To the Graduate Council:

I am submitting herewith a dissertation written by Laura Horvath Gagnon entitled "Efficacy of Pilates Exercises as Therapeutic Intervention in Treating Patients with Low Back Pain." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Education.

Wendell Liemohn___
Major Professor

We have read this dissertation
and recommend its acceptance:

Songning Zhang_____

Jack Wasserman_____

Schuyler Huck_____

Accepted for the Council:

__Anne Mayhew_____
Vice Chancellor and Dean of
Graduate Studies

(Original signatures are on file with official student records.)

EFFICACY OF PILATES EXERCISES AS THERAPEUTIC INTERVENTION IN TREATING PATIENTS WITH LOW BACK PAIN

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Laura Horvath Gagnon
May 2005

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Dedication

I dedicate this work and the degree associated with it to my Father God and Lord, Jesus, Who provided the opportunity, Who continues to sustain and guide me and Who knows where He plans for this work and me to serve.

> "For I know the plans I have for you," declares the Lord. Jeremiah 29:11
> The Bible, New International Version

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Abstract

The purpose of this research was to investigate the efficacy of Pilates exercises as a therapeutic intervention in treatment of low back pain (LBP). Pilates exercises have been integrated into many rehabilitation programs for those with LBP; however, no clinical research was found that supports its efficacy.

Twelve subjects who presented for physical therapy with LBP, were randomly assigned to either the traditional lumbar stabilization exercise group (A, n=6) or the Pilates exercise group (B, n=6) and completed participation in the study. The mean age for group A was 30.33 (SD 12.40) for group B was 36.00 (SD 11.43) P=0.430, and the percent with LBP over 3 months (chronic) was 83.3% in group A and 66.7% in group B.

Outcome measures used were the Visual Analogue Scale (VAS), the Revised Oswestry Disability Index (ODI), lumbar spine active range of motion (AROM), and measures of core stability on the Stability Platform (LaFayette Instrument Co), taken at pre-treatment, every fourth visit and at discharge from physical therapy.

Repeated measures ANOVAs were performed for measures of VAS, ODI and AROM for (pre, 4^{th} and post treatments) and measures of core stability (pre and post treatments). All subjects progressed significantly in measures of pain (P=0.004), function (P=0.004), and stability measures of center balance time (P=0.013) and deviations to the right (P=0.004). The measures of AROM and left deviations on the Stability Platform did not change significantly over time. There were no significant differences in any of the outcome measures between the groups over time.

Subjects participating in Pilates exercises as provided as part of physical therapy treatment for LBP under the guidance of a physical therapist and Stott™ trained clinicians improved in measures of pain, function, and core stability equal to that of those performing traditional lumbar stabilization exercises as typically provided in rehabilitation for LBP. Given that there have been no clinical studies performed assessing the benefits suggested from performing Pilates exercises, this study provides a legitimate and safe basis for inclusion of Pilates exercises, taught and progressed by appropriately trained clinicians, as therapeutic exercise intervention with patients who have LBP.

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Nomenclature

Abbreviations

AMA	American Medical Association
AROM	Active range of motion
COG	Center of Gravity
E-AROM	Extension active range of motion
EMG	Electromyography
EZ	Elastic Zone
F-AROM	Flexion active range of motion
HEP	Home exercise program
HNP	Herniated nucleus pulposus
HP/ES	Hot pack/electrical stimulation
IAR	Instantaneous axis of rotation
IVFE	Intervertebral flexion-extension
LBP	Low back pain
MT	Manual therapy
NZ	Neutral Zone
ODI	(Revised) Oswestry Disability Index
ORTHO	Orthotics
PT	Physical therapist
RCT	Randomized controlled trials
ROM	Range of motion
STAB C/L/R	Stability Platform center or left or right
STM	Soft tissue mobilization
T12, L1-L5, S1	Thoracic, Lumbar, and Sacral vertebrae
TNSMG	Tennessee Sports Medicine Group
TA	Transversus Abdominis
US	Ultrasound
VAS	Visual Analogue Scale
WHO	World Health Organization

Chapter I

Introduction

Background of the Problem

Low back pain (LBP) is a very common disorder with much documentation on its frequency, recurrence, treatment and costs [1-7]. Kelsey and White [7] and the World Health Organization (WHO) [8, 9] report LBP affects up to 80% of the population at some point in their lives. Andersson [1] reports that 70–85% of all people have back pain at some time in life, that back pain is the most common cause of limitation in activity in those younger than 45 years of age, and that prevalence rates are shown to be from 12% to 35 %. The World Health Organization [8, 9] reports LBP to be the most prevalent of musculoskeletal disorders and that it affects 3-44% of the population at any given time.

