could then have been enlarged increasing the accuracy of placement of the cursor on the fascial boundaries of transversus abdominis. An alternative post hoc method of measuring muscle thickness from an image of the anterolateral abdominal wall was carried out by Ferreira et al. (2004). They used a grid placed over the image, with measurements taken at three points: in the midline of the image and one centimetre either side, with the average of the three measures recorded for analysis.

The methodology used and skills required to carry out the measurements in this reliability study were similar to those used daily in practice by the sonographer in taking clinical measurements which may be the reason for the high reliability of measurements shown in this reliability study. For reliability transferable to other studies, however, inter-tester reliability needs to be established. Until that time it would be recommended for any further research investigating muscle thickness via ultrasound to first establish the reliability of measurements for the machine, operator and methodology utilised prior to examining the effect of other variables.

Summary

The ultrasound methodology to measure transversus abdominis in cross section in subjects with a history of low back pain was found to have a high level of reliability. The methodology used was therefore judged to be useful as a measurement tool in investigating the effects of a six week beginner pilates mat exercise programme on subjects with a history of low back pain.

PILATES INTERVENTION STUDY METHOD

Study Population

Sample

Research participants were accessed from the general public via convenience sampling. Participation was invited from the general public, the student body and Unitec staff. Invitation to participate was extended via word of mouth, notice board posters at Unitec, and a generic email invitation to all Unitec staff at the institution.

Subjects

From 46 volunteers, 22 subjects (five male and 17 female), aged 23 to 55 years were accepted for the intervention study. These 22 subjects are referred to as the pilates intervention group. The study was approved by the Unitec Research Ethics Committee (Unitec, New Zealand) and all subjects gave their written informed consent to participate in the study.

Criteria for Inclusion

Subjects were required to have a history of non specific low back pain. The subjects, however, were required to be in a period of remission experiencing no low back pain on entering the study. These criteria were enforced to maximise the subjects ability to fully participate in the pilates classes without being restricted by pain, and minimise the acute affects that pain may have on transversus abdominis thickness at the measurement sessions.

Subjects were required to be within the age range of 18 to 55 years at the time of the first ultrasound measurement session. The lower limit set as the age of consent without requiring parent or guardian permission and the upper limit set to minimise the complicating factor of the effect of age (sarcopenia) on muscle mass.

Criteria for Exclusion

With the aim of starting with a homogenous group of subjects with similar non specific low back pain characteristics, potential subjects were excluded if they had:

- Previously participated in pilates or yoga classes.
- Received treatment for back pain in the past three months.

- Any previous surgery for back pain.
- A history of neurological symptoms: pain, paraesthesia, numbness in limbs related to the subjects back pain. Thereby excluding those who had experienced neurogenic pain or neurological symptoms related to their low back pain.

Study Design

A within subject repeated measures design was used for this longitudinal study. During the nine week duration of the study, subjects participated in a six week programme of pilates exercise, with transversus abdominis thickness measures taken within two weeks prior to the first pilates class, and nine weeks later, within one week after the last pilates class. Questionnaires at entry to and during the study were used to monitor other potential factors that could influence muscle thickness. These factors were health status, nutrition, exercise levels, medical and physical therapy treatment, and medication.

Subject Selection and Data Collection

Individuals who volunteered for the study were orally questioned to establish if they met the inclusion criteria for the study. Those suitable were then given a participant information form (see Appendix 1 - Participant Information Sheets) and asked to complete in writing a pre exercise screening questionnaire (see Appendix 3 – Pre Exercise Questionnaire). The pre exercise screening questionnaire included questions on current health, medication, and exercise habits as well as collecting demographic information. Once the researcher was satisfied that the subject fulfilled the study criteria and was deemed fit to participate in the pilates exercise programme, the volunteer was then asked to complete a consent form (see Appendix 2 - Consent Forms). The volunteer then became a subject in the study, was given an information form on pilates classes (see Appendix 4 - Information on Pilates for Subjects), and scheduled for the ultrasound measurements and pilates classes. The first 22 eligible subjects by time of application were accepted for the study. The remaining volunteers were put on an ordered standby list in the event of any subjects pulling out of the study prior to the initial ultrasound measurement. One subject was included from the standby list in the pilates intervention study.

The initial ultrasound measurement was taken within 14 days prior to the commencement of the pilates classes. Exercise levels, injuries, illnesses and treatments were reported weekly by the subjects throughout the nine week period between ultrasound measurements via the exercise and injury/illness/treatment log (see Appendix 7 – Exercise & Injury/Illness/Treatment Log). In addition, as an assessment of nutritional intake, each subject completed a 24-hour food recall interview conducted by the researcher (see Appendix 6 – Nutrition: 24-Hour Food Recall Questionnaire), at a randomly allocated time within the nine weeks of the study. The final measurement of transversus abdominis thickness was taken within seven days after the completion of the pilates classes to minimise any detraining effect.

Ultrasound Measurement of Transversus Abdominis Thickness

Subjects had five consecutive measurements of transversus abdominis thickness taken at the end of expiration (functional residual capacity) during quiet resting breathing on two occasions approximately nine weeks apart at the pre and post pilates measurement sessions. The ultrasound measurement methodology utilised including equipment, sonographer, and protocol was identical to that used for the Reliability Study and is detailed under the heading Ultrasound Measurement of Transversus Abdominis, page 32.

Pilates Matwork Classes

Class Format

Twenty-two subjects were scheduled to complete two pilates classes per week over a six-week period. Four classes were run per week with a maximum of 12 participants in each class. Each class was of 45 minutes duration, with an additional 15 minutes allowed for administrative tasks.

Level of Class

Beginner pilates matwork class.

The classes followed the guidelines set by Pilates International, a Level 4 member of the international regulatory body, the Pilates Method Alliance Inc. For further information on Pilates International see http://www.pilatesint.com, or the Pilates Alliance, http://www.pilatesalliance.net. For an example of the pilates class format used, see Appendix 5 – Pilates Class Format & Sample Classes.

Instructor

The classes were conducted by the researcher, Ana Spurdle, who holds the Pilates Matwork Instructor Certification from Pilates International, and has been practising pilates for ten years.

Venue

The classes were held at the ETA O'Ryans Sports Centre, Carrington Rd, Mt Albert, Auckland.

Dates and Times

The classes were held between Monday 19 January and Thursday 26 February 2004, with subjects attending any two of the following classes held each week:

Monday	7.30 – 8.30 am	Except Mon 26 January, 9.00 – 10.00 am
Tuesday	12 noon – 1.00 pm	
Wednesday	7.30 – 8.30 am	
Thursday	12 noon – 1.00 pm	

Cost of Pilates Classes to Subjects

The pilates classes were free of charge to the subjects, as the classes were conducted by the researcher, Ana Spurdle, and the venue was provided free of charge by the Eta O'Ryans Sports Centre.

Health & Physical Activity Monitoring

Pre Exercise Screening Questionnaire

The pre exercise screening questionnaire (see Appendix 3 – Pre Exercise Questionnaire) served two purposes: firstly to screen volunteers to establish if they met the conditions required to be accepted as a participant in the study, and secondly to collect baseline data for the subjects who were accepted for the study. The data recorded for analysis from the pre exercise screening questionnaire included information on demographics (age, sex, ethnicity), current health status including medication, and current level of physical activity (mode, frequency, intensity, duration). The baseline data were compared with the information on health status and physical activity levels reported by subjects throughout the study in the weekly exercise and injury/illness/treatment logs.

Weekly Exercise & Illness/Injury/Treatment Log

Subjects were asked to complete a total of seven exercise and illness/injury/treatment logs (see Appendix 7 – Exercise & Injury/Illness/Treatment Log) during the study: weekly at the first pilates class attended each week, and at the post pilates measurement session. The questions on exercise levels were the same as those on the pre exercise screening questionnaire, asking for information on exercise performed during the previous week in terms of mode, frequency, duration, and intensity. Health status was assessed by asking if the subject had any increase in back pain, or suffered illness or injury requiring treatment in the past week. If the subject replied “Yes” to any of the above, further written details were requested.

Nutritional Assessment: 24-hour Food Recall Interview

The 24-hour food recall interview (see Appendix 6 – Nutrition: 24-Hour Food Recall Questionnaire) was used in an attempt to identify if any of the subjects fell into the extremes of either excess intake or severe lack of protein in the diet. Either excess or severe lack of protein has the potential to influence transversus abdominis muscle thickness during the course of the study.

Interviews with the 19 subjects who completed the study were conducted by the researcher. Each interview lasted approximately ten minutes. The interviews were conducted either immediately before or after a pilates class, or at the final ultrasound measurement session, with the day of the interview for each subject having been randomly selected.

The 24-hour food recall interview requested subjects recall all food consumed, type and serving size, over the previous 24 hours. A multiple pass method of interviewing was used. The subject was first asked to recall all food eaten the previous day. A more detailed list of the foods was then asked including type, brand and size of food, with household size items (bowl, cup, spoons) used to identify portion size. In the third pass the interviewer reviewed the list while the subject attempted to recall any other foods eaten.

Data Management

Ultrasound Measurement of Transversus Abdominis Thickness

Ultrasound measurement of transversus abdominis thickness data was managed as detailed under the heading Data, page 36.

Attendance at Pilates Classes

An attendance role was taken by the pilates instructor at each class. The number of classes attended by each subject was totalled and entered manually into an excel spreadsheet against each subject’s unique identifier.

Exercise Levels

Information on exercise patterns from the pre exercise screening questionnaire and exercise and injury/illness/treatment logs was recorded for each week against each subjects unique identifier code in an excel spreadsheet. Intensity, duration and frequency levels reported were categorised as detailed below and recorded as individual scores for each subject for each week. Scores for each week were then ranked between subjects.

Exercise Frequency Categories

0	=	0
1	=	1-2 sessions per week
2	=	3-4 sessions per week
3	=	5+ sessions per week

Exercise Duration Categories

0	=	0 mins
1	=	<20 mins
2	=	20-40 mins
3	=	40-60 mins
4	=	60+ mins

Exercise Intensity Categories

0	=	No exercise
1	=	Light
2	=	Moderate
3	=	Hard

Health Status

Information on health status from the pre exercise screening questionnaire and exercise & injury/illness/treatment logs were summarised by the researcher and recorded for each subject against a unique identifier in an excel spreadsheet under two headings: health status at entry to study, and, health during study. Health status of subjects at entry to study listed all reported medical conditions and medications. Health status which included all injuries, illnesses and treatments reported by subjects during the study was descriptively listed against the week in which it occurred. The weeks were categorised as shown below. Detail regarding medication was not specifically requested during the study, although some subjects volunteered the information.

