# Effectiveness of an Abdominal Training Protocol on an Unstable Surface versus a Stable Surface

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## Abstract

**Background and Purpose.** Control of the trunk musculature is essential for maintaining stability of the lumbar spine. Training the abdominal mechanisms on a stable surface is a well-established intervention. The clinical use of unstable surfaces when training the transversus abdominus is common, however, little is known regarding the effectiveness or added value of an unstable environment. The purpose of this study was to evaluate the clinical and subjective levels of improvement of the deep trunk muscles, following training, on an unstable versus stable surface under an abdominal pre-setting condition. **Subjects.** Volunteer subjects (n=25, 10 males and 15 females) from the Vancouver Dolphins Swim Club, between the ages of 14 and 19 years were randomly assigned into one of two groups: a group instructed on abdominal setting and then performing exercises on an unstable surface and, a second group also instructed on abdominal setting but performing the same exercises on a stable surface. **Methods.** Three commonly used trunk stability exercises were assigned to each subject and were progressed one per week over a period of six weeks. All subjects in the study were taught the proper abdominal setting action prior to beginning the study. Subjects met once per week with an instructor to ensure that proper exercise technique was maintained as well as to receive proper exercise progressions. Three testing sessions were conducted over the course of the study, at the zero, three and six-week marks. Baseline measures were taken using the Stabilizer™ pressure biofeedback unit and the Sahrmann testing protocol. A questionnaire and a logbook with follow-up data were also collected at the three and six-week testing sessions. **Results.** Significant within group differences were seen in each of the two groups throughout the entire length of the study as the abdominal training progressed. Between group differences were significant during the second half of the study when adjusting for the three-week score proving the unstable surface to be more effective than the stable surface as a measure on the Sahrmann scale using the pressure biofeedback unit, with a z-score of -2.2 and a p-value of 0.014. **Discussion and Conclusions.** As subjects learn to control their abdominal musculature, improvements in trunk stability are noted. Training on an unstable surface will improve the activation of the abdominal mechanism greater than training on a stable surface. With a baseline of neuromuscular activation following training on a stable surface progression to an unstable surface may result in even greater improvements. Subjective improvements in strength and power were noted upon analysis of questionnaires and log books, following a core training program.

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# Introduction and Review of Literature

## Back Pain is a Problem

Low back pain affects virtually everyone at some time during his or her life. Statistics indicate that each year 50% of working age adults exhibit symptoms of low back pain at some point[1]. For persons under the age of 45 years low back problems are the most common cause of disability[1]. There is a 60% rate of recurrence of low back pain indicating the lack of an effective treatment regime[2]. Chronic low back pain imposes an enormous economic and social burden on Western industrialized societies[2].

## Common Causes of Back Pain

Chronic low back pain is common in both the general and sporting populations where injuries can be caused by overload and poor postural control[4]. Pathologic changes are displayed as increased levels of stress that are too great for the joint complex to withstand[5]. These new stress levels may be induced by an increased external load, such as a heavy lift or a fall, or an internal load, as little as body weight alone. Regardless, uncoordinated muscular activity is the common culprit[5].

The spine is an inherently unstable structure; therefore failure of the muscular stabilizers leads to increased risk of injury to the lumbar spine[6]. With as little as two degrees of intersegmental rotation, microtrauma of the lumbar spine may occur[7]. Repetitive flexion and torsion stresses applied to the lumbar spine leads to intervertebral disc damage and facet joint strains progressing the degenerative process[8]. The increased risk for injury to the lumbar spine due to the delayed stiffening or altered patterns of muscular activation is significant[9]. The insufficient function of the trunk muscles leads to increased stress and undue load on the joints and ligaments of the spine creating increased levels of low back pain[6,10,11]. The control of back pain and the prevention of its recurrence can be assisted by improving the muscular control of the spinal segments[12].

**Anatomy of the Trunk Region**

The musculature of the trunk region can be divided up into two groupings, local and global muscles[13]. Global muscles are the large torque producing muscles linking the pelvis to the thoracic cage and their role is to provide general trunk stabilization[13]. Local muscles are those, which attach directly to the lumbar vertebrae and are responsible for segmental stability[13]. The local muscles are the lumbar multifidus, transversus abdominus and internal obliques[6,12].

The abdominal muscles can also be classified as a movement synergist or a stability synergist[14]. The transversus abdominus, internal obliques and external obliques are considered the stability synergists and the rectus abdominus is considered the movement synergist. The stability synergists are more deeply placed and made up of type I muscle fibres, whereas the movement synergist has a greater number of type II fibres and is preferentially recruited during rapid trunk movements[14].

Each of the transversus abdominus, multifidus and oblique musculature combined with the thoracolumbar fascia contribute to maintaining control of the trunk region[15]. The throacolumbar fascia also plays a key role in linking much of the abdominal musculature. The thoracolumbar fascia is attached posteriorly to the spinous processes and anteriorly to the midline with lateral attachments to the ribs superiorly and pelvis inferiorly[11]. In its mid-portion, the thoracolumbar fascia is continuous with the insertions of the transversus abdominus and internal oblique muscles[11]. Fibers of transversus abdominus arise from the middle layer of the thoracolumbar fascia beginning between the iliac crest and the twelfth rib, a distance of approximately seven centimeters[15]. Fibers of the internal obliques also arise from the thoracolumbar fascia but their number may vary considerably. Fibers of the internal obliques may arise uniformly from the iliac crest or, solely from the lateral raphe of the thoracolumbar fascia, or both[15].

Each of the mechanisms involved in increasing trunk stability are enhanced by the facilitation of the muscles surrounding the trunk region, including the oblique abdominals, transversus abdominus, erector spinae and multifidus[16]. The intersegmental stabilizers are deeper, therefore closer to the center of rotation of the spine and have a shorter lever arm than the superficial muscles[17]. "The shorter length of the intersegmental muscles gives them a faster reaction time, creating a smoother and more efficient stabilizing control system"[17,p.196]. The intersegmental nature of the multifidus allows greater control over the lumbar spine segments leading to an ability to 'fine tune' movements and contribute to increased spinal stability[18]. Each fascicle of multifidus fibres has a separate innervation by the medial branch of the dorsal ramus of the vertebra below[19]. The focused control of each fascicle of multifidus at each vertebral level may control segmental lordosis by matching imposed loading[18]. In a biomechanical study, Wilke et al demonstrated that the multifidus provided more than two-thirds of the stiffness increase at the L4-5 segment[20]. The rectus abdominus is considered to be the prime trunk flexor whereas the transversus abdominus and internal obliques are referred to as the stabilizers[14]. The transversus abdominus and internal obliques are the only abdominal muscles, which pass from the anterior trunk to the lumbar spine. It is not the strength of the stabilizers which is important but rather their ability to maintain a constant level of activation and react quickly to forces displacing the lumbar spine[14].

**Muscular Dysfunction**

Several researchers have linked dysfunction of the local muscles with a decreased level of spinal stability and control, resulting in back pain[14,21]. Recent studies indicate that the deep trunk muscles decrease in their functional performance due to an altered pattern of recruitment, in populations with low back pain[22]. This shift in the pattern of muscle activation is seen as an overriding recruitment of rectus abdominus and an inability to preferentially activate the deep abdominal muscles[12,22,23]. Biederman and colleagues discovered that multifidus demonstrated increased levels of fatigability compared to other parts of the erector spinae in the chronic back pain patient population versus the pain-free population[24]. Rantanen and colleagues found 'moth eaten' patterning of the type I fibers of the multifidus in the chronic back pain population[25]. Additionally Hides and colleagues discovered a significant reduction in cross sectional area of segmental multifidus in patients reporting acute, first episode, unilateral back pain[26]. A motor control deficit of transversus abdominus has also been clearly shown in back pain patients by Hodges and Richardson[27]. The timing of the onset of transversus abdominus with arm movement was delayed in the chronic low back pain population as compared to individuals who had never experienced back pain. Re-education and training of the trunk musculature is recognized as an important component of the treatment of low back pain and the prevention of its recurrence[23,28,29].

**Stabilizing Systems**

The lumbar spine is stabilized by a system which is made up of three components (as seen in figure 1): the passive, the active and the control subsystems[6]. The passive (osseous-ligamentous component) subsystem is known to be unstable at loads far less than those of body weight[30] and has negligible effect on the stability of the spine in the

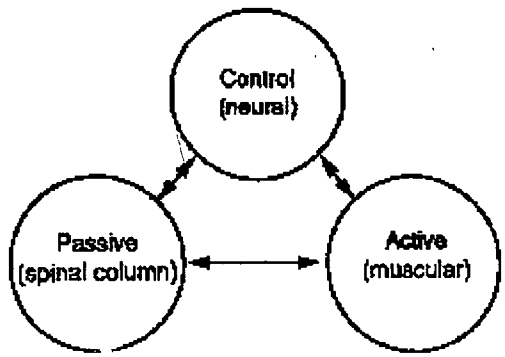


Figure 1. The spinal stabilizing system consists of three interrelated subsystems (Panjabi, 1992)

neutral zone (the region of movement around the neutral spine where little resistance is offered by the passive spinal column)[6]. Therefore, the active and control subsystems must fulfill the supplementary and adaptive roles of maintaining postural stability while performing a variety of functions[31]. The active (muscular component) subsystem provides the major component of stability to the spine during functional activities through the myofascial system, and the control system (neurological component) coordinates all actions through its central and peripheral nervous connections[17]. As one system becomes less active, possibly due to pathology, the other systems compensate to decrease the stress on the other system through a process termed "load sharing"[32].

**Instability**

When working towards achieving functional stability it is essential to understand when instability exists. Clinical instabilities are commonly referred to and discussed, yet in actuality are extremely poorly understood. White and colleagues define clinical instability as; "the loss of the ability of the spine under physiologic loads to maintain relationships between vertebrae in such a way that there is neither damage nor subsequent irritation to the spinal cord or nerve roots and, in addition there is no development of incapacitating deformity or pain from structural changes"[33,p.463]. Posner and colleagues have developed a checklist, based on x-ray findings, (as seen in table 1) outlining a number of criteria, that when combined, lead to the diagnosis of clinical instability.

| Elements | Point Value | Recorded Value |
|---|---|---|
| Cauda equina damage | 3 | |
| Relative Fexion sagittal-plane Translation > 16% or extension Sagittal-plane translation >12% | 2 | |
| Relative flexion sagittal-plane Rotation > 11 degrees | 2 | |
| Anterior elements destroyed | 2 | |
| Posterior elements destroyed or Unable to function | 2 | |
| Dangerous loading anticipated | 1 | |
| Total of 5 or more = clinically unstable | | |

Table 1. Checklist for diagnosis of clinical instability in the lumbar spine (White, 1978)

Kirkaldy-Willis and Farfan define instability as "the clinical status of the patient with back problems who with the least provocation steps from the mildly symptomatic to the severe episode"[5,p.118]. The above definitions have 'clinical instabilities' causing the patient to have back pain. It is clear that the malalignment between vertebrae, defined as clinical instability, causes pain. However, what remains unclear is: 1) why is there an altered relationship of the spine and, 2) what will maintain proper alignment, ultimately leading to stability.