The financial impact of LBP is personal and societal. In 1990 there were almost 15 million office visits for 'mechanical' LBP which ranked fifth as a reason for all physician visits [5]. LBP is the third most common cause of surgical procedures [3]. About 2% of the US workforce is compensated for back injuries each year [1]. Data from the 1998 Medical Expenditure Panel Survey showed that total incremental expenditures attributable to back pain were approximately $23.3 billion, and that those with back pain had approximately 60% higher health care expenditures ($3,498 vs. $2,178) than individuals without back pain [4].

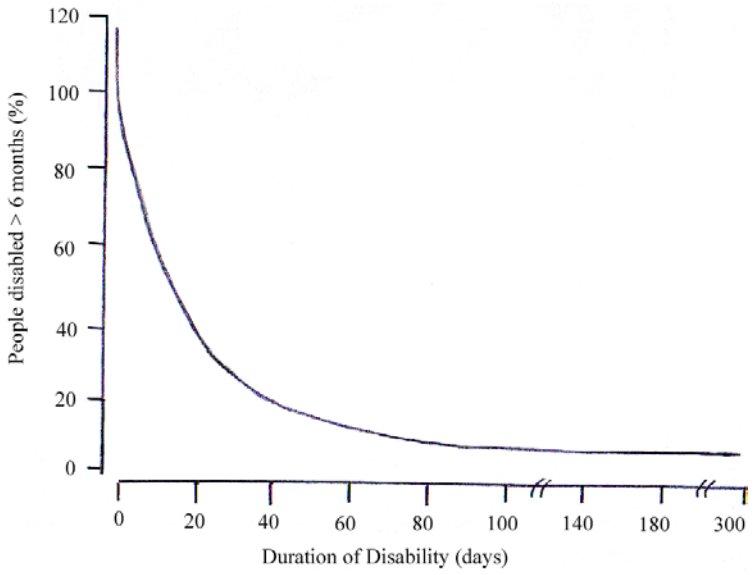


Figure 1 Time course of acute LBP. Adapted from Andersson [1].

Campello et al. [10] reported that 90% of all patients with nonspecific LBP will recover within six weeks regardless of treatment, while Andersson [1] reports roughly the same levels at 90% or more recovering over three months time period (see figure 1). Although these numbers sound good, the recurrence rates are markedly high. The WHO [8, 9] includes in their report a one year recurrence rate of 20-44% with a lifetime recurrence rate of up to 85%. Hides et al. [11] report recurrence rates to be 84% at one year and 75% at 2–3 years in those with LBP treated with medications and advice only.

Treatment options for LBP are wide and varied. A population based study conducted in 1991 revealed that only 39% of those with acute LBP sought medical care. A breakdown of the 39% indicated that 24% sought care from an allopathic physician, 13% from a chiropractor, and 2% from other providers [12]. Treatment

options for LBP typically include one or more of the following interventions: bed rest, medicine, advice, physical therapy modalities, manual therapy, manipulation, supports, antigravity methods, back school, therapeutic exercise, functional restoration, work reconditioning, chronic pain management, spinal injections, and operative treatment [13]. Although there is quite a discrepancy in what is recommended (see table 1), therapeutic exercise is a commonly prescribed treatment for LBP, usually in the course of physical therapy, but also at times provided in handout form or advice from the provider (managing physician, nurse practitioner, or chiropractor).

Although (1) there is a report that routine physical therapy (e.g. mobility and strengthening activities, and joint mobilization) is no more effective than advice in treating chronic LBP [14], and (2) a few studies indicate that there is no evidence that exercise is more effective in treating acute LBP than other conservative measures [15, 16], most studies using exercise as an intervention in treatment of LBP show positive results. Furthermore, the study by Frost et al. [14] has major problems: 79 therapists worked with 200 patients for a median number of 5 treatment sessions after a 1-hour evaluation, each therapist had a different background and training, and each therapist chose their own type of exercise program to include for their patients. This speaks more to this particular clinics' outcomes in treating LBP vs. the outcome of a particular exercise intervention. Van Tulder et al. [15] took a strict look at randomized controlled trials and concluded that based on the two studies that they deemed of 'high quality' concerning acute LBP, no conclusion could be drawn to support exercise as being efficacious. A significant problem in determining the

Table 1 Clinical Guidelines: Recommendations Regarding Treatment of LBP. (Adapted from Kirkaldy-Willis and Bernard [13]).