Week 1 The time between the pre pilates measurement and the first pilates class (maximum duration for any subject was two weeks)

Week 2 The seven days after week 1

Week 3 The seven days after week 2

Week 4 The seven days after week 3

Week 5 The seven days after week 4

Week 6 The seven days after week 5

Week 7 The time between the end of week six and the post pilates measurement.

Two further groups of information were categorised for analysis: history of respiratory dysfunction and subjects that experienced low back pain during the study. These two groups of data were chosen to be categorised based on the number of subjects with similar characteristics that emerged from the data. Whether or not subjects reported that they experienced low back pain during the study on the exercise and illness/injury/treatment logs or not was categorised as either ‘Yes’ or ‘No’. Respiratory dysfunction at entry into the study was categorised for each subject as either ‘Yes’ or ‘No’. The category respiratory dysfunction encompassed any condition that directly affected the respiratory system. At entry into the study, the following health conditions that were reported by the subjects were judged by the researcher to be indicative of the subject having some degree of respiratory dysfunction: asthma (medicated), hayfever (medicated), recurrent chest infections, and taking antihistamine and nasal spray medication for an allergy.

Nutrition: 24-hour Food Recall

All information from the 24-hour food recall interviews was recorded by the interviewer on a 24-hour food recall questionnaire for each subject. Food consumed, including nutritional supplements and drinks, was recorded by type, brand and quantity. The lists of foods for each of the 19 subjects who completed the study were entered into the computer database, Diet Cruncher (Way Down South Software, Version 1.6.0). The interviewer matched most of the foods directly with the food listed in the database. When food could not be matched to food listed in the database it was broken down into its separate components and entered individually.

Demographic Information

All demographic information collected (age, ethnicity and sex) was entered into an excel spreadsheet against each subject's unique identifier code. Ethnicity was categorised into three groups: New Zealand European, Maori and Other, based on the frequency. The group 'Other' consisted of five subjects all of different ethnicity: Chinese, Indian, European, Serbian/Montenegro and Filipino.

Statistical Analysis

Change in Thickness of Transversus Abdominis

An unequal variance t-test was performed between pre and post pilates intervention of thickness of transversus abdominis. Effect sizes were also calculated (Hopkins, 2002b) and the precision of all estimates was expressed using 95% confidence intervals. Descriptors were obtained from Cohen (1988) and Hopkins (2002a) for the magnitude of effect size and magnitude of confidence intervals.

Exercise Levels

Exercise data were analysed from the 19 subjects who completed the study. The Friedman test (Hicks, 1999) was used to compare differences in the subjects exercise patterns reported in the pre exercise screening questionnaire and the seven exercise and injury/illness/treatment logs. Separate calculations were computed in excel for exercise intensity, duration and frequency.

Nutrition: 24-hour Food Recall

Nutritional data were extracted from Diet Cruncher (Way Down South Software, version 1.6.0), with the total amount of energy (kJ) and protein (grams) consumed over the one day surveyed being calculated for each subject. Total protein levels for each subject were compared to the recommended daily intake levels stated in the New Zealand Food and Nutrition Guidelines (Ministry of Health, 2003). As subjects' height and weight were not measured during the study, it was not possible to calculate the recommended daily energy intake for each subject for comparison with the New Zealand Food and Nutrition Guidelines.

Relationship between Change in Thickness of Transversus Abdominis and Demographic, Health, Nutrition and Pilates Class Attendance Data

A Spearman test as described in Hicks (1999) was used to assess the strength of the correlation between each of the sets of data recorded for the 19 subjects that completed the study and the mean change in thickness of transversus abdominis. Data were grouped according to sex (male/female), ethnicity (NZ European, Maori, Other), history of respiratory dysfunction (yes/no), and if subjects reported that they had experienced low back pain during the trial (yes/no) prior to analysis.

In order to determine the strength of the relationship between interval data and mean change in thickness of transverses abdominis, data were first grouped according to age, protein intake (grams), and number of pilates classes attended prior to analysis before conducting Pearson correlations. Corresponding correlations were used with the associated degrees of freedom to generate 95% confidence limits using the Fisher calculation in the Hopkins (2002b) excel spreadsheet.

RESULTS

Descriptive Statistics

Twenty two subjects were accepted for the study and completed the pre exercise screening questionnaire and initial pre pilates ultrasound measurement. The age of the subjects ranged from 23 to 55 years, with a mean (SD) of 40.5 years (10.0). There were 17 females and five males, with the ethnicity of the subjects consisting of 14 New Zealand European, three Maori and one each of Indian, Chinese, European, Filipino and Serbian/Montenegro descent, with the last five categorised for the purposes of analysis as ‘Other’ (see Table 6).

Three subjects withdrew during the study. One withdrew prior to the first pilates class for family reasons, one withdrew due to health issues (diagnosed with pernicious anaemia) after three pilates classes, and the third attended seven pilates classes but did not attend the post pilates ultrasound measurement (see Table 4).

Nineteen subjects completed the study, five males and 14 females. The average age ranged from 23 to 55 years with mean of 39.9 years (10.2) (see Table 7). Of those that completed the study, the number of pilates classes attended ranged from six to twelve with mean of 10 (1) classes attended (see Table 4). The 19 subjects all completed the required exercise and injury/illness/treatment questionnaires and the 24-hour food recall interview.

Exercise Levels

The change in exercise levels for the pilates intervention group subjects during the study appeared to be minimal for duration (χr^2 =1.5), frequency (χr^2 =1.5) and intensity (χr^2 =3.0) when comparing the Friedman statistics to the critical value (χr^2 =14.1). There are no known published data on the magnitude of this statistic to enable interpretation of the degree of change in subject exercise levels; therefore without further detail, the magnitude of the difference is unknown.

Nutrition

The protein intake from the 19 subjects that completed the 24-hour food recall interview ranged from 17 to 128 grams, with mean intake of 74.0 grams (25.4) (see Table 7). When comparing protein intake for subjects to the recommended daily intake (RDI) (Ministry of Health, 2003), only one subject (subject 19), who had a protein intake of 17 grams, was lower than recommended daily intake for females of 45 grams. Subject 19 recorded an increase in measurement of transversus abdominis thickness after the pilates intervention, so the effect of protein intake in this subject on muscle thickness was judged to be negligible. For further information on the data output from Diet Cruncher, see Appendix 9 – Protein and Energy Intake.

Health Status

Health status by individual subject reported on entering the study and during the study is detailed in Table 4. On entering the study, five subjects reported taking medication (subject 3, 9, 13, 20, 23), four subjects were categorised as having a respiratory dysfunction (subjects 9, 13, 23, 24), and one subject had a thyroid condition (hypothyroidism) (subject 20). During the study, six subjects reported experiencing low back pain (subject 8, 9, 11, 13, 14, 15), with two of these subjects (subject 8 & 9) undergoing treatment (osteopathy consultation). Three other subjects reported injuries or illness: subject 22 experienced renal colic from kidney stones and was hospitalised for one night due to pain during the study; subject 15 suffered neck pain from a whiplash type injury, attending physiotherapy treatment during the study; and subject 20 suffered a "chest infection" and was taking a course of antibiotic medication at the time of the post pilates measurement session.

Further results from analysis of subjects who reported low back pain during the study, and subjects classified as having respiratory dysfunction at entry to study is detailed in the results section titled: Correlation between Change in Transversus Abdominis Thickness and Demographic, Health, Nutrition and Pilates Class Attendance Data, page 60.

Change in Transversus Abdominis Thickness

The mean thickness of the transversus abdominis measurements for the 22 subjects at the pre pilates measurement session ranged from 0.20 cm to 0.59 cm with a mean of 0.34 cm (0.09). The range of measurements from the 19 subjects at the post pilates measurement session was 0.25 cm to 0.59 cm with a mean of 0.36 cm (0.10) (see Table 4).

The mean change between pre pilates and post pilates thickness measurements ranged from -0.27 cm to +0.22 cm with a mean change of 0.02 cm (0.11) (see Table 4). Nine subjects recorded an increase and the same number a decrease in transversus abdominis thickness, with one subject recording no measurable change (see Table 6, Figure 13 and Figure 14).

Out of the 19 subjects who completed the study, the four categorised as having a history of respiratory dysfunction at entry into the study (subject 9, 13, 23, 24) all recorded a decrease in thickness of transversus abdominis (see Table 4 and Table 6). The three largest decreases in transversus abdominis thickness came from subjects who were classified as having a respiratory dysfunction on entry to the study. The subject with the largest decrease (-0.27 cm) was medicated for asthma (subject 13), the subject with the second largest decrease (-0.08 cm) reported recurrent chest infections (subject 24), and the subject with the third largest decrease (-0.06 cm) was medicated for hayfever (subject 9) (see Table 4). The subject with the lowest decrease in thickness (-0.01) from the respiratory dysfunction group (subject 23) reported taking a “nasal spray and antihistamines for an allergy”. Subject 20, who reported suffering from a respiratory dysfunction (chest infection) at the time of the post pilates measurement recorded the fifth largest increase in transversus abdominis thickness.

Table 4 Pre and post pilates transversus abdominis thickness measurements (means) for each subject categorised and ranked by change thickness, with information on the number of pilates classes attended and subjects' health prior to and during study.