One possible explanation that affects the maintenance of both the structural and functional alignment of the spine is the 'neutral zone' hypothesis[34]. "The neutral zone is the region of the intervertebral motion around the neutral posture where little resistance is offered by the passive spinal column"[6,p.386]. The neutral zone has been shown to increase with both injury and degeneration, and decrease with increased muscle activity across each segment, as seen in figure 2[6].

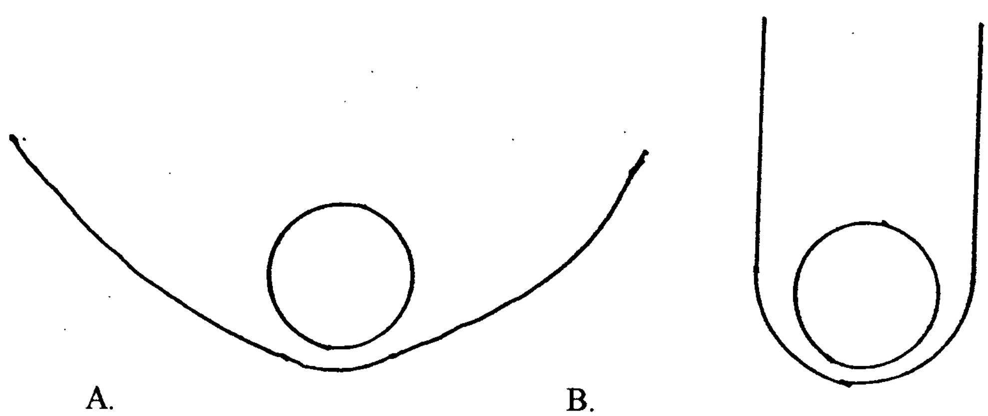


Figure 2. A) increased neutral, B) decreased neutral zone (Lee, 1999)

Injuries may include trauma to the spinal column or decreased activation of the muscles leading to spinal instability and back pain. The stabilizing systems, with heightened muscular recruitment, will help to maintain the physiological limits of the neutral zone and reduce the level of clinical instability[34]. With respect to the neutral zone hypothesis, clinical instability has been reinterpreted as; "a significant decrease in the capacity of the stabilizing system of the spine to maintain the intervertebral neutral zone within physiological limits so that there is no neurological dysfunction, no major deformity, and no incapacitating pain"[6,p.385]. With clinical instability redefined in relation to the neutral zone, back pain is more precisely linked to increases in the neutral zone as opposed to overall range of motion[34]. Therefore, by maintaining the physiological limits of the neutral zone with muscular stabilization, decreased amounts of strain is placed on the pain generating tissues, and pain relief is more likely[34].

**Stability**

Stability as defined by Euler is; "a column is stable at loads less than the critical load and unstable ie. buckles, without material failure, at loads greater than the critical load"[31,p.794]. The ligamentous thoracolumbar spine and the ligamentous lumbar spine buckle at critical loads of 19 N (4lb) and 88 N (20lb) respectively[31]. Nachemson found that the load on the lumbar spine in-vivo in the relaxed standing position was approximately twice body weight, and varied with specific postures[31]. As the ligamentous system is unstable at loads far less than body weight, the neuromuscular system must both complement and supplement the osseoligamentous system in order to maintain functional postural stability[31]. The essential feature of muscular stability is the ability of the myofascial system to maintain control throughout the entire range of movement. External loads and perturbations are balanced by forces generated internally by muscles[11]. The abdominal muscles and the tension generated through the thoracolumbar fascia contribute significantly to the balancing of external loads[11].

**Patterns of Muscular Activation**

Trunk stabilization can eliminate repetitive microtrauma seen in the lumbar spine segments, thereby encouraging healing, and slowing the degenerative process[9]. In healthy individuals, the onset of EMG activity of transversus abdominus is seen with all trunk movements, regardless of the direction of the movement[9]. Transversus abdominus activity is also observed with limb movements, prior to both the prime movers of the limb and all other abdominal muscles during that limb movement[35]. The discovery of the delayed response of transversus abdominus with limb movement seen in patients with low back pain compared with the early activation in healthy individuals has contributed to the understanding of the mechanism involved in poor trunk stabilization[35]. The consequence of dysfunction of transversus abdominus is decreased functional control of the trunk against forces acting against maintaining proper alignment of the spine[9]. It is not completely understood as to the mechanism of the delay of the abdominal muscles, nor is it clear if the delay of onset of the abdominal muscles precedes low back pain or is a result of the pain, however, a link between the altered recruitment pattern of transversus abdominus and back pain has been made[35]. Hodges and Richardson have shown that when rapid movements of the upper limb are performed by people with low back pain the onset of contraction of specific trunk muscles is delayed, indicating a change in the neuromuscular control of the postural response by the CNS[9]. Based upon the presence of altered patterns of muscular recruitment between trunk muscle synergists, Edgerton and colleagues were able to predict which subjects suffered from pain and which were controls with 88% reliability[36].

**Feed-forward Model**

A model, known as a 'feed-forward' pattern of activation, allows the understanding of trunk control strategies identifying the coordination and timing of activation of the muscles, which contribute to spinal stiffness and trunk stability[9]. Contraction of trunk muscles which occur prior to limb movement are know as 'feed-forward' postural responses, or anticipatory postural adjustments, and cannot be considered reflexive in origin as they occur prior to afferent feedback from the movement[6,37]. It is universally accepted that feed-forward or pre-programmed postural muscle activity is initiated either as part of the motor command[38], or coinciding with the motor command for movement[39]. This mechanism provides information regarding how the central nervous system deals with self-perturbation to maintain stability[37].

Feed-forward postural responses are specific to the direction of limb movements in order to control the direction of forces produced by the limb movements[40,41]. The time to onset of EMG activity of rectus abdominus, internal obliques, external obliques and multifidus, varied between movement directions with activation being earliest when the action of the muscle opposed the reactive forces associated with the specific direction of arm movement[35]. However, the reaction time of transversus abdominus does not change between movement directions demonstrating the role of this muscle in contributing to spinal stability in a non-direction specific manner[35]. Transversus abdominus is the first trunk muscle active with movement of both the upper and lower limb in any direction[42,43]. In subjects absent of low back pain, Hodges and Richardson[9] found that transversus abdominus was invariably the first muscle active preceding the prime mover of the shoulder for flexion, abduction and extension, indicating that transversus abdominus was not influenced by the direction of reactive forces. This was confirmed by, Hodges and Richardson[35], who demonstrated transversus abdominus contracts in a feed-forward mechanism, either prior to or less than 50 ms following initiation of the prime mover of the lower limb in three directions (flexion, extension, and abduction). Differences between lower limb and upper limb movement are, the onset of EMG of the trunk muscles preceding the prime movers were earlier during leg movements than arm movements, and each of the trunk muscles were active prior to the prime movers of the lower limb in all directions[42,43]. The onset of transversus abdominus EMG preceded that of the prime mover of the lower limb by 57-86 ms[35] versus –19 to –36 ms[43] for the upper limb. The increased relative latency of the lower limb compared with the upper limb is most likely associated with the increased requirement for trunk control necessary for movement of the lower limb due to its increased mass and closer proximity to the lumbar spine[35]. The feed-forward activation pattern of transversus abdominus, as well as other trunk muscles, is consistent with a number of previous studies of the upper limb[6,43,44].

When people with low back pain perform the arm movement task, the most consistent and distinctive finding is the associated delay in onset of activity of the transversus abdominus[35]. The consequence of the altered coordination of transversus abdominus with limb movement has not been confirmed but it has been hypothesized that the spine may be left unprotected from the reactive forces created by the limb movement[35]. The early feed-forward contraction of transversus abdominus may provide a mechanism by which the CNS is able to pre-stabilize the lumbar spine to prepare for either internal or external perturbations[35].

**Methods of Stabilization**

The internal obliques and transversus abdominus provide rotational and lateral control to the spine, maintain intra-abdominal pressure and create tension on the thoracolumbar fascia[44,45,46]. It is thought that co-activation of the deep trunk muscles increases the lumbar spine stiffness leading to enhanced dynamic stability[18]. One mechanism through which trunk stability is achieved is by transversus abdominus and the internal obliques restraining the thoracolumbar fascia edges[47]. With the contraction of both the transversus abdominus and internal obliques, there is a longitudinal tension whenever the abdominal musculature is firing[11]. The lateral pull is represented as a mechanical conversion into a longitudinal tension, as seen in figure 3[11].

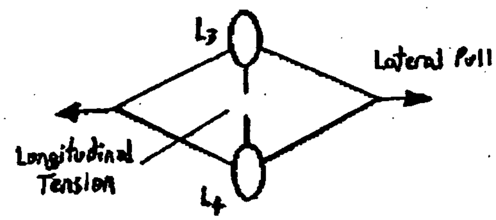


Figure 3. Mechanical conversion of a lateral pull into a longitudinal tension (Gracovetsky et al 1985)

The transversus abdominus is described as creating a lateral tension via the thoracolumbar fascia on the lumbar spine and acting as 'guy wires'[48] limiting intersegmental translation and rotation[43].

A second mechanism that is thought to increase trunk stability is related to increased intra-abdominal pressure. The primary reason for increased intra-abdominal pressure is to pressurize the abdominal cavity to a level at which the proper shape generated by the contracting musculature is maintained[11]. As the abdominal cavity becomes pressurized, the distance between the pelvic floor and diaphragm begins to increase[49]. The proper spatial orientation is maintained by the rectus abdominus contracting[49]. In this instance the rectus abdominus does not act to flex the spine but rather to simply counterbalance the action of the increased intra-abdominal pressure and to maintain the integrity of the abdominal cavity[11]. The increased intra-abdominal pressure is a function of the hoop tension created by the transversus abdominus and internal obliques[11]. Recent studies have shown that increased activity of the ventro-lateral abdominal muscles (primarily transversus abdominus and internal obliques) is associated with an elevation of intra-abdominal pressure[45,49,50]. The increase in intra-abdominal pressure has been interpreted as a mechanism to increase trunk stability[45]. Anatomically it is these muscles, which have the greatest potential to increase intra-abdominal pressure[45]. Through the use of intramuscular electromyographic recordings combined with measures from a pressure transducer and catheter, this rationale has been substantiated with transversus abdominus being the most highly correlated with increased intra-abdominal pressure[51]. Increased intra-abdominal pressure is interpreted as a mechanism to improve trunk stability and it appears that it is the rate at which intra-abdominal pressure is achieved that has the greatest effect[44]. Therefore, it seems reasonable to direct training towards the trunk rotators as opposed to the trunk flexors if the goal is to improve trunk stability using the mechanism of increased intra-abdominal pressure[44]. Cresswell et al has found that after 10 weeks of training aimed at the trunk rotators, primarily the transversus abdominus and internal obliques, an increase in trunk rotation strength and voluntary elevation of maximal intra-abdominal pressure was observed[46]. The rate of elevation of intra-abdominal pressure was also increased[46].