Country	Education	Medication	Exercises	Manipulation
United States	Reassurance; prognosis is favorable; no serious disease; gradually increase activities	Recommended Paracetamol NSAIDs option: muscle relaxants; opioids	Option: low stress aerobic exercises	Useful within the first month
Netherlands	Prognosis is favorable; no serious disease; stay active; gradually increase activities	Time contingent Paracetamol NSAIDs	Not useful <6 wk; after 6 wk, useful within active approach	Not useful <6 wk; after 6 wk, useful within active approach
New Zealand	Stay active; reassurance	Paracetamol NSAIDs	Specific back exercises not useful	Useful in the first 4-6 wk
Switzerland	Explain favorable prognosis; no serious disease; explain ergonomic principles; stay active.	Analgesic (Paracetamol) NSAIDS Muscle relaxant Local anesthetic	Optional (1st 4 wk) Active therapy, mobilizing, strengthening After 4 wk: training program	Optional (1st 4 wk)

effectiveness of exercise for LBP is the definition of what is the cause of the LBP (discal, stenosis, spondylolisthesis, facet, muscular, sacroiliac, ligamentous, and length of chronicity), bringing Tulder et al. to state a need for an evidence-based classification system for LBP in order to enhance the quality of LBP research [17].

There are many other studies that show therapeutic exercise as a treatment for LBP to have produced positive symptomatic and functional changes in patients ([15, 18-29]. One recent study in particular showed that most cases of chronic LBP can be managed by the less expensive cognitive intervention and exercise equally as well as those managed surgically with lumbar fusion [25]. Cleland et al. [27] performed a systematic review of clinical trials through MEDLINE from 1966-2002 and CINAHL 1982-2002 related to spinal stability and exercises. They conclude that therapeutic exercise can be beneficial in reducing pain and improving function in patients with instability related LBP. However, the variations in methodologies of the studies made it difficult for them to report which specific exercises were the most beneficial. Liddle et al. [28] reported from their survey of randomized controlled trials (RCTs) of exercise and LBP (51 RCTs were scored for methodology) that exercise did have a positive effect in all 16 trials that qualified for inclusion based upon their methodological quality, and chronicity of patient's symptoms. It is important to note, however, that some researchers have found that only those who continued with exercise intervention, or a home exercise program, were significantly better at 12 – 14 months [20, 30]. Therefore, one can draw the conclusion that researchers need to continue to refine the research process in particular in defining LBP and the specific exercise approaches, especially with respect to acute LBP.

Most of the exercises taught to physical therapists in the United States for LBP patients fall into general categories of spine range of motion (ROM) of McKenzie or Williams exercise protocols and strengthening. The strengthening exercises may be described as core stability, dynamic stabilization, co-contraction type mat or ball exercises, progressive resistive exercises with weights or elastic bands, functional activities, aquatic therapy, and/or work hardening [13, 31-38].

One increasingly common exercise regimen suggested for patients with LBP is Pilates. Evidence of this comes not from research studies, but from a variety of sources that include (as of 2/5/2005): MayoClinic.com; Medic8® Family Health Guide @medic8.com; spine-health.com; backcare.org; and the 56 books listed on Amazon.com for Pilates and LBP. These previous sources are available to back pain suffers, as well as the 74,600 hits on a Google internet search for 'physical therapy Pilates clinics' and 121,000 for 'Pilates and LBP'. There has also been a recent growth in continuing education courses available for physical therapists in Pilates exercises for spine rehabilitation. Some physical therapy state boards are now recognizing these courses as meeting their requirements for continued licensing, including Tennessee.

Current published research on the use of Pilates in rehabilitation is mostly descriptive in nature or report it as a treatment provided but not researched; these include Cozen [39] on ankle and foot rehabilitation with Pilates, Anderson and Spector [40] a review, and Kermode [41], a case study. A few studies are quantitative but do not address the use of Pilates mat exercises in the treatment of LBP, Self et al. [42] a reformer analysis of dancers and Hutchinson et al. [43], reformer exercise used

in jumping programs for gymnasts. One study of treatment for scoliosis using Pilates exercises as therapeutic intervention showed promising results, but it is a case study [44]. Anderson [45] addressed the theoretical biomechanical basis as to why Pilates is ideal for rehabilitation of musculoskeletal injures, including LBP, and concludes that the uses of Pilates in the rehabilitation fields merits investigation.