Subject ID	Mean Thickness of Transversus Abdominis			Pilates Classes Attended (Max=12)	Subject Health Status	
	Pre Pilates	Post Pilates	Change (Post – Pre)		Health History on Entry to Study	Health During Study
Increase in Transversus Abdominis Thickness						
1	0.28	0.50	+0.22	10		Wk 5 - lbp
14	0.41	0.59	+0.18	10		
8	0.30	0.43	+0.14	6		Wk 1 - lbp (after ultrasound, before classes started). Wk 7 -Osteopathy treatment lbp
19	0.33	0.46	+0.13	10		
20	0.20	0.33	+0.12	12	Hypothyroid. Medication=thyroxine.	Wk 7 – "chest infection". Medication – antibiotics.
10	0.28	0.34	+0.07	9		
4	0.33	0.35	+0.02	10		
5	0.28	0.31	+0.02	12		
12	0.55	0.57	+0.02	10		
No Change						
6	0.28	0.28	0.00	12		
Decrease in Transversus Abdominis Thickness						
13	0.59	0.32	-0.27	11	Asthma. Medication= Preventative inhaler & ventolin	Wk 5 - lbp, no treatment.
24	0.42	0.34	-0.08	10	Recurrent "chest infections"	
9	0.36	0.30	-0.06	12	Hayfever. Medication=Razene	Wk 1 - lbp & osteopathy treatment
15	0.28	0.26	-0.03	10		Wk3 – lbp. Wk 4 – whiplash type injury - neck pain & physio treatment until Wk 7
16	0.36	0.32	-0.03	10		
3	0.30	0.28	-0.02	10	Medication=Citalopram	
11	0.40	0.38	-0.02	12		Wk 7 - lbp
22	0.26	0.25	-0.01	9		Wk 4&7 - renal colic from kidney stones – hospitalised
23	0.26	0.25	-0.01	10	Medication=Nasal spray & Antihistamine for allergy	
Withdrew from Study						
2	0.29			0		Withdrew Wk 1 for family reasons
7	0.34			3		Withdrew Wk 2 – pernicious anaemia
18	0.43			7		Withdrew Wk 7
Totals						
Mean	0.34	0.36	0.02	9.3		
SD	0.09	0.10	0.11	3.0		
Range	.20-.59	.25-.59	-.27-.22	0-12		

Key:
lbp = low back pain
Wk = week during the study. See section Data Management, Health Status, page 50 for definition of time periods.
All data to 2dp

The difference in mean thickness of transversus abdominis between the pre and post pilates measurements analysed by *t*-test gave a p-value of 0.54. The effect size of 1.27 (95 % CI -2.9 to 5.5) indicated that there was a large magnitude of change in the mean thickness of transversus abdominis. Within 95% confidence intervals this could mean that the six week beginner pilates exercise programme effect on transversus abdominis thickness is likely to range from a very large negative effect to a nearly perfect positive effect (see Table 5).

Table 5 Effect of the six week beginner pilates matwork exercise programme on mean thickness of transversus abdominis in subjects with a history of low back pain.

Mean Thickness of Transversus Abdominis		p-value	Effect Size Statistic	Confidence Interval (95%)	Magnitude of Effect Statistic
Pre Pilates (n=22)	Post Pilates (n=19)				
0.34 (0.02)	0.36 (0.02)	0.54	1.27	-2.9 to 5.5	Large (Very large negative to nearly perfect positive)

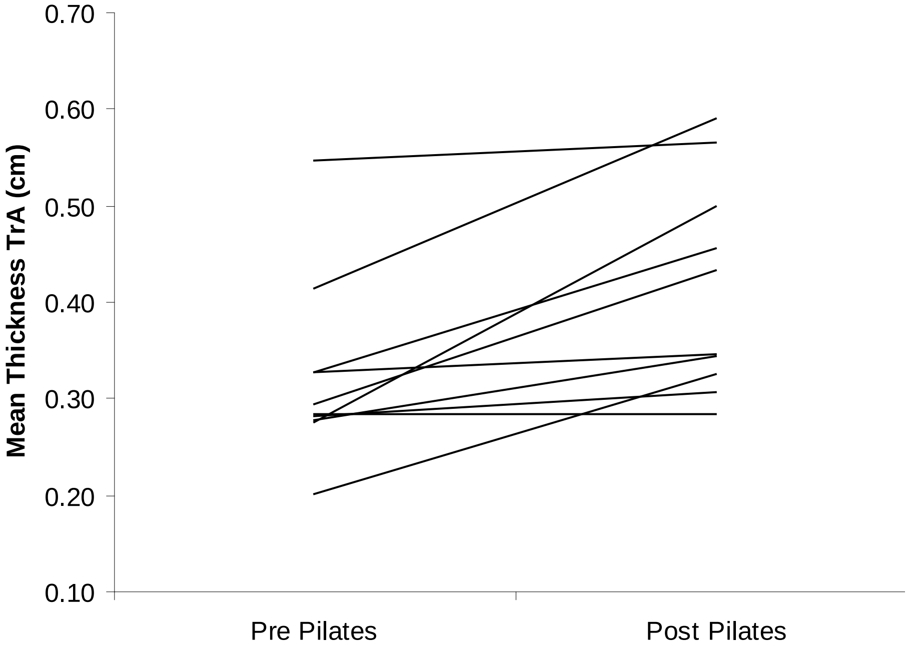

Figure 13 Subjects who recorded an increase or no change in the mean thickness of transversus abdominis measured by ultrasound after the six week beginner pilates exercise programme (n=10).

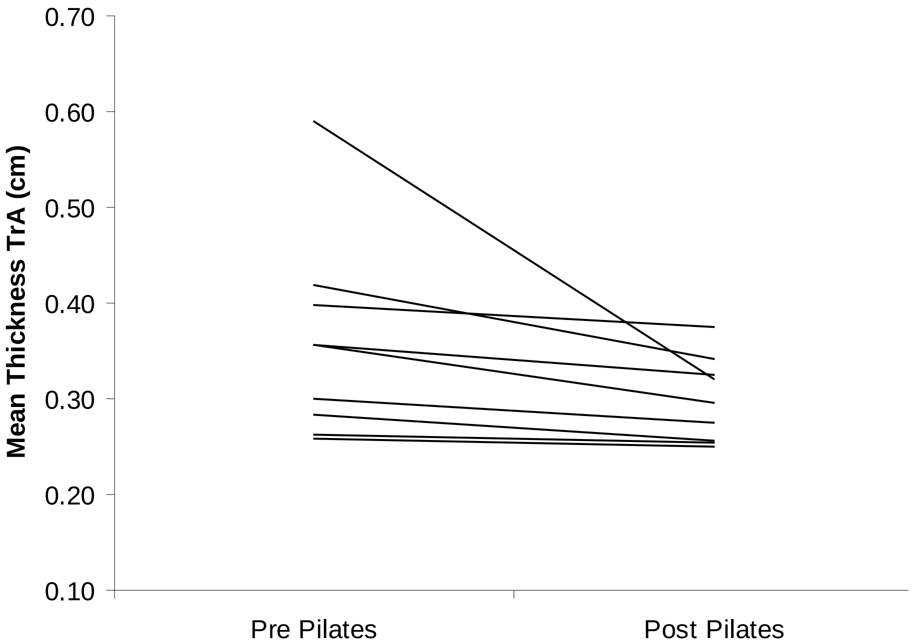

Figure 14 Subjects who recorded a decrease in the mean thickness of transversus abdominis measured by ultrasound after the six week beginner pilates exercise programme (n=9).

Correlation between Change in Transversus Abdominis Thickness and Demographic, Health, Nutrition and Pilates Class Attendance Data

There was a range of small to moderate magnitudes of correlations found when using the Spearman test to assess the relationship between mean change in thickness of transversus abdominis and sex (r=0.1, 95% CI -0.4 to 0.5), ethnicity (r=0.3, CI 0.2 to 0.6), and low back pain reported by subjects during the study (r=0.2, CI -0.2 to 0.6) (see Table 6).

For the relationship between change in thickness of transversus abdominis and history of respiratory dysfunction, however, there was a very high magnitude of correlation found (r=0.7, CI 0.3 to 0.9). At worst, when applying the lower confidence limit, subjects stating that they had a history of respiratory dysfunction at entry into the study had a moderate correlation with decrease in mean thickness of transversus abdominis after the six week beginner pilates exercise programme.

Table 6 Correlation between change in transversus abdominis thickness and sex, ethnicity, history of respiratory dysfunction, and low back pain during study (n=19).

	Number of Subjects	Number of Subjects with …			Spearman Correlation (r) (95% CI)	Magnitude of Correlation
		Increase thickness	No change thickness	Decrease thickness		
Number of Subjects	19	9	1	9	-	-
Sex					0.1 (-0.4 to 0.5)	Small
Male	5	3	-	2		
Female	14	6	1	7		
Ethnicity					0.3 (-0.2 to 0.6)	Moderate
NZ European	12	6	1	5		
Maori	2	-	-	2		
Other	5	3	-	2		
History of Respiratory Dysfunction	4	-	-	4	0.7 (0.3 to 0.9)	Very high
Low Back Pain During Study	6	2	-	4	0.2 (-0.2 to 0.6)	Small

The Pearson correlation for mean change in transversus abdominis thickness and the variables age (r=0, CI -0.4 to 0.5), protein intake (r=0, CI -0.5 to 0.5), and number of pilates classes attended (r=-0.3, CI -0.7 to 0.2) ranged in magnitude from trivial to moderate (see Table 7). From these correlation calculations and confidence limits, age, protein intake and number of pilates classes attended, appeared to have a minimal relationship to the change in thickness of transversus abdominis.

Table 7 Correlation between change in transversus abdominis thickness and age, protein intake and number of pilates classes attended (n=19).

	Subjects Mean (SD) (n=19)	Mean value for subjects with …			Pearson Correlation (r) (95% CI)	Magnitude of Correlation
		Increase Thickness	No Change Thickness	Decrease Thickness		
Age (years)	39.9 (10.2)	42	55	37	0.0 (-0.4 to 0.5)	Small
Protein Intake (grams/day)	74.0 (25.4)	74	55	76	0.0 (-0.5 to 0.5)	Small
Pilates Classes Attended	10.3 (1.4)	10	12	10	-0.3 (-0.7 to 0.2)	Moderate

DISCUSSION

Effect of Pilates Intervention on Transversus Abdominis Thickness

A large magnitude of change in the thickness of transversus abdominis as measured by B-mode ultrasound at the end of expiration during quiet breathing was observed after the six week beginner pilates matwork exercise programme in subjects with a history of low back pain. Statistically, the effect of the pilates intervention could range from a 'very large' decrease to a 'nearly perfect' increase in transversus abdominis thickness as measured at the end of expiration during quiet breathing.

It is not known why there was a wide variation observed in terms of magnitude and direction of change of transversus abdominis thickness. There were insufficient data collected on subject nutrition, exercise levels (excluding pilates), demographics, health status (excluding respiratory dysfunction) and medication to suggest that these were factors in the large variation of changes observed in transversus abdominis muscle thickness. There was statistically, however, a 'moderate' correlation found between reported history of respiratory dysfunction at entry to the pilates intervention study and change in transversus abdominis measured.