A third mechanism proposes that through the contraction of transversus abdominus tensioning on the thoracolumbar fascia the lumbar spine is converted into a rigid cylinder, with the intra-abdominal pressure maintaining the 'hoop-like' geometry of the abdominal muscles, and thus increasing the functional stability of the lumbar spine[47]. Studies of trunk movement[20] and trunk loading[45] have shown that transversus abdominus may contribute primarily to trunk stabilization. It is therefore reasonable to conclude that in the presence of poor muscular activity there would be a decreased level of function and an increased incidence of injury and low back pain[11].

A fourth mechanism contributing to lumbar stabilization involves maintaining an optimal level of muscle stiffness[52]. The agonist and antagonist muscles (transversus abdominus and multifidus), which lie on either side of a joint (the lumbar segments) increase in muscle stiffness and co-contract to enhance stability[53]. Although functional differences between the abdominal muscles do exist[44,45,46] the muscles which make up the abdominal mechanism function in patterns of synergy and do not work in isolation from one another[54]. A submaximal co-contraction of transversus abdominus and internal obliques with the lumbar multifidus provides a stiffening effect on the lumbar spine leading to enhanced dynamic stability[18].

A combination of the above mechanisms results in increased efficiency of the system and greater trunk stability[11]. It has been suggested that muscular dysfunction and motor control errors are possible causes of some low back disorders and chronic low back pain[34,55]. The stabilizing functions of the trunk musculature are especially important around the neutral spine posture as the spine exhibits a minimal amount of stiffness[55].

**Measurement**

Objective measurement of the deep trunk musculatures ability to stabilize is essential. It is well documented that the local muscles contract isometrically when stabilizing the trunk and pelvis[9,12,14,16,27,35], therefore a test of the stabilizing capacity of the abdominal muscles to initiate and hold a static contraction is appropriate[56]. The stabilizing capacity of the transversus abdominus and internal obliques can be measured by assessing the rotary control of the lumbar spine during sagittal plane loading[21]. A model was designed to assess the appropriate control of the trunk musculature at low load conditions to isolate target muscles[21]. The static model allowed the measurement of axial and sagittal plane movement while applying a sagittal load[21]. Excessive lumbar spine movement indicates an inability of the stabilizing trunk musculature to coordinate muscular recruitment to maintain a neutral spine posture, as load was applied[21]. Lumbar spine movement was measured using a pressure sensor, which operates on the principle that body movements and positional changes cause volume changes in the air chambers as measured by pressure changes (figure 4)[21]. On the application of leg load the pressure changes in each of four cells was measured simultaneously indicating the direction and movement of the lumbar spine in the rotational and sagittal directions[21].

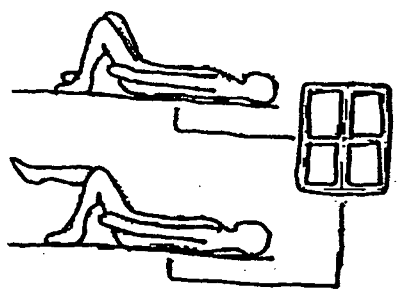

Figure 4. Measurement design and positioning of pressure sensor (Jull and Richardson, 1992)

Jull et al found that groups unable to automatically stabilize showed poor rotary control when measured with the pressure cell[21]. However, when assessed following performing an abdominal setting pattern the same group displayed much improved scores on a rotary control index[21]. The results confirmed the importance of the transversus abdominus and internal and external obliques in a stabilizing function as a sagittal load was applied in both symptomatic and asymptomatic individuals[21].

**Optimal Recruitment**

Exercise programs designed to improve the function of the local trunk muscles, specifically the transversus abdominus, internal obliques and multifidus, have been supported by clinicians to increase segmental stability leading to decreased incidence of back pain[12,57]. Exercises involved in specific activation of the deep abdominal muscles include activating a co-contraction of these muscles and maintaining a low-level tonic contraction[57]. The activation of these muscles leads to increased levels of trunk stability as previously discussed.

Differentiation or selective recruitment of the segmental stabilizers from the torque producers is essential to enhance trunk stability[58]. The investigation of a variety of abdominal exercises has enabled researchers to confirm that there are some exercises, which are more effective at specifically activating the deep abdominal muscles[21]. Exercises, which involve an applied rotary resistance to the trunk, appear to facilitate the trunk stabilizing musculature[16]. Exercises, which increase the activation of the musculature, which contribute to, increased intra-abdominal pressure and thoracolumbar fascia tension without simultaneously contracting rectus abdominus, lead to improved trunk stability[59]. Rectus abdominus appears to make little contribution to the stability of the trunk and pelvis region[54,59]. Research has shown that with practice of the abdominal drawing-in maneuver selective recruitment of the deep abdominal muscles without coactivation of rectus abdominus is possible as seen with increased activation of the internal obliques[57]. Therefore, exercises aimed at the deep musculature will enhance recruitment of the muscles involved with increased spinal stability[57]. Consideration of the stabilizing role of the abdominal musculature should be of prime consideration when designing and implementing a program to promote strength and endurance in the trunk region.

**Achieving Muscular Stability**

Researchers agree that by increasing lumbar stability, back pain can be decreased[57]. The goal of the stabilization exercise routine is to achieve engram motor programming through controlled precise movement patterns[10]. An engram is a neurophysiologic phenomenon that provides the necessary motor information involved in performing functional movement patterns[10]. Each component of a complex movement task is grouped together as a unit, forming an engram. Once motor engrams are created the movement patterns are formed in the motor cortex and at this point become automatic, and conscious control of movement is no longer needed[10].

A proper diagnosis and evaluation of the patient's needs is essential prior to implementing a trunk stability program in order to identify both indications and contraindications of treatment[60]. The purpose for developing a stability program is to teach the patient to control the trunk and pelvis in a neutral position while performing functional tasks. Automatic neuromuscular control can be achieved through the precise repetition of exercise[29,61]. The abdominal setting action is essential in being able to perform trunk stabilization exercises[35]. Learning to recruit the necessary musculature can be very difficult and frustrating to both the patient and clinician, but once learned this contraction becomes the key to building a stable base[61]. Stability training progresses from non-weightbearing supported positions and progresses to dynamic high-speed functional exercises[23]. Each stabilization level increases in difficulty as exercises are progressed and the increased demand is placed on the postural reflexes, as external support and stability are altered[23]. Advanced levels challenge the trunk musculature to accommodate rapidly to sudden changes of unanticipated loads of external resistance or unstable surfaces[23]. Through the use of proprioceptive neuromuscular facilitation techniques such as approximation, rhythmic stabilization, slow reversals and graded resistance, increased facilitation of the trunk musculature can occur leading to improved control over the trunk and pelvis[62].

**The "Sit-up"**

A commonly used exercise for trunk strengthening is the trunk curl-up[63], which leads to increased strength of trunk flexion. During the initial 30% of the sit-up movement, initial head up and shoulder up phases, the oblique abdominals and rectus abdominus are most active[64]. Perhaps a more beneficial function of the trunk musculature is its ability to co-contract isometrically to increase lumbo-pelvic stability to handle the loads of the upright posture[64]. Traditional exercises, such as the trunk curl-up appear to increase the individual's ability to perform trunk flexion as rectus abdominus is targeted, with little impact on the local muscles involved with trunk stabilization[16]. The increased recruitment of rectus abdominus reinforces the recruitment pattern of the global muscles[12]. In patients with chronic low back pain muscle substitution occurs as the global muscles contract when contraction of the deep abdominal muscles are attempted[12].

**The Abdominal Drawing-In Maneuver**

The abdominal drawing-in maneuver is known to be an exercise, which preferentially activates the transversus abdominus and internal obliques with little contribution from the rectus abdominus[22]. Thus, the abdominal drawing-in maneuver provides an ideal pattern of muscle activation enabling the deep trunk muscles to function as dynamic stabilizers[12]. Subjects with chronic low back pain are unable to differentiate between internal oblique activation and rectus abdominus during the abdominal drawing-in maneuver whereas healthy individuals have this ability[22]. Patients with chronic low back pain have a tendency to have weakened deep trunk muscles and develop altered motor recruitment patterns, enabling other synergistic muscles to generate the necessary force required for functional tasks[36]. This muscle substitution strategy is known as abdominal bracing and is often observed in patients with chronic low back pain[36]. These substitution patterns are seen as overriding activity of the rectus abdominus, predominantly the upper rectus abdominus, and the external oblique muscle while attempting to activate the deep trunk muscles[12,23,56]. Significant differences exist in the activation strategies of the abdominal stabilizing mechanism when comparing a group of subjects suffering from chronic low back pain and a pain-free group[22]. Subjects in the control group are able to preferentially activate internal oblique and transversus abdominus without significant activation of rectus abdominus as compared with a group suffering from chronic low back pain being unable to isolate this pattern to the same degree[22]. Richardson et al found that exercises, which used an isometric contraction and were required to resist a rotation force lead to effective muscular stabilization patterns[16]. These researchers found that exercises performed in crook lying, sitting and bridging produced the most favorable stabilization patterns[16]. Limitations of their study appear to be their measurement tools, as surface EMG of transversus abdominus result in high levels of background noise[57] and the exercises chosen are limited to a stable surface. In the presence of a decreased ability to recruit the deep trunk muscles, subtle changes in activation patterns develop into substitution strategies[22]. Therefore, close attention must be given when developing exercise programs as these substitution strategies begin to reinforce altered patterns of synergistic muscle recruitment and affect the ability to stabilize the lumbar spine effectively[22].

**Selective Recruitment**

The correct muscle recruitment patterns of the local muscles, transversus abdominus, internal obliques, and multifidus, are critical to maintain the dynamic stability and postural control of the lumbar spine during functional activities[12]. Basmajian[65] believes that motor learning is not simply a process of strength training, but also depends on the patterning and inhibition of motor neurons, with the acquisition of skills occurring through the selective inhibition of unnecessary muscular activity in some muscles, as well as the activation of additional motor units in others[65]. O'sullivan et al believe "that in the clinical setting, inhibiting unwanted synergistic muscle action when attempting to facilitate another muscle within a synergy requires a high level of skill and specificity with a need for patience and perseverance to prevent over facilitation. Such a treatment approach in the early stages appears to be more reflective of facilitating a change in the neural control of the muscular system rather than a simply strengthening underlying muscles"[22,p.93].