Although Pilates is currently used in treatment of LBP in clinical settings and treatment costs are reimbursed by insurance, research on the efficacy of Pilates as a form of treatment for LBP is scant. In theory the Pilates form of exercise appears appropriate to address goals of strengthening in physical therapy treatment of LBP with core stability and posture being emphasized in the Pilates regimen. However, efficacy of treatments medically prescribed needs to be scientifically demonstrated before prescription and insurance reimbursement.

Statement of the Problem

With data showing LBP is so prevalent, with such a high rate of recurrence without therapeutic exercise and with a significant reduction of those recurrences when proper specific exercise therapy is provided, health care providers prescribing exercises need to have solid objective support for the types of therapeutic intervention that they choose. From the physician, osteopath or chiropractor writing the prescription for physical therapy to the physical therapist determining the specific exercises needed, these providers need objective data to back their specific choices of exercises. Furthermore, with such a high influx of Pilates exercise recommendations available to the general public in the way of reputable internet sites (Mayo, etc.) and

books, the general public deserves some objective data concerning this new trend. There is an obvious need for objective data on the efficacy of treatment of LBP with the Pilates regimen as the basis of the therapeutic exercise program. Do Pilates exercises promote the restoration of function, a decrease in pain and positive objective outcome measures in the treatment of LBP? Do Pilates exercises promote the strengthening and retraining of the deep abdominal and back muscles to improve core stability? Does a Pilates based therapeutic exercise program provide the same or improved outcomes as compared with the traditional lumbar stabilization exercises typically provided to LBP patients? Are the traditional lumbar stabilization exercises commonly prescribed now the most efficient at training the deep trunk musculature or does Pilates more appropriately address this concern? Do the basic Pilates mat exercises meet the goals of retraining the deep trunk muscles and meeting the rehabilitation goals or does one have to perform the exercises on the associated pieces of equipment (reformer, Cadillac, barrels, see appendix A)? Do patients more frequently remain consistent with there home exercises during and after completion of clinical treatment when they are taught Pilates exercises that can be easily continued with videos or gym programs so available today? Are there fewer recurrences of LBP after treatment including Pilates? Are Pilates exercises a good tool in the prevention of low back injuries and pain? Should insurance be reimbursing Pilates treatments for LBP? Not all of these questions can be answered in one study, but they eventually need to be addressed.

Purpose of the Study

The main objective of this research study was to assess the effectiveness of Pilates mat exercises as a therapeutic exercise intervention in the clinical treatment of patients with LBP. This study sought to provide healthcare consumers and professionals, especially physicians and physical therapists, objective data on the outcomes of clinical treatment of LBP with this particular form of therapeutic exercise intervention. The study aims were to directly measure these outcomes in a healthcare practice setting, (i.e., an orthopedic physical therapy clinic), thus providing evidence-based practice information. The specific goals included objectively demonstrating the treatment effects of Pilates mat exercises as compared with traditional therapeutic exercise for LBP in terms of: 1) pain, 2) function in activities of daily living, 3) strength and endurance of back and abdominal musculature, 4) trunk control, 5) lumbar spine range of motion, and 6) the possible associations with noted clinical tests used by physical therapists for evaluation of sacroiliac joint dysfunction. These goals directly relate to providing efficacy of treatment necessary before such treatment is utilized in medical settings, and the costs of such is reimbursed by insurance.

Research Hypotheses

The following are the research theories and assumptions that the hypotheses are based upon:

• Research suggests and current practice includes therapeutic exercise components as an efficacious and medically necessary component of treatment of LBP [26, 35].

• An important component of the therapeutic exercise program is the use of co-contraction of the deep abdominal and back muscles during the exercises [35, 46] to increase spine stability during functional usage of larger muscles of the back, legs and arms as well as decrease recurrences of LBP by restoring the girth to the deep back muscles [11, 47].

• Qualitative biomechanical analysis [40] of Pilates mat exercises reveals a focus on engaging the deep abdominal musculature and maintaining a stabile spine position while using the back, hip and upper extremity musculature. This appears to meet the same criteria as noted just above.

• The objective outcome measurement tools are the Visual Analogue Scale, Revised Oswestry Disability Index, Lumbar spine active range of motion (AROM) measured by double fluid goniometers, and balance performance on the Stability Platform have all been subjected to adequate testing.