Out of the 19 subjects that completed the study, three recorded a decrease in transversus abdominis thickness greater than 10%, six recorded an increase of greater than 10% and ten subjects recorded a less than 10% change in transversus abdominis thickness. For the purpose of the discussion, subjects that had a change in transversus abdominis thickness greater than 10% have been discussed as having an increase or decrease, and the remaining as having minimal change in transversus abdominis thickness (reliability study coefficient of variation 8.1%, 95% CI 5.5 to 18.0).

Possible Reasons for Decrease in Transversus Abdominis Thickness

The best predictor of change in transversus abdominis thickness from the data collected and analysed was respiratory dysfunction at entry to the study. No conclusions can be made, however, due to the small sample size in this preliminary study.

A decrease in transversus abdominis thickness after the pilates intervention was measured in all of the subjects categorised with having a respiratory dysfunction at entry to the study. The only subjects who recorded a decrease of over 10% in transversus abdominis thickness over the study were also from the respiratory dysfunction group.

The pilates intervention could have lead to a decrease in transversus abdominis thickness measured in the respiratory dysfunction subjects due to, (a) a decrease in the actual resting thickness of transversus abdominis, and/or, (b) a decrease in the contractile activity of transversus abdominis at the end of expiration, resulting in a recorded decrease in thickness of transversus abdominis. The literature on functional and dysfunctional relationships between respiration and transversus abdominis, will be discussed along with potential reasons how the pilates intervention may have influenced this relationship in individuals with respiratory dysfunction and a history of low back pain.

Activation of Transversus Abdominis during Respiration

In healthy subjects the abdominal muscles, including transversus abdominis, should only take part in the respiratory cycle when expiratory flow is increased, remaining relaxed in normal quiet breathing (Richardson et al., 1998). Variable activation of transversus abdominis has been observed by De Troyer et al. (1990) and Abe et al. (1996) during expiration in healthy adults. In subjects with a history of chronic low back pain, Critchley & Coutts (2002) observed that in some subjects the abdominal muscles changed thickness slightly in rhythm with respiration. In forced expiration, the abdominal muscles act both to depress the thoracic cage and to elevate the diaphragm by raising the intra-abdominal pressure (De Troyer et al., 1988). Ninane, Rypens, Yernault & De Troyer (1992) found that more than half of patients with chronic obstructive pulmonary disease actively recruited transversus abdominis during resting expiration in the supine position and that recruitment was related to the degree of airway flow obstruction ($p < 0.005$). Estenne, Derom & De Troyer (1998) found that the pattern of increased activation of transversus abdominis during expiration in resting breathing in patients with severe thoracic scoliosis (with marked reductions in lung and chest-wall compliance) is similar to that seen in normal subjects with increased ventilatory drive (such as during hyperoxic hypercapnia) and in patients with advanced chronic obstructive pulmonary disease (airway obstruction) and concluded that this pattern of activation was neither load nor disease specific. Misuri et al. (1997), however, suggested the possible value of studying the abdominal muscles using ultrasound in various respiratory disorders due to the major contribution during forced expiration of transversus abdominis in generating gastric pressure in healthy individuals.

The range of respiratory conditions reported by subjects at entry to the pilates intervention study were asthma (requiring medication), recurrent chest infections, hayfever (requiring medication) and an undefined “allergy” (requiring nasal spray and antihistamine medication). It has been shown both in asthmatics (Pelacek, 2001) and in histamine induced airway resistance (Muller, Bryan & Zamel, 1980) there is a tendency during resting respiration toward hyperinflation of the lungs, an increase in functional residual capacity, and an increase in activity of the abdominal muscles during expiration. De Troyer et al. (1990) stated that whenever expiratory contraction of the abdominal musculature was induced involuntarily in healthy subjects, the transversus appeared to be the first muscle brought into action.

Research on the relationship between respiratory dysfunction, abdominal control and low back pain in the literature is sparse. It has been shown that when respiratory demand is increased either artificially in healthy adults or as occurs chronically in people with respiratory disease, electrical activity of transversus abdominis, the diaphragm and pelvic floor muscles are reduced in association with initiation of rapid limb movement (Hodges & Gandevia, 2000a; Hodges & Gandevia, 2000b). A study by Hurwitz and Morgenstern (1999) found that people with asthma are 50% more likely to have back pain than those without. Additionally, Nordin, Hiebert, Pietrek, Alexander, Crane & Lewis (2002) found that people who take sick leave from work for back pain are more likely to take longer to return to work if they suffer from a respiratory disease. Citing clinical experience, Bradley & Clifton-Smith (2002) suggest that decreased diaphragm movement seen in respiratory disorders can lead to inefficient breathing patterns, dysfunction in abdominal and spinal muscles leading to subsequent postural dysfunction and spinal pain. It has been postulated by Richardson, Hodges & Hides (2004), that people with respiratory disease may have increased incidence of low back pain due to dysfunction in motor control of trunk muscles to stabilize the spine under load. However, both of these ideas are yet to be investigated under research conditions.

The arguments of both Bradley & Clifton-Smith (2002) and Richardson, Hodges & Hides (2004) outlined above (if true) would support the observation in the current study that the subjects with a history of respiratory conditions had dysfunctional motor control of transversus abdominis at entry to this study. Transversus abdominis contraction during quiet breathing during and at the end of expiration in these subjects possibly contributed to increased gastric pressure assisting in overcoming potentially dysfunctional increased resistance to expiration.

At the pre pilates measurement, it is proposed that either contraction of transversus abdominis during expiration lead to a recorded thickness greater than resting thickness in the respiratory dysfunction group subjects, or, that the transversus abdominis thickness was measured ostensibly at rest, but due to a history of repetitive dysfunctional overuse during quiet respiration, this had lead to a hypertrophied thicker muscle. In either case, it is thought most likely that in the subjects with respiratory conditions transversus abdominis activity was increased during resting respiration. Any increase in thickness from resting levels due to muscle contraction of transversus abdominis (conscious or unconscious) at the point of ultrasound capture is not known as it was beyond the scope of this clinical study to concurrently measure transversus abdominis electrical activity. Further investigation would be useful to examine the relationship between transversus abdominis activity (with fine wire EMG) and thickness (M-mode ultrasound) during quiet respiration in people with respiratory dysfunction.

Pilates, Respiration and Transversus Abdominis Activation

Due to the pilates exercise intervention, there may have been changes in breathing patterns and respiratory function, with a decrease in the activation of transversus abdominis during respiration. The decrease in muscle activity during quiet respiration could have lead to muscle atrophy and a decrease in thickness at rest as measured by ultrasound, and/or, as is thought more likely by the researcher, a decrease in the contraction of transversus abdominis at the end of quiet expiration, leading to the decrease in muscle thickness measured. Further intervention studies looking at pilates exercise or breathing exercises, assessing subjects abdominal muscle activity and thickness pre and post during quiet respiration, plus clinical respiratory tests and functional disability questionnaires, could be beneficial to investigate the possible effects of such an intervention on respiratory and abdominal muscle function.

One of the core principles of pilates is breathing. Joseph Pilates stated that "before any real benefit can be derived from physical exercises, one must first learn how to breathe properly" (cited in Latey, 2002, p. 98). Similarly, Lewit (1980) proposed, based on clinical experience, that respiration must first be corrected before faulty movement patterns can be successfully addressed. Richardson et al. (1998) in a seminal text on therapeutic exercise for low back pain also stressed the importance of first establishing good control of the diaphragm in patients with dysfunctional breathing patterns. Dysfunctional breathing patterns included upper chest breathing, overuse of accessory muscles of inspiration and over activity of the external oblique during quiet inspiration and expiration. From clinical experience with chronic low back pain patients Richardson et al. (1998) comments that facilitating an isolated contraction of transversus abdominis and multifidus is challenging without diaphragmatic breathing patterns.

Effect on respiratory function was one of the earliest claims Joseph Pilates made of the health benefits from his exercise. Joseph Pilates felt that correct breathing would accomplish more toward attaining and maintaining maximum health standards than "all other remedies" (as cited in Latey, 2002, p. 98). Joseph Pilates trained fellow internees in England during the First World War, and boldly claimed that the practice of his exercise regimen was the reason why not one of them died from influenza, the viral respiratory infection that killed thousands in the 1918 epidemic (Robinson & Thomson, 1997). This early example of Joseph Pilates, suggests that there may be a basis for exploring the nature of the relationship between respiratory health and practicing pilates exercise, although detailed scientific and clinical investigation is required before any claims may be substantiated.

Over eighty years later, Bradley & Clifton-Smith (2002) recommended breathing exercises, core stability exercise and stretches for the trunk, chest and shoulders, similar to exercises performed in pilates, to help prevent chest infections and for people with asthma, hayfever, sinusitis and respiratory dysfunction due to allergies. The stretches, core stability exercises and breathing exercise to retrain resting breathing patterns for better health described by Bradley & Clifton-Smith (2002) are generally aimed at decreasing use of accessory respiratory chest muscles, improving posture, encouraging breathing through the nose and decreasing respiratory rate. Bradley & Clifton-Smith (2002) state that from their clinical experience, changes from faulty to ‘normal’ breathing patterns can be achieved in six weeks, which was the duration of the pilates exercise intervention in this study.

People with respiratory disorders tend to have a higher than physiologically required respiratory rate, increased blood oxygen saturation levels and overly decreased carbon dioxide levels (Bradley & Clifton-Smith, 2002). Palecek (2001) stated that in slowing the respiratory rate and increasing the duration of expiration, functional residual capacity decreases, thus reducing hyperinflation. In pilates, a slow respiratory rate is required for correct execution of most exercises due to the coordinated instruction of inspiration and expiration with different movements performed in each exercise.