Low load exercises are beneficial in rehabilitation exercises as they reduce the chance of pain and reflex inhibition[16]. Low loads restore tonic function in muscle as needed in the local trunk musculature[16]. Tonic functions of muscle fibers operate at levels below approximately 30-40% maximal voluntary contraction (MVC)[66]. The presence of pain leads to the inhibition of specific trunk muscles and produces alteration in the neural strategies of recruitment[22]. Low-level contractions will provide stability; Hoffer and Andreassen found that contractions as low as 25% maximum voluntary contraction provide a maximal joint stiffness during increased levels of activity[67]. Therefore, it seems reasonable to expect that no more than 5% of MVC is necessary around a neutral spine to maintain stability in order to avoid fatigue and injury throughout the course of daily activities[55].

**Exercise and Rehabilitation**

The active and control subsystems may be developed through the use of exercise therapy in both the rehabilitation and prevention of lumbar spine pathology. One model of an active lumbar stabilization program can be divided into four overlapping stages[21].

Stage 1 involves the facilitation of the stabilizing musculature and the removal of compensatory movement patterns[21]. Through the abdominal hollowing action the transversus abdominus and internal oblique musculature are selectively activated with rectus abdominus and external obliques being deactivated[22]. The multifidus muscle is also facilitated at this stage[22]. Precise instruction is given regarding how to recruit the deep muscles. Instructions include drawing in and hollowing the lower abdomen or drawing the navel up and towards the spine[14,68]. Alternate cues may include the analogy of transversus abdominus working as if tightening a belt or drawing the two sides of the body closer together. The abdominal setting action must be taught with quiet continuous breathing[22]. The contraction is a submaximal contraction and requires a controlled effort[22]. A stretch facilitation may also be an effective tool, utilizing the pressure created by the abdominal contents on the abdomen in the four point kneeling or prone positions[56].

A rotary resistance applied to the trunk via the pelvis or shoulders will facilitate activation of the stabilizing muscles[16]. A submaximal effort is encouraged working at approximately 30% of maximal effort, as tonic control is emphasized[66]. Rhythmic stabilization and alternate isometric resistance contractions are techniques that enhance facilitation[62].

Stage 2 includes the progression of static stabilization exercises[21]. Both internal and external loads are placed on the trunk while the static posture is maintained[21]. Functional eccentric control of the trunk during limb movements is achieved as distal loads are applied challenging the trunk musculature to maintain the neutral spine position[21]. Strength and endurance components are added at this stage while remaining focused on precise control[21]. All exercises are performed in a 'neutral zone' or neutral spine to avoid any end-range stresses[34].

Stage 3 progresses to dynamic stabilization and the control of the lumbar spine and pelvis in a pain-free range[21]. As the ability to avoid end-range stress is achieved within a functional range, the stabilization process has progressed from static to dynamic. Stabilization of the trunk is achieved during controlled movements of the lumbar spine. Automatic muscular activation begins in this stage with the application of functional movement patterns[10].

Stage 4 begins with functional movements specific to the individual, with the speed of movement increasing, progressing to the development of automatic stabilization during high-speed movement of the limbs and trunk[21]. Phasic acceleration and deceleration movement patterns challenge the tonic supportive function of the local muscles[21]. The abdominal setting pattern is maintained while daily tasks are performed[22].

The final stage of rehabilitation involves converting the conscious or cortical level of stabilization to the subconscious or subcortical level of control of the correct movement patterns[21]. As sensory stimulation is increased an improved activation of the subcortical level is achieved[10]. At this point the stabilizing system becomes automatic and is activated at a faster rate[21]. This improved muscle reaction time has been shown to improve the stability of the lumbar spine and pelvis and lead to decreased levels of low back pain[29,69].

## Introduction to Research Study

It is well documented that back pain is an enormous problem among the general population[3]. Low back pain affects virtually everyone at some time during his or her life[2]. Statistics indicate that each year at least 50% of working age adults exhibit symptoms of low back pain at some point[1]. This back pain often comes from the lumbar spine and problems related to both osseoligamentous and muscular insufficiencies[6]. As the spine is inherently an unstable structure, failure of the muscular stabilizers leads to increased risk of injury to the lumbar spine[6].

Back pain sufferers have been shown to have an altered muscular recruitment pattern of the deep trunk stabilizers compared with pain-free subjects[12]. The insufficient function of the trunk muscles leads to increased stress and undue load on the joints and ligaments of the spine creating increased levels of low back pain[6,10,11]. The deep trunk muscles decrease in their functional performance due to an altered pattern of recruitment in populations with low back pain[22]. A shift in the pattern of muscular activation is seen as an overriding recruitment of rectus abdominus and an inability to preferentially activate the deep abdominal muscles[12,22,23].

Re-education and training of the deep trunk musculature to control spinal segments has been shown to decrease the level of low back pain and help prevent its recurrence[12,23,28,29]. Trunk stability is achieved through the combination of a number of mechanisms requiring increased activation of transversus abdominus, internal obliques and multifidus[11]. The first mechanism involves the transversus abdominus and internal oblique muscles which creates a lateral pull that is converted into a longitudinal tension via the thoracolumbar fascia limiting intersegmental translation and rotation[11,43,47]. A second mechanism functions as the transversus abdominus and internal obliques also act to increase intra-abdominal pressure in a manner described as 'hoop tension' as the ventrolateral abdominal region contracts increasing trunk stability[11,49,50]. A third mechanism is described with the contraction of the transversus abdominus tensioning on the thoracolumbar fascia which leads to the lumbar spine being converted into a rigid cylinder, with the intra-abdominal pressure maintaining the 'hoop-like' geometry of the abdominal muscles, and thus increasing the functional stability of the lumbar spine[47]. A fourth mechanism works as the agonist and antagonist muscles (transversus abdominus and multifidus), which lie on either side of a joint (the lumbar segments) increase in muscle stiffness and co-contract to enhance stability[53]. It is clear that improved function of the deep trunk muscles, specifically the transversus abdominus, internal obliques and multifidus, increases segmental stability via a combination of the above mechanisms leading to decreased incidence of low back pain[12,57].

Through the investigation of a number of abdominal exercises, researchers have determined that certain exercises are most effective at facilitating a contraction of the deep abdominal muscles[21]. The abdominal drawing-in maneuver has been shown to be the most effective recruitment pattern of the transversus abdominus and the internal oblique musculature[57]. Increased recruitment of the deep muscles leads to increased stability of the lumbar spine[57]. Clinically, the abdominal drawing-in maneuver is used on a stable surface such as a plinth, and more often is being used on an unstable surface such as a physio-ball or Sissel. Research has shown the ability of the abdominal drawing-in maneuver to facilitate a contraction of transversus abdominus, internal obliques and multifidus on a stable surface[22,16], but not on an unstable surface. Anecdotally many clinicians believe that there is increased facilitation of the deep trunk muscles on an unstable surface but do not know for certain. There has been a recent study showing increased activity of rectus abdominis and external obliques on a labile surface but not the deep musculature such as transversus abdominis or internal obliques[70]. It is not clear if there is increased facilitation of the appropriate trunk stabilizers when on an unstable surface, or if there is increased facilitation of the other trunk muscles leading to a compensatory pattern of activation[23,36]. The need to assess the effectiveness of training the deep trunk muscles on an unstable as compared with a stable surface is apparent. The purpose of this study was to evaluate the clinical and subjective levels of improvement of the deep trunk muscles, following training, on an unstable versus stable surface under an abdominal pre-setting condition. The following hypotheses were tested:

1. Abdominal exercises performed following abdominal presetting of the deep trunk musculature improves clinical function.
2. Abdominal exercises practiced in an unstable environment improves the clinical function of the deep trunk muscles greater than performing the same exercises in a stable environment.
3. Subjective improvements in function are noted following training the abdominal musculature in an unstable environment.

**Methods**

Subjects

Subjects (n=25) were participants from the Vancouver Dolphins Swim Club between the ages of 14 and 19 years (10 males and 15 females) and were of average statistical height and weight[16,21,35]. Subjects were randomly assigned into one of two groups: a group (n=13) instructed on abdominal setting and then performing exercises on a stable surface ie. an exercise mat, and second a group (n=12) instructed on abdominal setting and then performing the same exercises on an unstable surface, ie. Sissel's (inflatable discs). Subjects were excluded if they had; any musculoskeletal or neuromuscular conditions, any history of significant low back pain or minor low back pain within the last three years, any history of abdominal surgery, or any history of hip pain interfering with activities. Subjects were also excluded if they had tightness of their erector spinae or iliopsoas muscles as examined by standard clinical muscle length tests, [see appendix 2][71], or if they were assessed to have had a marked lordotic, sway back or flat back posture as any of theses conditions indicate trunk muscle imbalance[63,72]. Subjects were not selected if they had previously been involved in a regimented abdominal muscle-training program. Subjects received an explanation of the study including the expectations of their involvement. Subject's rights were protected at all times and subjects or legal guardians signed an informed consent form prior to their involvement in the study, [see appendix 5]. Ethical approval was obtained from the UBC Ethics Committee.

## Setting

The testing was conducted at the Allan McGavin Sports Medicine Centre, War Memorial Gym, location in Vancouver, B.C. on the University of British Columbia campus. Assigned exercises were completed at the clinic or at the UBC Aquatic Centre. The study was conducted by co-investigator Sam Brovender and supervised by the investigator Dr. Timothy Inglis.

## Instrumentation

### Stabilizer™ Pressure Biofeedback Unit

The Stabilizer™ pressure biofeedback unit (Chattanooga Group, Australia)[6,21,49] was used to determine the ability of the subject to maintain a neutral spine posture while undergoing abdominal testing procedures. The Stabilizer™ is a tri-sectional rectangular inflatable cushion (23 x 14 cm) connected to a pressure gauge (measuring 0-300 mmHg) and inflation device, [see Appendix 4][12,21]. The cushion was inflated to accommodate for the irregular space between the subjects lumbar spine and exercise mat (approximately 40 mmHg)[12,21]. The device is sealed and volume changes are reflected by changes in pressure, which reflect uncontrolled movement of the lumbar spine[49]. The Stabilizer™ can be used to detect successful or unsuccessful activation of the stabilizing synergy from a baseline pressure of 40 mmHg[49]. Correct abdominal setting registers an increase in pressure of 10-15 mmHg[21]. An inability to activate the stabilizing musculature registers a nil increase in pressure or a decrease in pressure as the abdominal testing occurs, whereas a substitution pattern with the firing of rectus abdominus causes flexion of the lumbar spine and registers an increase in pressure of 20-30 mmHg or greater[21]. Correct activation of transverus abdominus compared with firing of rectus abdominus or minimal recruitment of any of the abdominal musculature, are all distinctly different activation patterns and can easily be observed clinically.