Retraining nose breathing is a starting point for many patients with respiratory dysfunction and breathing disorders (Bradley & Clifton-Smith, 2002). Hypersensitivity of the bronchioles in response to foreign substances in the air is a common cause of asthma (Guyton & Hall, 2000), and when the nasal mucosa is affected by an allergen or congestion such as in hay fever (allergic rhinitis) or sinusitis, this can also trigger off bronchoconstriction (Bradley & Clifton-Smith, 2002). Breathing through the nose is therefore important as it allows warm, humidified, filtered air into the respiratory tract and lungs which reduces the amount of potential irritation to the tissues (Bennett, Zeman & Jarabek, 2003). When compared to breathing through the mouth, nose breathing increases the resistance to inspiration by up to 50 per cent acting to reduce the rate at which air is inspired and reduce the tendency for hyperinflation (Bradley & Clifton-Smith, 2002). Inspiratory muscle training through increasing resistance to inspiration over a six month period in subjects with asthma was shown to decrease hyperinflation and functional residual capacity, reduced asthma symptoms and to reduce medication (Weiner, Azgad, Ganam & Weiner, 1992). In pursed lip breathing, with chronic obstructive pulmonary disease subjects inspiring through the nose and expiring through the mouth lead to a reduction in end expiration chest wall volume, increased the time of expiration and total respiratory cycle and reduced breathlessness (Bianchi, Gigliotti, Romagnoli, Lanini, Castellani, Grazzini & Scano, 2004). Breathing in through the nose and out through the mouth (usually with purse lips) is advocated in pilates classes for all exercises. Instruction on this pattern is emphasised at the start of class with participants being continually reminded to maintain this breathing pattern for the duration of the class.

Stretches of the accessory respiratory muscles and exercises in training core stability and activation of transversus abdominis are included in breath retraining by Bradley & Clifton-Smith (2002). In pilates, the major focus is on developing the core stability so that the extremities can work more efficiently from a strong, flexible centre. To complement the core stability, focus is placed on identifying and reducing unnecessary accessory respiratory muscle activity and unnecessary muscle activity around the chest, shoulders and neck. This is carried out by instructing participants to maintaining deep breathing into the lower rib cage while relaxing the shoulders back and down, engaging activity of latissimus dorsi, nodding the head slightly forward in an attempt to lengthen the back of the neck, while relaxing the neck and throat. Attention to the neck, shoulders and chest is revisited repetitively in each class for participants to gain awareness of, and as a reminder, to reduce excessive or unnecessarily held muscle tension.

Summary

The most likely explanation for the observed decreases in thickness in the four individuals categorised as having respiratory dysfunction was that there was a change in the transversus abdominis activation patterns with respiration between the two measurement sessions. After the pilates intervention the activation of transversus abdominis was comparatively reduced at the end of expiration, therefore overall showing a reduction in thickness of transversus abdominis across the study for the respiratory dysfunction subjects. To further investigate this idea, ultrasound image capture for measurement would need to be concurrently recorded with electrical activity of transversus abdominis. Generalisation about the effects of pilates exercise on transversus abdominis in people with respiratory dysfunction can also not be made due to the very small number of subjects in the respiratory dysfunction group in the present study. Due to the scarcity of information available in the literature, there is a need for further research into the relationship between the following variables: respiratory dysfunction, low back pain, transversus abdominis and benefits of breathing and exercise training.

Possible Reasons for Minimal Change in Transversus Abdominis Thickness

Ten subjects out of the 19 that completed the pilates intervention study recorded a less than 10% change in transversus abdominis thickness before and after the pilates intervention. Possible explanations for the lack of change observed in these subjects are (a) that the pilates intervention did not train the transversus abdominis in these subjects and/or (b) the pilates intervention did train the transversus abdominis in these subjects but the ultrasound methodology used did not measure the resultant change. Both explanations are discussed further in the next sections.

Pilates Ineffective in Training Transversus Abdominis

Pilates instructors claim that the exercise method focuses on training the core stability muscles, including transversus abdominis. However, according to Richardson et al. (1998), and consistent with the researchers clinical observation, many people with low back pain find it very difficult to gain a perception of the required contraction to activate transversus abdominis. In the clinical setting, commonly observed patterns of faulty recruitment include over activation of the external oblique (Richardson et al., 1998). Critchley & Coutts (2002) observed via ultrasound a reduction in the thickness of transversus abdominis and a concurrent increase in another abdominal muscle (undefined by the author) during abdominal hollowing in some subjects with chronic low back pain, concluding that these subjects were employing compensatory patterns to perform the abdominal hollowing manoeuvre. Richardson et al. (1998) state that there is a high level of clinical skill required to teach people with these compensatory patterns, with a need to first employ facilitation strategies in the initial phase of teaching.

To teach transversus abdominis contraction in the present study, each subject had a period of individual attention at some stage during the first week of the pilates matwork classes. However, as there were up to 12 participants in each class as is typical in many pilates matwork classes, it was not possible to individually monitor subjects abdominal muscle activation patterns throughout each class. Subjects may have been overly activating compensatory muscles, such as the external oblique, and reinforcing incorrect muscle recruitment strategies while performing the pilates exercises.

It is likely that there would be limited training effect on transversus abdominis if subjects in the pilates classes were using incorrect abdominal muscle recruitment patterns, but there may have also been a training effect on other abdominal wall muscles. The change in thickness of the other abdominal muscles (e.g. external oblique) could be assessed in future from the data collected in this study, to give further information to support the possibility that individuals that recorded a relatively small change in thickness of transversus abdominis were incorrectly recruiting compensatory muscles during the pilates exercise classes.

It would be beneficial in the clinical setting to check that a patient can repetitively perform the abdominal drawing in manoeuvre by correctly recruiting the transversus abdominis prior to commencing a pilates exercise programme. It would also be advisable to recheck and refine transversus abdominis activation after starting pilates classes. The patient testing and education in the clinical setting could be enhanced by utilising a biofeedback tool such as real time ultrasound.

Pilates Training Effect on Transversus Abdominis Not Measured by Ultrasound

Transversus abdominis may have developed in response to training in the pilates intervention subjects that recorded minimal change in thickness, but with the changes not able to be measured by ultrasound. One of the limitations of ultrasound is the inability to assess the effects of changes in the internal structure on muscle size (Hides, Richardson, Jull et al., 1995). Type II muscle fibre atrophy and type I internal structural changes have been observed in the lumbar multifidus muscle of low back pain surgery patients with herniated discs (Rantanen, Hurme, Falck, Alaranta, Nykvist, Lehto, Einola & Kalimo, 1993). The size of the type I and II fibres, however, were largely unaffected. In those patients that had a positive clinical outcome from the surgery five years later, a reduction in the internal structural abnormalities of type I and type II fibres were shown (Rantanen et al., 1993). The patients with a negative outcome from surgery, however, showed an increase in derangement especially in type I fibres (Rantanen et al., 1993). Rantanen et al. (1993) concluded that these pathological structural changes are reversible and can be diminished by adequate therapy. To the knowledge of the researcher, there are no published studies on transversus abdominis muscle fibre composition in subjects with low back pain. There is a possibility that transversus abdominis may show muscle fibre structural abnormalities in patients with low back pain, and that training this muscle through pilates exercises could have lead to internal structural changes which were not measurable by ultrasound.

Transversus abdominis may have changed in thickness in response to the pilates training in the subjects who recorded little change, but this change may have occurred at a different location in the muscle from where the ultrasound measurement was taken. Unilateral measurement of transversus abdominis (right hand side) were conducted in this study, as they had been in previous studies of transversus abdominis in low back pain patients (Hodges & Richardson, 1996; Ferreira et al., 2004).

In low back pain patients, a difference in cross sectional size of lumbar multifidus and psoas muscles between left and right sides has been shown (Barker, Shamley & Jackson, 2004; Stokes, Cooper, Morris & Jayson, 1992; Hides et al, 1994). Hides, Richardson & Jull (1996) found that asymmetry persisted in multifidus despite resolution of the symptoms of acute low back pain. Specific exercise involving co-contraction of transversus abdominis and multifidus muscle over a four week period, however, resulted in a rapid recovery in muscle size on the atrophied side and very little change in the opposite side (Hides et al., 1996).

Critchley & Coutts (2002) commented that it is possible that transversus abdominis may demonstrate differences between sides in low back pain patients. If at entry to the present study subjects had reduced transversus abdominis thickness on the left compared to the right, an asymmetrical training effect increasing the thickness of the left side of transversus abdominis may have occurred that was not measured. Further studies investigating the differences in transversus abdominis muscle thickness on the left and right in subjects with low back pain, and the effect of pilates exercise on muscle thickness would be beneficial to assess the potential asymmetry and change with training in low back pain patients.

The positioning of the ultrasound transducer and location of muscle thickness measurement may also require reconsideration in further studies to fully evaluate the effect of training on transversus abdominis. In patients with low back pain the asymmetry found in multifidus size by Hides et al. (1996) was limited to a specific segmental level in the lower back, with this specific level of multifidus responding with increased size to the specific exercise training intervention. Narici, Roi, Landoni, Minetti & Cerretelli (1989) found that the greatest degree of hypertrophy in the quadriceps muscle after 60 days of strength training was in the proximal area of these muscles. Narici et al. (1989) suggested that multiple sites are required to gain a valid indication of muscle hypertrophy after exercise training.

The results in this present study may have underestimated the gain in muscle thickness by measuring transversus abdominis thickness at a single point in the muscle, midway between the inferior edge of the rib cage and the iliac crest. There is potential for further analysis of the data collected in the present study to assess the change in thickness along multiple sites along the image captured of transversus abdominis in each subject.

Possible Reasons for Increase in Transversus Abdominis Thickness

An increase in transversus abdominis thickness of greater than 10% was measured in six of the 19 subjects after the pilates intervention. The increase in measured muscle thickness when compared to the pre pilates measurement could be due to either (a) an increase in the actual resting thickness of transversus abdominis, and/or, (b) an increase in the contractile activity of transversus abdominis (voluntary or involuntary) at the time of ultrasound image capture at the end of expiration.

Pilates Training Increases the Resting Thickness of Transversus Abdominis

Increase in resting thickness of transversus abdominis could be due to training effect of the six week pilates exercise intervention. Almost all pilates exercises require activation of transversus abdominis, either by an isometric contraction to assist in stabilising the core while another part of the body is moving, or concentric contraction with movement of the trunk of the body.