## Testing

The ability to stabilize the lower trunk and pelvis was monitored using the Stabilizer™ and progressively increasing loads were obtained by using movements of the lower limb[12,21,49]. In order to attain each new level of the test exercise the lumbar spine position had to be maintained as indicated by the Stabilizer™[12,21,49]. The baseline level of the Stabilizer™ was monitored and any drop or increase in pressure (within a range of 10 mmHg) indicated a failure at that particular level.

The test exercise consisted of five levels, from one to five, with each level increasing in difficulty. The resistance load produced by movement of the legs added stress to the lumbopelvic region as each level increases. The degrees of difficulty of the test progressed as follows, [see appendix 3][72]:

Level 1 – from a crook lying position abdominal presetting was performed. The subject slowly raised one leg to a position of 100 degrees of hip flexion with comfortable knee flexion and then slowly raised the other leg into the same position without a change in the lumbar spine posture as noted by the Stabilizer™. This position was the start position for the following levels. The pressure readings of the Stabilizer™ were noted and any change in the readings beyond the allowable limits indicated that the lumbopelvic control had been lost at that level of the test exercise. Subjects were graded at the exercise level at which they were able to control a neutral spine posture. The neutral spine posture is the position in which subjects stand or lay naturally. The individual differences in lumbar spine curves will affect individual's neutral spine postures.

Level 2 – from the start position, the subject slowly lowered one leg and, with the heel down on the exercise mat, slid the leg out to straighten the knee, then slid it back up into the start position.

Level 3 – from the start position, the subject slowly lowered one leg and, with the heel maintained approximately 12 cm off the ground, fully extended the leg and then moved it back to the start position.

Level 4 – from the start position, the subject lowered both legs together, and with the heels down on the exercise mat, slid the legs out to straighten the knees and then slid them back and raised them to the start position.

Level 5 – from the start position, the subject simultaneously extended both legs keeping the heels approximately 12 cm off the ground and then flexed the legs back to the start position.

Daily Log

A daily log was used to document compliance and the amount of time-spent training, and any subjective comments related to function and performance were recorded, [see appendix 7].

**Procedure**

This study involved the determination of the effectiveness of a training protocol on an unstable surface versus the same training protocol on a stable surface. Subjects were randomly assigned into one of two exercise groups. The first group performed exercises on a stable surface and the second group performed the same exercises on an unstable surface. The stable surface used was a traditional exercise mat and the unstable surface included two Sissel pads. Sissel pads are air filled bladders and they were placed side by side allowing subjects to be in crook lying on the pads with one pad under the hips and the other under the thoracic region. Subjects performed their exercises in crook lying either on the exercise mat or on the Sissel's with their head supported by a pillow so as not to stress the neck flexors and engage any compensatory muscle patterns. The exercises assigned to the subjects were standard exercises used widely in physiotherapy practice with a focus on the activation of the stabilizing synergy, including transverus abdominus and thoracolumbar fascia. The exercises included the 'deadbug', the 'bridge' and the 'prayer' and were progressed once each week over the course of the six-week study. Progressions included increases in the time each exercise was performed, the length of the lever arm used during the exercise, the base of support and the amount of external resistance. Details of specific progressions for each exercise, each week, are given in appendix 1. Each exercise was performed five days each week and during each session subjects performed five sets of each exercise with the sets increasing in time from 30 seconds to 80 seconds, increasing at 10-second increments each week over the period of the six-week study. Each exercise was performed at a moderate rate, with each repetition taking approximately 1-2 seconds throughout the entire training program. Once assigned to an exercise group all subjects were instructed on the proper abdominal setting pattern until they were able to perform the contraction to a satisfactory level. The instructor taught each subject on a one on one basis. Each subject's ability to perform the abdominal setting pattern was checked by the tester prior to the commencement of the study to ensure a consistent evaluation process. Subjects met once a week with an instructor at the Allan McGavin Sports Medicine Centre, War Memorial Gym, at the same time each week to ensure the proper exercise technique was maintained as well as to receive the pre-determined sequence of progression of their exercises. Three testing sessions were conducted over the course of the six-week study, [see appendix 6]. The first test was conducted following the abdominal setting education session and prior to the commencement of the exercise sessions, the second test was conducted at the three-week mark and the final test was conducted at the six-week mark. Baseline measures were taken using the Stabilizer™ and the Sahrmann testing protocol, and the logbook. At both the three and six-week testing sessions subjects were assessed using the Stabilizer™ and testing protocol as well as copies of the logbooks were collected. The tester was a physiotherapist at the Allan McGavin Sports Medicine Centre with a sound understanding of the abdominal setting pattern. The same tester was used at each of the three testing sessions. The tester also checked the abdominal presetting action of each subject prior to the commencement of the study. The tester was blinded as to the exercise group allocation of each subject. Subjects were asked to participate in the abdominal training program assigned and refrain from any other specific abdominal training exercises.

**Data Analysis**

The analysis of results included determining if greater improvements are attained following training on an unstable surface versus performing the same exercises on a stable surface, as well as observing how the two groups changed over time. The ability to control the lumbopelvic region with the stability synergy pattern of muscle activation was evaluated using the Stabilizer™ Pressure Biofeedback Unit and the Sahrmann testing protocol. Perceived improvements in functional performance were noted when evaluating the results of the logbooks.

The response collected at each measurement, using the Sahrmann testing protocol, was an integer between zero and five inclusive, which indicates the level attained of a progressively more difficult series of movements that the subject was able to perform. The data collected is of an ordinal nature due to the fact that a subject who scored three is at a higher level than a subject who scored one. The magnitude of change from a score of one to that of three is not the same as the change from three to five.

The Wilcoxon Rank Sum Statistic was used to test for between group differences at both the three-week and six week testing sessions but does not control for previous scores or differences. The Stratified Wilcoxon Rank Sum Statistic was used to test for between group differences at the six-week testing session while taking into account the three-week score. When stratifying the data at six-weeks on the scores at three-weeks, some strata may have observations while there are no observations in other strata with which to compare. In this case, the data for which no comparison is available must be discarded. McNemar's test was used to test within group differences from zero to three weeks and from three weeks to six weeks. All statistical analysis were performed using the IBM SAS Package (SAS Inc 1985).

**Results**

At the three-week testing session when looking at the between group differences while not controlling for baseline measures the Wilcoxon Rank Sum Statistic was used. Under the null hypothesis that the two groups are drawn from distributions having equal medians the probability of the observed outcome is 51.5%. This test therefore fails to reject the null hypothesis that the unstable surface is of equal value to the stable surface. At the six week testing session, using the same analysis, under the null hypothesis the probability of the observed outcome is 19.4%, which also fails to reject the null hypothesis of equal medians. Therefore, when using the Wilcoxon Rank Sum Test at the both the three and six week marks of the study there appears to be no difference between the stable and unstable groups.

However, the most significant result is found when using the Stratified Wilcoxon Rank Sum Test to test for between group differences at the six-week testing session taking into account the three-week testing session scores. A different test at each unique three-week score, which is common to both groups, was calculated. A score of four was not obtained in the stable group at the three week testing session therefore that score was excluded. The results of the Stratified Wilcoxon Rank Sum Test are seen in Table 2.

| (a) Three week score | (b) Wilcoxon statistic | (c) Expected value of (b) | (d) Standard Error of (b) | (e) Number in Stratum | (f) z |
|---|---|---|---|---|---|
| 0 | 5.0 | 7.0 | 2.1 | 6 | -0.73 |
| 1 | 26.0 | 33.0 | 4.4 | 10 | -1.48 |
| 2 | 4.0 | 5.0 | 1.0 | 4 | -0.50 |
| 3 | 3.5 | 4.0 | 0.71 | 3 | 0.00 |

Table 2. Stratified Wilcoxon Rank Sum Test for between group differences at six weeks taking into account the three-week scores.

The z-statistic which corresponds to the Stratified Wilcoxon Rank Sum Test is –2.2 with a one sided p-value of 0.014. This leads us to reject the null hypothesis that the groups are drawn from populations having equal medians in favour of the alternative hypothesis that the median of the population from which the unstable group has been drawn is greater. Thus, after adjusting for the three week score, we reject that the training regimen on an unstable surface has no effect in favour of the hypothesis that training on an unstable surface is superior to training on a stable surface. Using the Stratified Wilcoxon we see that there are significant between group differences in the ability to control the lumbopelvic region with the greatest improvements seen in the subjects training on the unstable surface as compared to the participants training on the stable surface, as seen in figure 5.

When observing how the two groups changed over time McNemar's test was used to look at the within group differences. The stable group on the interval from zero to three weeks included twelve participants, nine of which improved their score from the baseline to the third week. None of the participant's scores declined on this interval, three

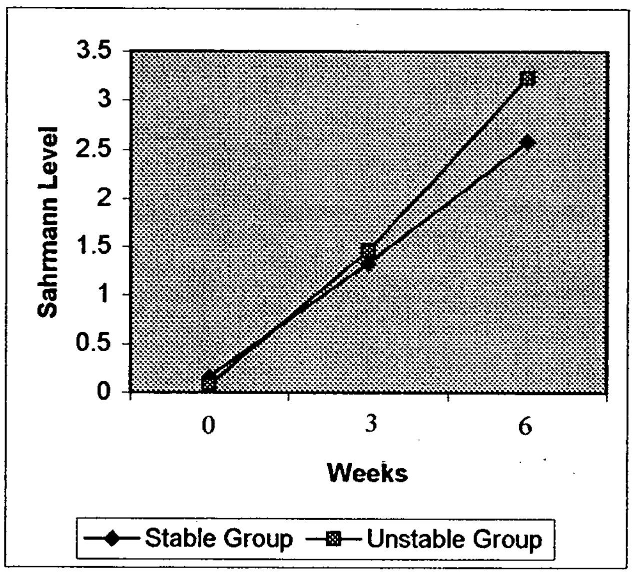


Figure 5. Group mean scores of the stable group compared to the unstable group at baseline, three weeks and six weeks.

had constant scores and therefore do not enter into the analysis. Under the null hypothesis of no trend in the score, the one-sided p-value observed in this outcome is 0.002. Therefore, we reject that there is no trend in favor of the hypothesis that the scores are increasing and subjects are improving. The stable group on the interval from three to six weeks demonstrated nine of twelve scores increasing, one subject's score declined and two participants had constant scores and were excluded from this portion of the analysis. Once again, under the null hypothesis of no trend in improvement the one sided p-value is 0.011 which is evidence of a trend supporting the alternate hypothesis. The unstable group on the interval from zero to three weeks included thirteen participants, nine of which improved their score, none of the participant's scores declined, but four of the participants scores were constant and therefore excluded. Under the null hypothesis of no trend in the scores, the one-sided probability of observing this outcome is 0.002, therefore we reject that there is no trend in favor of the hypothesis that the scores are increasing. On the interval from three to six weeks ten of the thirteen scores in the unstable group increased, none decreased and three participants are uninformative because they had constant scores on this interval. Under the null hypothesis of no trend the one-sided p-value is 0.001, and again a trend is evidenced supporting the hypothesis. Analysis of the within group changes supports the hypothesis on all accounts that undertaking a progressive training protocol increases lumbopelvic control, as seen in figure 6.