In healthy subjects, sixteen or more workouts have been identified as the typical number of sessions required to produce a significant increase in muscle size (Staron, Karapondo, Kraemer, Fry, Gordon, Falkel, Hagerman & Hikida, 1994). Hypertrophy of muscle in the early phases (1-8 weeks) has been shown, however, in various types of training (Cannon & Cafarreli, 1987; Carolan & Cafarelli, 1992; Garfinkel & Cafarelli, 1992; Thornstensson, Karlsson, Viitasalo, Luhtanen & Komi, 1976). In acute low back pain patients, muscle hypertrophy as measured by ultrasound has been demonstrated over a four week period (Hides et al., 1996). An exercise program based on co-activation of transversus abdominis and multifidus resulted in unilateral increases in lumbar multifidus cross sectional area in these subjects with acute low back pain (Hides et al., 1996). The side that increased was the relatively smaller one at the start of the intervention, with the difference between sides starting at 24.03% ± 8.67% (range 12 to 46%) and reducing to 0.71% ± 2.49% after the four week intervention (Hides et al., 1996). Hides et al. (1996) proposed that due to the acute low back pain, reflex inhibition and resultant muscle atrophy lead to the relatively smaller muscle size ipsilateral to the low back pain. The specific training of multifidus and transversus abdominis co-contraction resulted in the return to more equal muscle sizes bilaterally after four weeks.

There is the potential that some subjects in the present study started with a difference in size between the right and left transversus abdominis. Subjects that showed a greater than 10% increase in transversus abdominis thickness could have started with a relatively smaller muscle on the right (side measured) than the left on entry to the study. The relatively smaller muscle which has potentially undergone atrophy due to reflex inhibition could, if responding in a similar pattern to multifidus, have a greater response to training than the larger side. Alternatively, transversus abdominis could have started with a uniform thickness across both sides and due to pilates training could have resulted in muscle hypertrophy and a larger resting thickness.

The pilates intervention therefore could have contributed to unilateral or bilateral hypertrophy of transversus abdominis, resulting in an increase in resting thickness as measured by ultrasound after the exercise programme. Without knowledge of the differences in size between the left and right transversus abdominis in subjects in the present study, it is not possible to make any judgements as to the state of transversus abdominis at entry into the study and how that might have affected the response to the pilates intervention.

Increase in Transversus Abdominis Activation at Post Pilates Measurement

There is the potential that some subjects may have consciously or unconsciously activated their transversus abdominis at the time of ultrasound image capture at the post pilates measurement, leading to an increase in recorded thickness of transversus abdominis. It is possible that the subjects had become more skilful at controlling transversus abdominis contraction over the duration of the six week pilates programme. Very little perception of effort in contracting transversus abdominis is required to give measurable changes in thickness on ultrasound. Hodges, Pengel, Herbert & Gandevia (2003) demonstrated clear changes in transversus abdominis thickness and length with contraction levels as measured by EMG as little as 12 to 23%.

In the present study if the subject appeared to be consciously contracting the abdominal muscles, the sonographer delayed capture of the ultrasound image for measurement until the abdomen appeared relaxed. However, subtle changes in voluntary activation of transversus abdominis may not have been detected by the sonographer at the post pilates measurement session if subjects were consciously minimally contracting transversus abdominis.

Alternatively, there could have been an increase in unconscious activation of transversus abdominis at the post pilates measurement in some subjects. Interestingly, the subject who recorded the fifth largest increase in transversus abdominis thickness reported suffering from a chest infection at the time of the post pilates measurement. This increase in thickness may have been contributed to by unconscious activation of transversus abdominis during expiration as a result of the chest infection and changed respiratory mechanics and/or breathing patterns. Again, these possibilities can only be discussed and not judged, as electrical activity of transversus abdominis was not recorded at the time of the ultrasound image capture for measurement.

Study Limitations

Validity of Ultrasound Measurement

Not knowing the degree of transversus abdominis activation and contraction at the timing of image capture for subsequent measurement of thickness was the biggest limitation of this study. If subjects had varying levels of activation of transversus abdominis at the pre and post pilates measurement sessions, then conclusions about the change in resting muscle thickness of transversus abdominis and magnitude of hypertrophy from the training effect of the pilates exercise programme is invalid.

The validity of using B-mode ultrasound at all in measuring resting muscle thickness at the end of expiration is therefore questionable. Without concurrent measurement of electrical activity using EMG it is difficult to judge the degree of contraction in transversus abdominis at the time of measurement. As respiration appears to be interrelated with the degree of contraction of transversus abdominis, the phase and timing during the respiratory cycle should be recorded with the timing of transversus abdominis thickness image capture for measurement.

Reliability of Methodology

For transfer of the reliability of the methodology in measuring transversus abdominis thickness in subjects on separate days to the pilates intervention study, there should have been a match between the subjects in the reliability group and the pilates intervention group. However, post study analysis by *t*-test revealed a difference in age between the groups ranging from ‘moderate’ to ‘large’ (effect size =1.0, CI 0.3 to 1.7).

There was also a difference in the duration between measurements of transversus abdominis for the reliability group and the pilates intervention group. Subjects in the reliability group were measured one week apart, with the pilates intervention group subjects being measured up to nine weeks apart.

To test reliability of the ultrasound measurement methodology, the study could have included a control group with subjects matched to the pilates intervention group. For both groups, measurements of transversus abdominis could then have been taken nine weeks apart. Alternatively, the pilates intervention group subjects could have acted as a control within themselves. By taking repeated measured in the same subjects prior to the exercise programme, each individual's variability in transversus abdominis thickness could have been established over time.

Evaluating Subjects at Entry and During the Longitudinal Study

It was difficult to establish the physical condition of the subjects objectively at entry to the study. The effect of the pilates training depended on the initial level of subjects at the start of the training. The aim was to recruit a homogenous group of subjects with a history of non specific low back pain. Subject details, however, were not taken on to the history of low back pain in terms of onset, location, duration, pain and disability levels etc. This could have lead to a varied group in terms of pain, disability and chronicity of low back pain. If further details on each subject's non specific low back pain had been recorded, further analysis on the relationship between subject pain status at entry to the study and change in transversus abdominis thickness could have subsequently been performed.

Respiratory function appeared to be an important factor in the change transversus abdominis thickness across this study. Ideally, the selection of subjects for the study would have excluded those with respiratory dysfunction or included only those with respiratory dysfunction, giving a more homogenous group. Further characteristics which were not identified in the subjects at entry into the study and during the study may have explained reasons for subsequent increases, decreases or minimal change recorded in transversus abdominis thickness. For example, in other studies examining transversus abdominis function, other subject information regarding the abdominal wall, pelvic floor and respiratory system were collected including parity (females), abdominal surgery, incontinence, other abdominal training, and history of smoking.

Information on study participants was also reliant on the information being volunteered through questionnaires. The questionability of the quality of the information collected was also compounded as the questionnaires used for gathering information on exercise levels, current health and medical history were not previously validated questionnaires.

Nutrition and medication were major factors that could substantially affect muscle thickness that were not monitored throughout the course of the study. An attempt at assessing subjects' nutrition was made by conducting a 24-hour food recall interview with each subject. It is unknown how representative the information volunteered by each subject was representative of their nutritional status throughout the trial.

The intensity of the pilates training would also have varied for each individual during the study, with this variable not being measured. Despite the fact that they were attending the same formatted classes, the intensity of the exercise would have varied according to each subjects physical condition at entry into the study (e.g. ability to isolate and contract transversus abdominis, respiratory function status), and their approach to performing each of the exercises in the class (e.g. form, duration, breathing control).

Future Research

As there is very little research on the relationship between transversus abdominis, low back pain, pilates exercise and respiration, there are many directions for future research to enhance the understanding of these areas. Potential areas for further investigation include:

Transversus Abdominis

Difference between left and right transversus abdominis thickness in the individuals with and without low back pain.

Internal structural changes in Type I and Type II transversus abdominis muscle fibres in individuals with and without low back pain.

Variation in transversus abdominis thickness and contraction with the respiratory cycle in individuals with respiratory dysfunction (e.g. hyperventilation, asthma, hayfever).

Variation in transversus abdominis thickness and contraction with the respiratory cycle in individuals with low back pain.

Relationship between chest wall compliance and transversus abdominis activation during expiration.

Pilates

Transversus abdominis thickness in individuals who regularly practice pilates.

Respiratory function in individuals who regularly practice pilates.

Effect of pilates on tidal volume, functional residual capacity, respiratory rate in individuals with and without respiratory dysfunctions after a class, and after a series of classes.

Effect of pilates on pain levels, functional disability, quality of life and mood scores in individuals with low back pain, and individuals with respiratory dysfunction.

Difference in ability to activate transversus abdominis and correctly perform the abdominal drawing in manoeuvre before and after pilates exercise programme in individuals with and without low back pain, and respiratory dysfunction.

Ability to activate transversus abdominis and correctly perform the abdominal drawing in manoeuvre in individuals who regularly practice pilates.

Incidence of compensatory patterns of abdominal muscle activation (e.g. external oblique) during the abdominal hollowing manoeuvre in individual who regularly practice pilates.

Perceived health benefits of attending a pilates exercise programme.

Ability of pilates instructors to assess dysfunctional breathing patterns in participants.

Low Back Pain

Relationship between respiratory function and low back pain.

Respiration

Incidence of dysfunctional breathing patterns in "normal" asymptomatic individuals.

Diaphragmatic breathing versus lateral costal cage breathing patterns. What are the effects on transversus abdominis thickness, diaphragm thickness and their muscle activity during the respiratory cycle? How does this affect functional residual capacity, tidal volume, respiratory rate and thoracic wall compliance?

CONCLUSION

The effect of the six week pilates matwork exercise programme on transversus abdominis thickness in subjects with a history of low back pain was large. The changes in transversus abdominis thickness varied between individuals from very large decreases to very large increases. It is not known why there was a wide variation observed in terms of magnitude and direction of change of transversus abdominis thickness.

The best predictor of change in transversus abdominis thickness from the data collected and analysed was respiratory dysfunction status at entry to the study. Subjects that reported a respiratory dysfunction at entry to the study all recorded a decrease in thickness of transversus abdominis. It is thought that changes in transversus abdominis thickness measured by ultrasound at the end of expiration (functional residual capacity) were related to respiratory function status. This relationship may have been modified by the six week beginner pilates exercise programme in subjects with a history of respiratory dysfunction. It is postulated that this relationship changed by reducing the contraction of transversus abdominis at the end of expiration. No conclusions can be made, however, due to the small sample size in this preliminary study.

The validity of using changes in muscle thickness as a measure of training effect as measured by ultrasound at the end of expiration was questioned in subjects with low back pain. Concurrent measurement of EMG activity is required to establish the degree of contribution of muscle contraction to muscle thickness. Further investigation as to the relationship between the respiratory cycle, transversus abdominis thickness and transversus abdominis activation is required in subjects with a history of low back pain, before using these measures to further assess exercise interventions.

APPENDICES

Appendix 1 - Participant Information Sheets

UNITEC
Te Whare Wananga o Wairaka

Ultrasound imaging of abdominal muscles before and after a six week pilates matwork programme

Pilates Group Participant Information Sheet

Thank you for your interest in participating in this research project. The purpose of this form is to provide you with information about the project, and to help answer any queries you may have. Please don't hesitate to contact us for any further information.

Why are the investigators interested in this area of research?
The underlying scientific basis for the role of the deep abdominal muscles in protecting the spine is well established. However, there has been relatively little research into the effects participating in pilates matwork classes has on these muscles.

Are their any criteria for my involvement?
There are only six criteria:

1) You are between the age of 18 and 55 years.
2) You have experienced low back pain at some point in your life, although you are not currently experiencing any low back pain.
3) You have not ever had surgery for back pain
4) You have not received any treatment for a back complaint in the past three months.
5) You have not ever had any pain, pins & needles, numbness in the legs that was related to back pain
6) You have not previously participated in a yoga or pilates class

You will also be required to fill out a Pre Exercise Screening questionnaire to ensure that you are fit to participate in a pilates matwork programme.

Ultrasound Measurement Sessions

You will need to attend a session prior to and after the six-week pilates matwork programme. At these sessions ultrasound imaging of your abdominal muscles will be performed.

Is their any risk involved?
Ultrasound is a very safe technique, and uses sound waves rather than any potentially harmful x-rays. Ultrasound is widely used in scanning pregnant mothers. A trained technician will be performing the imaging. The study has been reviewed and approved by the UNITEC Research Ethics Committee.

What do I need to do at the session?
We will use ultrasound imaging to visualise your deep abdominal wall. The ultrasound handset will be placed against the lower stomach. The recording will probably take no longer than one or two minutes, and will be repeated several times. We will need to apply a small amount of water-based gel to the skin. This helps to provide quality pictures. Be assured that the gel will be pre-warmed prior to application!

What should I wear?
You should wear shorts or comfortable trousers (tracksuit pants etc). Women should wear a sports bra / crop top that they are comfortable in. We need to be able to place the ultrasound device on the skin of your lower stomach. If any gel contacts your clothes it is non-staining and washes off in water. Changing facilities will be available.

How long will the session take?
Please allow 30 minutes for the session. If you are running late for the appointed time or need to cancel or reschedule then please contact us on 021 178 3840 or 845 2378.

Where do I need to come?
Ultrasound imaging is to be conducted at Mercy Radiology, RAD 2, Gate 1, 98 Mountain Rd, Epsom, under the professional services of the Mercy Radiology Group. Parking is available at mercy Radiology (see map attached). We will arrange to meet you at a prearranged time, which will be confirmed by phone the day prior to your appointment.

Pilates Classes

What do I need to do at the pilates classes?
You will participate in a pilates class with a maximum of twelve participants in the class. The class will be lead by qualified pilates instructor and Masters of Osteopathy student, Ana Spurdle. If you are unable to perform an exercise, modifications will be given for you to continue the exercise in an achievable non-painful way.

Prior to each session you will be required to sign an attendance sheet, and indicate whether you have suffered any injuries, illnesses, or back pain or received any treatment in the past week. You will also be asked to briefly record any exercise you have participated in since the previous class. At the end of a session you may be randomly selected to complete a 24-hour food recall questionnaire that takes on average 20 minutes to complete.

What should I wear?
Clothing should be comfortable and easy to move in such as loose pants and a tee shirt, and we ask you to bring a clean pair of socks to wear.

How long will the class take?
Each class is scheduled for one hour. If you are running late for the appointed time or need to cancel or reschedule then please contact us on 021 178 3840 or 845 2378.

Where do I need to come?
The pilates classes will be held in the Yoga Room at the O'Ryans Sports Centre, UNITEC Institute of Technology (Mt Albert).

What if I want to withdraw from the study?
Your participation is completely voluntary, and you are free to withdraw from the study at any time.

Who do I contact for further information?
Ana Spurdle
Researcher
Tel: 845 2378
Mob: 021 178 3840
Email: spurda01@studentmail.unitec.ac.nz

Confidentiality

Confidentiality and your anonymity will be protected in the following ways:

- Any information recorded about you will be seen only by the researchers. UNITEC will only receive summaries and reports in which all personally identifying features are removed.

A copy of the final report will be available at the UNITEC Institute of Technology Central Library. All participants are welcome to view this.

If you have any concerns regarding your rights as a participant in this research you may wish to contact a Health and Disability Advocate, Ph: 0800 555 050.

Finally, we would like to thank you for your valuable contribution to this research.

UNITEC
Te Whare Wananga o Wairaka

Ultrasound imaging of abdominal muscles before and after a six week pilates matwork programme

Reliability Study Participant Information Sheet

Thank you for your interest in participating in this research project. The purpose of this form is to provide you with information about the project, and to help answer any queries you may have. Please don't hesitate to contact us for any further information.

Why are the investigators interested in this area of research?
The underlying scientific basis for the role of the deep abdominal muscles in protecting the spine is well established. However, there has been relatively little research into the effects participating in pilates matwork classes has on these muscles.

Are their any criteria for my involvement?
There are only six criteria:

1) You are between the age of 18 and 55 years.
2) You have experienced low back pain at some point in your life, although you are not currently experiencing any low back pain.
3) You have not ever had surgery for back pain
4) You have not received any treatment for a back complaint in the past three months.
5) You have not ever had any pain, pins & needles, numbness in the legs that was related to back pain
6) You have not previously participated in a yoga or pilates class

Ultrasound Measurement Sessions

You will need to attend two ultrasound measurement sessions which are currently scheduled for Wednesday 3 March and Wednesday 10 March between 5.30 pm and 6.30 pm at Mercy Hospital, Radiology 2, 98 Mountain Rd, Epsom. At these sessions ultrasound imaging of your abdominal muscles will be performed. There may possibly be the requirement of a third measurement session in April 04.

Is their any risk involved?
Ultrasound is a very safe technique, and uses sound waves rather than any potentially harmful x-rays. Ultrasound is widely used in scanning pregnant mothers. A trained technician will be performing the imaging. The study has been reviewed and approved by the UNITEC Research Ethics Committee.

What do I need to do at the session?
We will use ultrasound imaging to visualise your deep abdominal wall. The ultrasound handset will be placed against the lower stomach. The recording will probably take no longer than one or two minutes, and will be repeated several times. We will need to apply a small amount of water-based gel to the skin. This helps to provide quality pictures. Be assured that the gel will be pre-warmed prior to application!

What should I wear?
You should wear shorts or comfortable trousers (tracksuit pants etc). Women should wear a sports bra / crop top that they are comfortable in. We need to be able to place the ultrasound device on the skin of your lower stomach. If any gel contacts your clothes it is non-staining and washes off in water. Changing facilities will be available.

How long will the session take?
Please allow 20 minutes for the session. If you are running late for the appointed time or need to cancel or reschedule then please contact Ana Spurdle on 021 178 3840 or 845 2378.

Where do I need to come?
Ultrasound measurements are to be conducted at Mercy Hospital, Radiology 2, 98 Mountain Rd, Epsom, under the professional services of the Mercy Radiology Group. Parking is available at Mercy Radiology (see map attached).

What if I want to withdraw from the study?
Your participation is completely voluntary, and you are free to withdraw from the study at any time.

Who do I contact for further information?
Ana Spurdle
Researcher
Tel: 845 2378
Mob: 021 178 3840
Email: spurda01@studentmail.unitec.ac.nz

Confidentiality

Confidentiality and your anonymity will be protected in the following ways:

- Any information recorded about you will be seen only by the researchers. UNITEC will only receive summaries and reports in which all personally identifying features are removed.

A copy of the final report will be available at the UNITEC Institute of Technology Central Library. All participants are welcome to view this.

If you have any concerns regarding your rights as a participant in this research you may wish to contact a Health and Disability Advocate, Ph: 0800 555 050.

Finally, we would like to thank you for your valuable contribution to this research.

Appendix 2 - Consent Forms

Ultrasound imaging of the abdominal muscles before and after a six-week pilates matwork programme

Pilates Group Consent Form

The project is investigating the change in abdominal muscle thickness before and after a six week pilates matwork programme. We are interested in finding out if pilates is effective in developing the deep abdominal muscles which have been identified as being important in protecting the spine and in rehabilitation of low back problems. This will contribute to knowledge about how to treat back pain more effectively. Ana Spurdle from UNITEC Institute of Technology is undertaking this research under the supervision of Robert Moran and Dr Andrew Stewart.

Name of Participant:…………………………………………………………………….

I have seen the Information Sheet dated 18 December 2003 for people taking part in the project titled "*Ultrasound imaging of the abdominal muscles before and after a six week pilates matwork programme*". I have had the opportunity to read the contents of the information sheet and to discuss the project with the principle investigator Ana Spurdle, and I am satisfied with the explanations I have been given. I understand that taking part in this project is voluntary (my choice) and that I may withdraw from the project at any time and this will in no way affect my access to the services provided by the UNITEC Institute of Technology.

I understand that I can withdraw from the project if, for any reason, I want this.

I understand that my participation in this project is confidential and that no material that could identify me will be used in any reports on this project.

I have had enough time to consider whether I want to take part.

I know whom to contact if I have any questions or concerns about the project.

The contact details of the principal researcher for this project are:

Ana Spurdle	Telephone: (09) 845 2378
UNITEC Institute of Technology	or 021 178 3840
School of Health Sciences	Email: spurda01@studentmail.unitec.ac.nz
Private Bag 92025	
Auckland	

Signature of participant …………………………………Date ....

Project explained by…………………..……………………………

Signature…………………………………………………Date ………………………..

The participant should retain a copy of this consent form.

This study has been approved by the UNITEC Research Ethics Committee from 10 December 2003 to 10 December 2004. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the Secretary (ph: 09 815-4321 ext 8571). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

UNITEC
Te Whare Wananga o Wairaka

Ultrasound imaging of the abdominal muscles before and after a six week pilates matwork programme

Reliability Study Group Consent Form

The project is investigating the change in abdominal muscle thickness before and after a six week pilates matwork programme. We are interested in finding out if pilates is effective in developing the deep abdominal muscles which have been identified as being important in protecting the spine and in rehabilitation of low back problems. This will contribute to knowledge about how to treat back pain more effectively. Ana Spurdle from UNITEC Institute of Technology is undertaking this research under the supervision of Robert Moran and Dr Andrew Stewart.