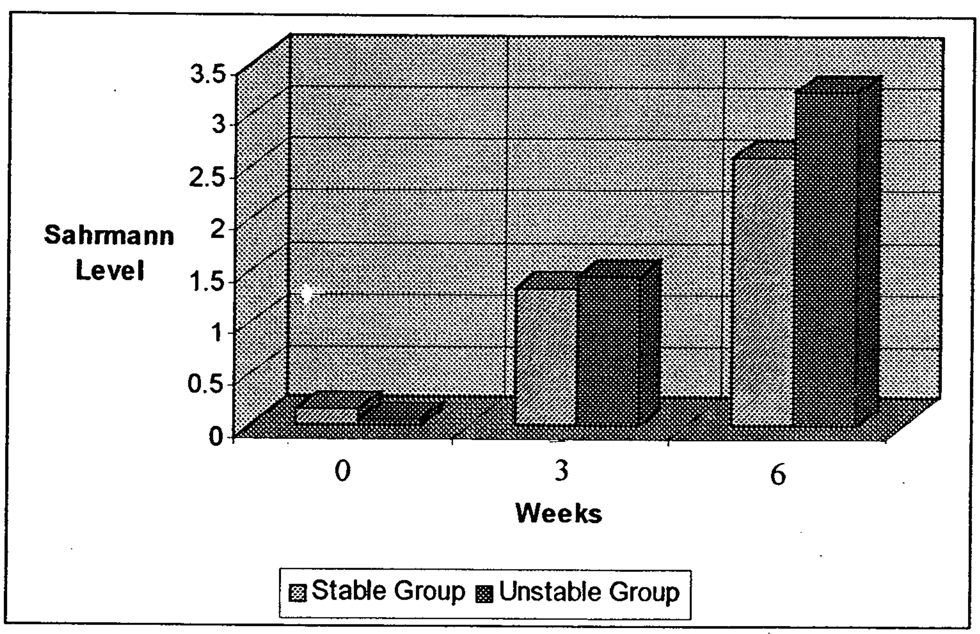


Figure 6. Group mean Sahrmann Level scores showing improvement from zero, to three and six weeks respectively.

When reviewing the logbooks, there appears to be a subjective link between training and performance. All subjects felt as though they got stronger throughout the period of the study and felt more powerful in the water. There did not appear to be any between group differences from a subjective standpoint.

**Discussion**

Performing the abdominal drawing in maneuver prior to undertaking an abdominal training program, on either a stable or an unstable surface, improves the clinical function of the abdominal musculature[12,16,23]. Following a base level six-week training program subjects improved their lumbopelvic control through the activation of one of the stabilizing mechanisms. When using the pre-setting technique and then progressing through the Sahrmann levels, while monitored with a pressure bio-feedback unit, all subjects were able to achieve a higher level of clinical function. None of the subjects had any previous knowledge or ability to activate the transversus abdominus muscle. Subjects consistently practiced the abdominal drawing in maneuver while performing their exercises. A number of opportunities were given for each subject to practice the abdominal drawing in maneuver prior to the three-week testing period, including an initial training session, an outlined training program, and weekly progressions of exercises. At the three-week mark both the stable and unstable groups noted significant improvements within their own groups and there was no significant difference between the two groups to indicate which of the training environments were superior. This improvement in performance is most likely related to a learning affect as opposed to an increase in strength, as strength changes take a minimum of four to six weeks to occur[16]. The lack of significant differences between groups was most likely due to the equal learning effect of all subjects. Because none of the subjects had any previous knowledge regarding the activation of the transversus abdominus, all subjects, regardless of which group they were in, began to improve as their neuromuscular awareness increased. Improved neuromuscular activation of the transversus abdominus has been shown to improve lumbopelvic function in a stable environment, but not in an unstable environment[21,35,72]. The group performing their exercises in an unstable environment did show within group improvements, but these improvements were not significantly greater than those of the group performing the same exercises in an unstable environment. The stable group may have had an advantage in the learning process as they were learning a new skill in a closed environment with controlled variables as opposed to the unpredictable nature of the unstable environment. There was no significant difference between the two groups at the three-week mark, but it would not have been unreasonable to find that the stable group had improved their trunk stability greater than the unstable group. The increasing trend of improved clinical function within each group continued through the six-week mark. The improvements seen in each group are presumed to be due to greater neuromuscular control of the abdominal musculature and the beginnings of increased strength levels.

When evaluating the between group differences at the six-week mark the results become of greater interest. When comparing the gross levels attained on the Sahrmann scale, using the Pressure Bio-feedback Unit, there is no difference between the two groups. However, significant findings are recorded at the six-week mark when taking into account the three-week scores to assess improvement. The exercise group training in the unstable environment proved to obtain significantly higher scores than the group training in the stable environment. The unstable group gained greater control over the lumbopelvic region by improving their neuromuscular control of transversus abdominus. Clinically, this reaffirms the thought of using an unstable surface as a training tool to improve trunk stability. Subjectively, based on the logbooks, all subjects felt that their performance improved as they improved their trunk strength, regardless of being in the stable or unstable group.

There are a number of pathologies, which can create back pain such as discogenic, pelvic malalignment and facet joint irritation, among others. When addressing any of these conditions one aspect of treatment includes controlling shear forces and creating torsional rigidity in the lumbar spine and pelvis region. By learning to activate transversus abdominus and gaining neuromuscular control over this muscle individuals are able to create the 'rigid cylinder', helping to decrease irritation causing low back pain. Back pain patients must relearn activation patterns in a methodical manner in order to avoid developing compensatory patterns of activation. Individuals must relearn the proper motor program to activate transversus abdominus beginning in a controlled stable environment progressing to a more dynamic unstable environment. As the time of activation of transversus abdominus is improved individuals daily function becomes less painful.

**Conclusions**

When combining all of the findings of the study a number of very applicable clinical findings are evidenct. Learning the abdominal pre-setting action is crucial to improving trunk stability. It is likely that a majority of athletes have poor neuromuscular awareness of transversus abdominus. Learning to activate transversus abdominus in a stable environment while performing basic exercises will allow for individuals to perfect a new motor program with a minimal number of uncontrolled variables. Once an individual is able to activate transversus abdominus effectively in a stable environment while performing basic movement patterns the same person will be able to progress to an unstable environment. Having the base level of activation will allow the individual to continue to progress in a more functional and dynamic environment minimizing the likelihood of developing compensatory patterns of activation. This individual will have greater control over their trunk region. Decreasing the bodies need to react to a situation and increasing its ability to control its movement patterns will lead to improved performance.

Improving trunk control in asymptomatic athletes will improve performance. More importantly learning to activate mechanisms, which stabilize the lumbopelvic region is crucial when treating low back pain. Activating the deep trunk musculature enables the stability mechanisms that are essential in order to decrease back pain in a number of pathological conditions surrounding the lumbar spine and pelvis. Learning to control the deep musculature on a stable surface initially, improves neuromuscular activation establishing new motor programs. Once appropriate muscle activation patterns are learnt in a stable environment an unstable and more functional environment may be introduced. As control over the lumbopelvic region is improved patient's symptoms will decrease and begin to establish a base for the prevention of future back pain.

**Future Considerations**

This study provided us with a starting point to evaluate the use of the unstable environment in the clinic to improve trunk stability and ultimately improve performance.

To control better for the learning effect and to be able to differentiate for strength improvements as well as isolating the effects of the training environment a few changes could be made. The study could begin with two groups, both training in a stable environment, performing the same exercises for a six-week period. This would control for motor learning and some strength changes. At the six-week mark one of the groups would progress their exercises into an unstable environment and the other group would progress their exercises in the same manner in a stable environment. This new twelve-week study would control for neuromuscular education in the early stages and isolate the effects of the unstable environment as the training progresses. The exercises themselves would progress more slowly over the increased time period to ensure strict movement patterns. These findings would continue to provide us with clinical methodology regarding the progression of individuals. A very difficult study to undertake, but of great value, would be to validate a non-invasive measurement tool of trunk stability using indwelling electrodes.

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## Appendix 1 – Exercises and Progressions

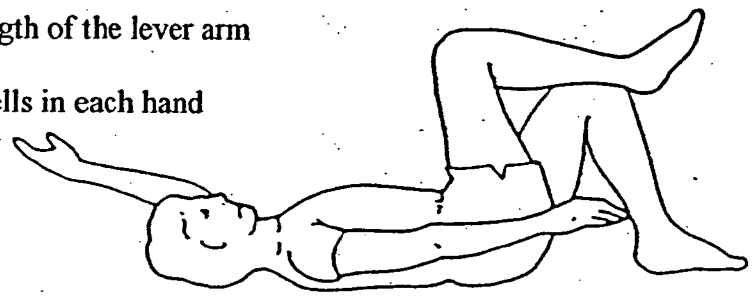
Each of the three exercises are performed five times per week, with each session consisting of five sets of each exercise. Each week all three exercises are progressed by 10 seconds per week beginning at 30 seconds and ending with 80 seconds. The individual exercises have unique progressions every two weeks.