Name of Participant:……………………………………………………………….

I have seen the Information Sheet dated Monday 1 March 2004 for people in the control group taking part in the project titled "*Ultrasound imaging of the abdominal muscles before and after a six week pilates matwork programme*". I have had the opportunity to read the contents of the information sheet and to discuss the project with the principle investigator Ana Spurdle, and I am satisfied with the explanations I have been given. I understand that taking part in this project is voluntary (my choice) and that I may withdraw from the project at any time and this will in no way affect my access to the services provided by the UNITEC Institute of Technology.

I understand that I can withdraw from the project if, for any reason, I want this.

I understand that my participation in this project is confidential and that no material that could identify me will be used in any reports on this project.

I have had enough time to consider whether I want to take part.

I know whom to contact if I have any questions or concerns about the project.

The contact details of the principal researcher for this project are:

Ana Spurdle
UNITEC Institute of Technology
School of Health Sciences
Private Bag 92025
Auckland

Telephone: (09) 845 2378
or 021 178 3840
Email: spurda01@studentmail.unitec.ac.nz

Signature of participant ………………………………………………..…….(date)

Project explained by…………………..……………………………

Signature……………………………………………………………………...(date)

The participant should retain a copy of this consent form.

This study has been approved by the UNITEC Research Ethics Committee from 10 December 2003 to 10 December 2004. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the Secretary (ph: 09 815-4321 ext 8571). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Appendix 3 – Pre Exercise Questionnaire

Date:________

Pre Exercise Questionnaire

Name: ____ DOB: ___________

Sex: ______________ Ethnic Group________________________________

Address: ____

____

Contact Phone: (day)________________(after hours)__________________

Occupation: ____

Person to be contacted in case of emergency:

Name: _______________________________Phone:__________________

Have you previously participated in a pilates or yoga class Yes No

Low Back Pain

Low back pain is defined as any period of discomfort in the lower back related to sitting, standing or walking.

Have you ever experienced low back pain? Yes No

If No, you have now completed the questionnaire
If Yes, please complete the following questions:

Have you received treatment for back pain in the past three months Yes No

Have you ever had surgery for back pain Yes No

Have you ever experienced pain, pins and needles, and/or numbness in the thigh, calf or foot which was related to your low back pain Yes No

General Health

Have you had or do you have any pain or major injuries in the following areas:

- Neck Yes No
- Shoulder Yes No
- Back Yes No
- Hips Yes No
- Knees Yes No
- Ankle Yes No
- Other Yes No

If you answered Yes to any of the above questions please give details and approximate date below.

____

____

____

Have you ever had or do you have:

Diabetes	Yes	No
Asthma	Yes	No
Epilepsy	Yes	No
Hernia	Yes	No
Arthritis	Yes	No
Dizziness or fainting	Yes	No
Stomach or duodenal ulcer	Yes	No
Any heart condition	Yes	No
Heart murmur	Yes	No
High Blood Pressure	Yes	No
Palpitations/Chest Pain	Yes	No
Are you on any prescribed medication?	Yes	No
Have you given birth in the last 6 weeks?	Yes	No
Are you pregnant?	Yes	No

If you have answered Yes to any of the above questions please give details of conditions, medications and approximate dates cleared below.

What type of exercise have you been doing recently?
(please circle the appropriate answer)

Type(s) of exercise

Swim Walk Bike Gym Other

If Other, please list:

Frequency – number of sessions per week

1 – 2 3 – 4 5+

Duration of each session

<20 mins 20-40 mins 40-60 mins 60+ mins

Intensity of exercise

Light Moderate Hard

I recognise that the pilates instructor is not able to provide me with medical advice with regard to my medical fitness, and that this information is used as a guideline to the appropriateness of my ability to exercise. I have answered the questions honestly and to the best of my ability and take it upon myself to discuss any changes in my current health status.

Signed:______________________________ Date:_______________

Appendix 4 - Information on Pilates for Subjects

What is Pilates?

The pilates method of exercising offers a total body conditioning programme which enhances one's quality of life through improving body awareness and alignment, strength, flexibility, balance and co-ordination.

This exercise method was developed in the early to mid 1900's by Joseph Pilates (pronounced Pi-lah-tees), who referred to his techniques as a method of physical and mental conditioning. He defined physical fitness as "the attainment and maintenance of a uniformly developed body with a sound mind capable of naturally, easily and satisfactorily performing our many and varied tasks with spontaneous zest and pleasure", and was known for his favourite quote from the poet Schiller, "It is the mind itself that builds the body." Hence, pilates is often termed the thinking person's workout.

Pilates unique form of exercise was invented fifty years ahead of its time, its central focus on creating a strong "centre" or core around which the rest of the body can operate is in line with current thinking on core stabilisation and abdominal stability. In addition, most forms of sport or exercise concentrate on the larger stronger muscles developing and becoming bulkier, while the smaller weaker muscles are forgotten. The pilates method focuses on accessing and strengthening the smaller stabilising muscles, working all muscles through their full range of movement, and developing long lean muscles that are free to operate as part of a balanced, integrated body.

The pilates method relies on careful supervision so that each client understands how to work correctly and not reinforce faulty movement patterns. Emphasis is on balancing out each person's strengths and weaknesses, taking into consideration individual postural problems, injuries or conditions and working at your own pace.

All levels of fitness are catered for in pilates. Pilates is ideal for sufferers of back pain, post injury recovery, pregnancy and after birth, general fitness and elite athletic performance.

What to Wear at Pilates Mat Classes?

Clothing should be comfortable and easy to move in such as loose pants and a tee shirt or leotard and tights, and we ask you to bring a clean pair of socks to wear.

Appendix 5 – Pilates Class Format & Sample Classes

Classes were programmed in blocks of exercises following the Pilates International protocol. Each block consisted of similar types of exercises that work a specific function. As the level of the class progressed, more difficult exercises were added within the blocks and the pace transition between exercises increased. Modifications were given, including the use of props (e.g. theraband, blocks), for individuals to assist them in performing exercises with the correct form as required.

Sample Classes

Class 1 Exercises
Supine breathing
Printing
Imprinting
Pelvic Curl
Chest Lift
Leg lifts I
Spine twist
Oblique reaches
Hundreds prep I
Leg circles
Hamstring stretch
Rolling basic
Single leg – intro
Spine stretch
Spine twist sitting
Roll back
Side lift I & II
Prone breathing
Rest Position
Hip flexor stretch
Total time = 50 minutes

Class 12 Exercises
Roll downs
Standing balance
Supine breathing
Printing
Imprinting
Pelvic Curl
Chest Lift
Leg lifts II, III
Hula
Hundreds
Roll ups
Leg circles
Hamstring stretch
Rolling
Single leg stretch
Criss cross
Spine stretch
Saw
Spine twist sitting
Roll back
Shoulder Bridge
Glut series I, II, III & Glut stretch
Swimming
Flight
Rest Position
Front support I, II
Back support I, II
Seal puppy
Roll downs
Total time = 45 minutes

Blocks and exercises covered during the six week course included the following:

Blocks - in all classes	**Exercises**
Warm up	Supine breathing, Printing, Imprinting, Roll downs, Standing balance
Foundation series	Pelvic curl, Chest lift, Leg lifts I, II, III, Spine twist, Oblique reaches, Hula.
Abdominal	Hundreds prep, Hundreds, Shoulder bridge
Leg work	Leg circles, Single leg stretch, Criss cross.
Spinal Flexion	Roll ups, Rolling, Roll backs, Seal puppy.
Sitting	Spine stretch, Spine twist sitting, Saw basic, Saw.
Sides	Side series – I, II, III.
Spinal Extension	Prone breathing, Flight, Swimming, Back extension.
Full Body Integration	Front support I, II, Back support I, II, Quadraped.
Stretches	Hamstring, Hip flexor, Quad, Gluteal, Piriformis, Rest position
Additional Optional Work	Arm series – I, II, III, Gluteal series – I, II, III, Clam.

Appendix 6 – Nutrition: 24-Hour Food Recall Questionnaire

24 hour recall

Morning (when you get up/ before work):

During the morning:

Lunch Time:

During the afternoon:

Evening meal(s):

Before bed:

During the night:

Appendix 7 – Exercise & Injury/Illness/Treatment Log

What type of exercise have you done in the past week?

(please circle the appropriate answer)

Type(s) of exercise

Swim Walk Bike Gym Other

If Other, please list:

____

____

Frequency – number of sessions per week

1 – 2 3 – 4 5+

Duration of each session

<20 mins 20-40 mins 40-60 mins 60+ mins

Intensity of exercise

Light Moderate Hard

Have you had any increased back pain or sustained any injuries, illness or accidents that required treatment in the past week?

Yes No

If Yes – please give brief details

____

____

____

____

____

____

Appendix 8 – Reliability Group Exercise Questionnaire

Reliability Study Exercise Questionnaire - 10 March 2004

Name: ______________________________ **DOB:** __________________

Ethnic Group: _____________________________

What exercise have you been doing recently?

(please circle the appropriate answer)

Type(s) of exercise

Swim Walk Bike Gym Other

If Other, please list:

____

____

Frequency – number of sessions per week

1 – 2 3 – 4 5+

Duration of each session

<20 mins 20-40 mins 40-60 mins 60+ mins

Intensity of exercise

Light Moderate Hard

Appendix 9 – Protein and Energy Intake of Pilates Intervention Group

Protein recommended daily intake per day for healthy adults (Ministry of Health, 2003).

- Women 45 grams
- Men 55 grams

Daily median energy intake per day for New Zealander people (Ministry of Health, 2003).

- Males 11,631 kJ
- Females 7,701 kJ

Subject ID	Protein Intake (g)	Energy Intake (kJ)
Females		
19	17	4,200
20	47	3,300
6	55	7,600
5	59	7,700
23	61	5,000
4	63	6,700
13	65	6,100
3	73	6,400
11	74	8,200
9	77	12,600
22	81	7,400
8	87	9,500
15	88	11,000
10	128	9,400
Males		
1	53	6,200
24	80	10.989
12	86	12,900
16	88	4,200
14	124	12,300
All Subjects		
Mean (SD)	74 (25)	7,400 (3,380)

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