**Deadbug**

Weeks 1 & 2 – reciprocal arm and leg movements

Weeks 3 & 4 – increasing the length of the lever arm

Weeks 5 & 6 – two pound dumbells in each hand

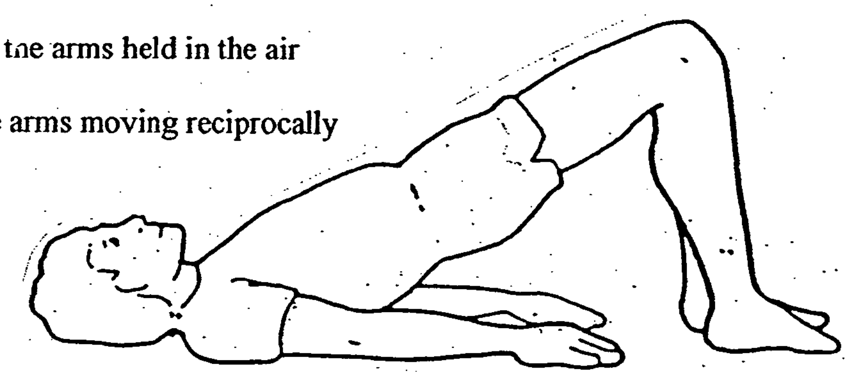


**Bridge**

Weeks 1 & 2 – marching with the arms on the ground

Weeks 3 & 4 – marching with the arms held in the air

Weeks 5 & 6 – march with the arms moving reciprocally

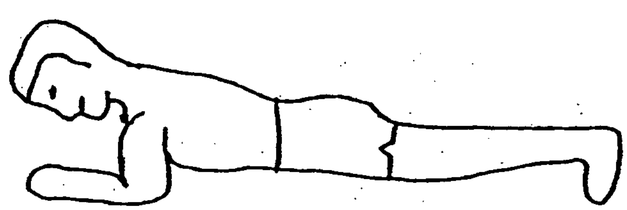


**Prayer**

Weeks 1 & 2 – holding the static position

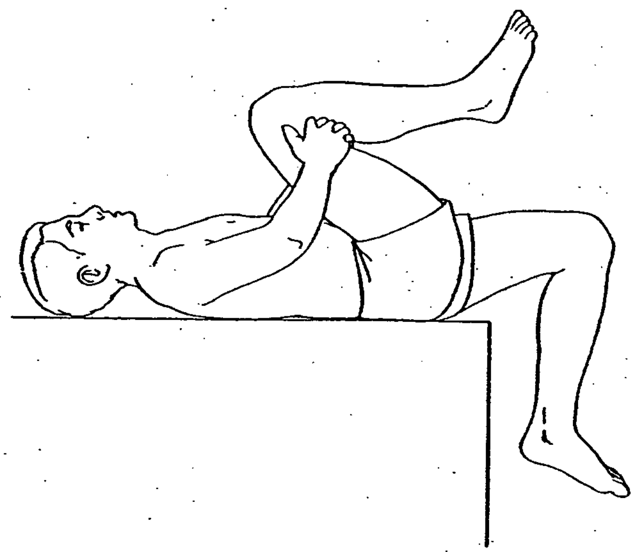
Weeks 3 & 4 – lifting alternate legs

Weeks 5 & 6 – lifting alternate legs and arms

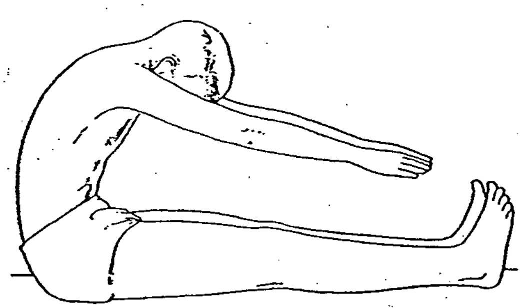


## Appendix 2 – Clinical Muscle Length Tests

Iliopsoas muscle length test (Thomas test)

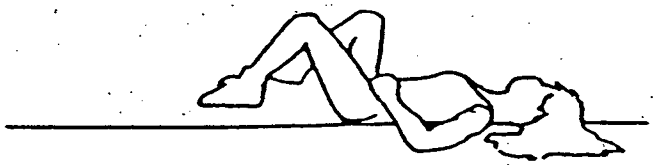


Erector spinae muscle length test (sit and reach)

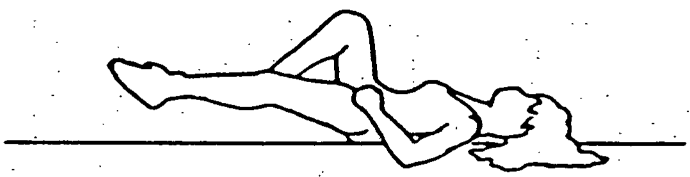


## Appendix 3 – Testing Levels

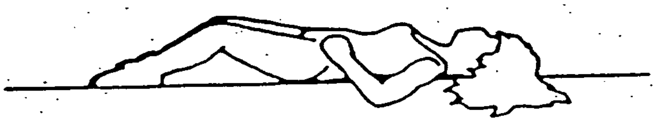
Level I



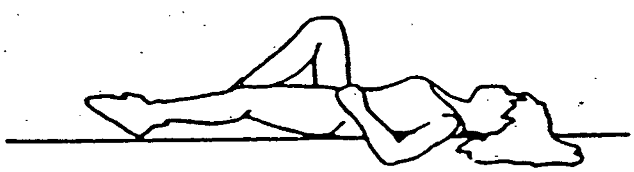
Level II



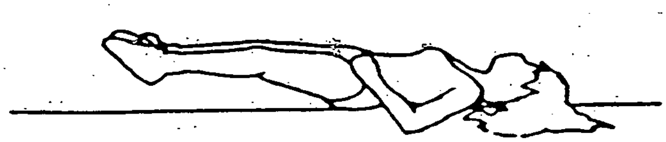
Level III



Level IV

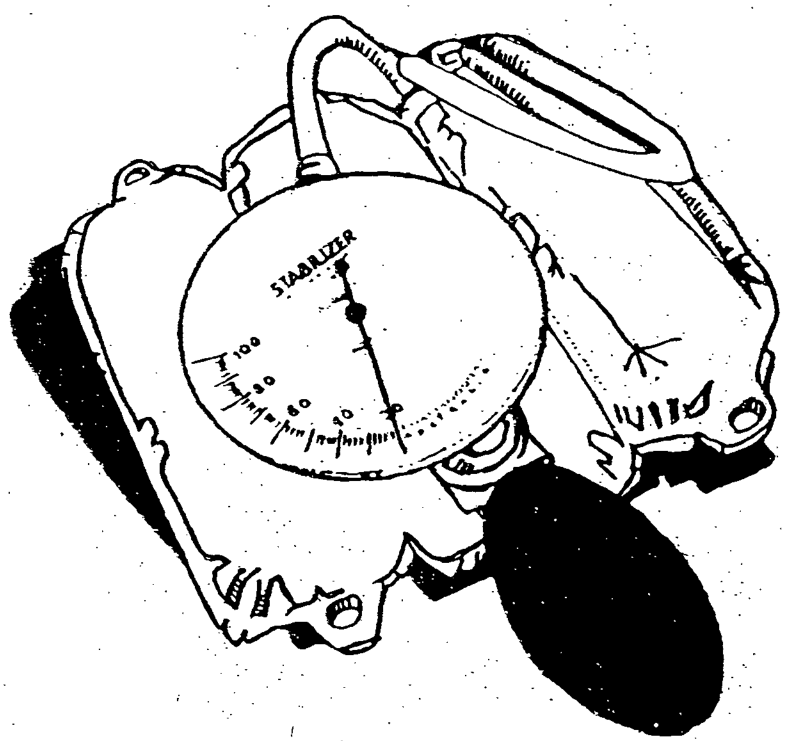


Level V



## Appendix 4 – Pressure Biofeedback Unit (Stabilizer™)

The Stabilizer™ Pressure Biofeedback Unit will be used as the measurement tool. The three chamber cell is placed between the lumbar spine and the plinth. The unit is inflated to fill the space between the lumbar spine and the plinth to approximately 30-40 mmHg. Pressure changes are noted and related to a changes in the neutral spine posture.



## Appendix 6 – Research Schedule

Core Training Schedule

Friday, June 9 – 4:30pm / introduction (30 minutes)

Wednesday, June 14 – 4:30pm / testing session #1 (1-2 hours)

Wednesday, June 21 – 4:30pm / training session (20 minutes)

Wednesday, June 28 – 4:30pm / training session (20 minutes)

Wednesday, July 5 - 4:30pm / testing session #2 (1-2 hours)

Wednesday, July 12 - 4:30pm / training session (20 minutes)

Wednesday, July 19 - 4:30pm / training session (20 minutes)

Wednesday, July 26 - 4:30pm / testing session #3 (1-2 hours)

# Appendix 7 – Daily Activity Log

Initials (first, middle, last): __ __ __

Week 1

| | Deadbug (level) | Bridge (level) | Prayer (level) |
|---|---|---|---|
| Day 1 | | | |
| Day 2 | | | |
| Day 3 | | | |
| Day 4 | | | |
| Day 5 | | | |

Week 2

| | Deadbug (level) | Bridge (level) | Prayer (level) |
|---|---|---|---|
| Day 1 | | | |
| Day 2 | | | |
| Day 3 | | | |
| Day 4 | | | |
| Day 5 | | | |

Week 3

| | Deadbug (level) | Bridge (level) | Prayer (level) |
|---|---|---|---|
| Day 1 | | | |
| Day 2 | | | |
| Day 3 | | | |
| Day 4 | | | |
| Day 5 | | | |

Comments:

Initials (first, middle, last): __ __ __

Week 4

| | Deadbug (level) | Bridge (level) | Prayer (level) |
|---|---|---|---|
| Day 1 | | | |
| Day 2 | | | |
| Day 3 | | | |
| Day 4 | | | |
| Day 5 | | | |

Week 5

| | Deadbug (level) | Bridge (level) | Prayer (level) |
|---|---|---|---|
| Day 1 | | | |
| Day 2 | | | |
| Day 3 | | | |
| Day 4 | | | |
| Day 5 | | | |

Week 6

| | Deadbug (level) | Bridge (level) | Prayer (level) |
|---|---|---|---|
| Day 1 | | | |
| Day 2 | | | |
| Day 3 | | | |
| Day 4 | | | |
| Day 5 | | | |

Comments:

## Appendix 8 – Data Collection

| Initials (F/M/L) | T1 (1-5) | VAS | QUEST | T2 (1-5) | VAS | QUEST | T3 (1-5) | VAS | QUEST |
|---|---|---|---|---|---|---|---|---|---|
| AML | 0 | 5.5 | 63 | 1 | 5.7 | 66 | 4 | 6.6. | 68 |
| AMT | 0 | 3.1 | 43 | 2 | 3.7 | 54 | 4 | 5.3 | 55 |
| CML | 0 | 6.5 | 63 | 2 | 7.4 | 74 | 4 | 6.9 | 74 |
| DLD | 1 | 3.2 | 60 | 3 | 4.3 | 62 | 4 | 6 | 67 |
| GFS | 0 | 5.4 | 51 | 3 | 6.6 | 55 | 5 | 7.9 | 56 |
| KDC | 0 | 3.1 | 60 | 1 | 4.3 | 62 | 4 | 5.7 | 65 |
| KML | 1 | 3.6 | 54 | 0 | 4.7 | 55 | 1 | 7.2 | 52 |
| DI | 0 | 1.7 | 42 | 1 | 3.3 | 46 | 2 | 4.8 | 48 |
| DLP | 0 | 5.4 | 59 | 0 | 6.9 | 62 | 0 | 8.3 | 66 |
| DNS | 0 | 2.7 | 51 | 1 | 4.2 | 55 | 2 | 6.3 | 59 |
| JAS | 0 | 3.5 | 56 | 1 | 5.6 | 58 | 1 | 5.4 | 64 |
| JH | 0 | 4.1 | 52 | 1 | 6 | 66 | 4 | 6.7 | 53 |
| MAS | 0 | 1.7 | 51 | 2 | 3 | 47 | 4 | 4.2 | 66 |
| OPL | 0 | 3.1 | 68 | 1 | 4.8 | 66 | 5 | 6.8 | 74 |
| AEO | 0 | 3 | 70 | 2 | 5.6 | 54 | 2 | 7.2 | 58 |
| AKL | 0 | 2.5 | 50 | 0 | 4.2 | 55 | 4 | 5.8 | 66 |
| AKS | 0 | 2.7 | 61 | 4 | 3.7 | 66 | 4 | 4.9 | 68 |
| CAW | 0 | 5 | 59 | 4 | 7.7 | 52 | 2 | 8.1 | 56 |
| CEC | 1 | 4.2 | 42 | 1 | 5.7 | 48 | 4 | 7.9 | 44 |
| FNR | 0 | 3.9 | 51 | 1 | 4.3 | 49 | 3 | 5.7 | 67 |
| IVB | 0 | 4.3 | 58 | 0 | 7.4 | 62 | 0 | 8.2 | 64 |
| KAL | 0 | 4.3 | 53 | 1 | 6.6 | 57 | 1 | 5.3 | 53 |
| MEB | 0 | 3.7 | 52 | 1 | 4.9 | 54 | 4 | 6.6 | 68 |
| MYP | 0 | 2.2 | 50 | 3 | 3.8 | 59 | 5 | 4.1 | 72 |
| CKS | 0 | 1.7 | 59 | 0 | 2.2 | 64 | 1 | 5.7 | 69 |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

Test session – T1 (initial test, 0 weeks), T2 (mid-test, 3 weeks), T3 (final test, 6 weeks)
Visual Analog Scale out of 10 – VAS
Questionnaire score out of 75 – Quest
Sahrmann Level out of 5 – 0-5

## Appendix 9 – Sign-up Sheet

| Name | Initials(F/M/L) | Age (Yrs.) | Sex (M/F) | Group (S/U) |
|---|---|---|---|---|
| | AML | 15 | F | S |
| | AMT | 17 | F | U |
| | CML | 15 | F | S |
| | DLD | 17 | F | U |
| | GFS | 17 | F | S |
| | KDC | 16 | F | U |
| | KML | 18 | F | S |
| | DI | 14 | M | U |
| | DLP | 17 | M | S |
| | DNS | 15 | M | U |
| | JAS | 18 | M | S |
| | JH | 15 | M | U |
| | MAS | 15 | M | S |
| | OPL | 19 | M | U |
| | AEO | 16 | M | S |
| | AKL | 16 | F | U |
| | AKS | 16 | F | S |
| | CAW | 16 | F | U |
| | CEC | 19 | F | S |
| | FNR | 16 | M | U |
| | IVB | 17 | M | S |
| | KAL | 16 | F | U |
| | MEB | 16 | F | S |
| | MYP | 17 | M | U |
| | CKS | 16 | F | S |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

## Appendix 10 – Cadaver Dissection

### Introduction

The abdominal musculature extends between the pelvis and the thorax. On each side of midline there are four principal muscles, three of which are flat muscles and the other being a straplike muscle. The flat muscles are arranged in layers on the lateral part of the abdominal wall and consist of the external oblique being the most superficial layer, the internal oblique being deeper and the transversus abdominus being the deepest layer. The straplike muscle is perhaps the best known of the abdominal muscles and is referred to as the rectus abdominus[1,2]. As each of the flat muscles extend antero-medially the fleshy portion of the muscles blends into an aponeuroses, this connection forms a line known as the linea semilunaris[3]. The linea semilunaris is a curved line or groove that extends from the ninth costal cartilage to the public tubercle. The aponeurosis forms a sheath, known as the rectus sheath, around the rectus abdominus[4]. The midline where the aponeuroses from each side of the body interdigitate it is known as the linea alba, and extends from the xiphoid process to the symphisis pubis[4].

### External Oblique

The external oblique is the largest and most superficial of the three flat abdominal muscles[4]. The muscle fibers of the external obliques slope inferiorly and medially, in a similar direction to your fingers if placed in your jacket pocket[5]. Superiorly the attachment is to the outer surfaces of the lower eight ribs with connections to the serratus anterior on the upper portions and latissimus dorsi on the lower portions[4]. The most posterior and inferior fibers attach to the anterior lip of the iliac crest[4]. As the muscle fibers extend medially they give way to the aponeurosis which extends anterior to the rectus abdominus to connect into the linea alba. The lower portion of the aponeurosis extends from the anterior superior iliac spine to the public tubercle and folds back on itself to form the inguinal ligament, marking the boundary between the abdominal wall and the anterior aspect of the thigh[6,7]. Some fibers of the inguinal ligament cross the linea alba and attach to the opposite pubic tubercle and form the reflex inguinal ligament[7]. Directly above the medial end of the inguinal ligament there is an opening in the aponeurosis known as the superficial inguinal ring, which is the medial opening of the inguinal canal[7]. The external oblique muscle is innervated by the lower six thoracic nerves and the subcostal nerve and acts to compress and support abodminal viscera as well as bilaterally flex and unilaterally rotate the trunk to the contralateral side[8].

Internal Oblique

The internal oblique is the intermediate of the three flat muscles. The fibers, of the internal obliques, run superioanteriorly and at right angles to the external obliques[4]. Inferiorly the internal obliques run from the lateral two-thirds of the inguinal ligament, the anterior part of the iliac crest and the thoracolumbar fascia to superior attachments of the costal margins between the ninth and twelfth ribs[7]. The medial aspect of the muscle gives rise to the aponeurosis at the linea semilunaris and extends to the linea alba[7]. The aponeurosis, of the internal obliques, splits with some fibers running anteriorly to the rectus abdominus, and others running posteriorly to form the rectus sheath[8]. The inferior fibers of the aponeurosis curve medially and downwards posterior to the superficial inguinal ring and connect with aponeurotic fibers of the transversus abdominus to form the conjoint tendon and attach to the pectineal line on the pubic bone[8]. The internal oblique muscle is innervated by the ventral rami of the inferior six thoracic vertebrae and the first lumbar nerves and acts to compress and support abdominal viscera as well as bilaterally flex and unilaterally rotated the trunk to the ipsilateral side[4,9].

Transversus Abdominus

The transversus abdominus is the deepest of the flat abdominal muscles with the majority of its fibers running horizontally with the exception of the most inferior fibers which pass inferiorly and parallel the lower internal oblique fibers. The upper most fibers of this muscle attach to the inner aspect of the lower six costal cartilages and interdigitate with the costal attachments of the diaphragm[7]. The middle fibers fuse with the thoracolumbar fascia and the lower fibers extend from the iliac crest and the lateral half of the inguinal ligament[1]. The horizontally running fibers blend into an aponeurosis at the linea semilunaris where the superior aponeurosis runs posteriorly to the rectus abdominus and the inferior portion runs anteriorly to the rectus abdominus all of which attaches to the linea alba. The lowest fibers of the transversus abdominus run off of the inguinal ligament and arch over the inguinal canal and join with the fibers of the internal oblique to form the conjoint tendon[8]. The transversus abdominus is also innervated by the ventral rami of the inferior six thoracic vertebrae and first lumbar nerves and acts to compress and support the abdominal viscera.

Rectus Abdominus

The rectus abdominus is a long, broad, straplike muscle and is the primary vertical muscle of the anterior abdominal wall. The rectus abdominus runs from the pubis to the front of the chest wall and is separated by the linea alba[4]. It is broad and thin superiorly and narrow and thick inferiorly. The lateral border of the rectus abdominus and its sheath are convex and form the linea semilunaris[7]. The majority of the rectus abdominus is enclosed in the rectus sheath, which is formed by the aponeuroses of the three flat muscles. The anterior aspect of the sheath is firmly attached to the rectus by three or more tendinous intersections, which are commonly located at the levels of the xiphisternum, the umbilicus and midway between the two[7,8]. The rectus abdominus attaches inferiorly to the anterior aspect of the pubic symphisis and to the pubic crest and superiorly to the anterior surfaces of the fifth, sixth and seventh costal cartilages. The rectus abdominus is innervated by the ventral rami of the inferior six thoracic nerves and acts to flex the trunk and compress the abdominal viscera[4].

Rectus Sheath

The rectus sheath is the strong fibrous compartment of the rectus abdominus muscle. It is formed by the fusion and separation of the aponeuroses of the flat abdominal muscles[6,9]. The anterior wall of the sheath covers the entire length of the muscle and is anchored by tendinous intersections. The posterior wall of the sheath hangs freely and does not cover the entire length of the rectus either superiorly or inferiorly. The posterior wall of the sheath terminates superiorly at the costal margin at which point the rectus abdominus is in direct contact with the costal cartilages[7]. Inferiorly the posterior wall of the sheath terminates just below the umbilicus at the arcuate line at which point the rectus abdominus is in direct contact with the transversalis fascia[7]. Above the costal margin the anterior portion of the rectus sheath consists solely of the external oblique aponeurosis however, between the costal margin and the arcuate line the anterior sheath is made up of both the external and internal oblique aponeuroses[8]. Above the level of the costal margin the posterior sheath is absent but below this level the posterior sheath is made up of the internal oblique and transversus abdominus aponeuroses and continues to the arcuate line[4,7,8]. Below the level of the arcuate line all three aponeuroses of the flat muscles pass anteriorly to form the anterior rectus sheath.

Superficial and Deep Fascia

Over the majority of the anterior abdominal wall the superficial fascia consists of one layer that contains a variable amount of fat. The superficial fascia just superior to the inguinal ligament can be divided into two layers: a fatty superficial layer known as Camper's fascia and a membranous deep layer known as Scarpa's fascia with very little fat[1,6,9]. The fatty superficial layer merges with the superficial layer of the thigh and the membranous deep layer is continuous with the deep fascia of the thigh called the fascia lata[1,6,9].

Transversalis Fascia

This very thin layer lines the majority of the abdominal wall. It fuses posteriorly with the thoracolumbar fascia and it covers the deep surface of the transversus abdominus muscles and it fascia and is continuous from side to side deep to the linea alba[3,6]. Each part of the transversalis fascia is named according to the structures it covers for example, the diaphragmatic fascia over the diaphragm or the iliac fascia over the iliacus muscle.

Thracolumbar Fascia

The thoracolumbar fascia is an extensive sheet covering the deep muscles of the back extending between the twelfth rib and the iliac crest[1]. It attaches laterally to the internal oblique and transversus abdominus muscles. The throacolumbar fascia splits into three with quadratus lumborum between the anterior and middle layer and the deep back muscles enclosed between the middle and posterior layers[1]. The thin anterior layer is attached to the anterior surfaces of the lumbar transverse processes, the thick middle layer is attached to the tips of the transverse processes and the dense posterior layer is attached to the spinous processes of the both the lumbar and sacral vertebrae[1].

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