The hypotheses:

- Ho: The mean of groups A (traditional lumbar stabilization exercises) will be greater than or equal to the mean of group B (Pilates based mat exercises) over the length of the subjects' treatment time of the outcome measurements (4): Visual Analogue Scale, Revised Oswestry Disability Index, Lumbar

spine active range of motion (AROM), and mean in-balance time on the Stability Platform.

Ho: $\mu A \geq \mu B$

Ha: $\mu A < \mu B$

Ha: The alternative hypotheses present the expectation of the means of group B being greater than those of group A.

Importance of the Study

Pilates has been incorporated into spine rehabilitation programs throughout the world, for example the following is directly off of a Stott Pilates website (www.stottpilates.com) for health professionals (italics added):

> LUMBAR & SHOULDER GIRDLE STABILIZATION ON MAT & REHAB REFORMER [RMR1] introduces the biomechanical principles of STOTT PILATES and their application to modified matwork, small equipment and Rehab Reformer exercises. Emphasis is on pelvic and shoulder girdle stabilization and the role they play in preventing and *rehabilitating lumbar and cervical injuries*
>
> prerequisite: health professional degree or STOTT PILATES IMP and IR or CMR
>
> course duration: 24 hours of instruction and supervised teaching conducted over four days. CEC's:2.4 (continuing education credits).

As noted previously the sources that are suggesting use of Pilates exercises and reporting its use are broad and diverse; they include MayoClinic.com, Medic8® Family Health Guide @medic8.com, spine-health.com, backcare.org, the 56 books listed on Amazon.com for Pilates and LBP, the 74,600 hits on a Google internet search for 'physical therapy Pilates clinics', and 121,000 hits for 'Pilates and LBP' (as of 2/5/05). Positive clinical evidence is needed to support the continued use of this therapeutic tool. Furthermore, many insurance companies reimburse for this treatment as an essential medical component of treatment for LBP, even though the clinical research supporting its use with LBP patients is meager. Current trends in the prescription of exercise protocols for patients with LBP include lumbar stabilization or core strengthening components. If Pilates is used in the rehabilitation of patients with LBP, it is essential to know if the goals that are expected to be met with the lumbar stabilization exercises are being met with the Pilates exercise intervention, or are they only a supplement to the established protocols of lumbar stabilization?

There are currently no objective outcome research studies showing the efficacy of using Pilates as therapeutic intervention for LBP. Efficacy of treatments medically prescribed needs to be scientifically demonstrated before prescription and insurance reimbursement. It is absolutely necessary that some objective assessments of the efficacy of Pilates as therapeutic intervention for treatment of LBP be conducted as soon as possible for this treatment is currently being provided to

patients. Based on clinical experience, the expectations are that this regimen of therapeutic exercise will prove to be very effective. Objective verification of positive results could provide greater usage of this form of treatment in clinical settings, and sound reasoning to include its usage in the basic education of physical therapists. Implications of this study for outcomes in a healthcare delivery setting are: 1) improved outcomes in treatment of LBP; 2) objective data from outcome measures to both foster appropriate use of Pilates in the clinic and as post-clinical treatment in the form of home exercise programs, likely increasing its availability to LBP patients; and 3) implementation of an efficacious therapeutic exercise intervention to facilitate a decrease in recurrences of LBP thereby providing a more cost effective treatment program.

Summary

The incidences of LBP and recurrence rates are high. Treatment methods are varied and outcome reports suggest a need for continued research to reach and report improved treatment options, lower recurrence rates, lower financial burdens, as well as establish preventative tools that are meaningful. Pilates exercises as a help for LBP suffers have permeated our society in the form of books, videos and DVD's, websites, continuing education for health professionals, and actual physical therapy clinical treatments since the release of the trademark in 2000. This study has sought to answer one of the myriad of questions concerning this recent change in

rehabilitation for patient with LBP: Are Pilates mat exercises efficacious in the treatment of patients with LBP?

Chapter II

Literature Review

Introduction

In seeking to answer questions concerning the efficacy of treatment of LBP with either Pilates or traditional back exercises, it is essential to understand as best possible what the exercises are aimed at addressing from a biomechanical perspective. As the lumbar spine (and associated musculature) support and transmit the loads from the upper body, it needs to remain stable against the compressive and shearing forces from everyday life. The lack of control of these forces across the lumbar spine can promote spine dysfunction, injury and pain [48]. What is considered a stable spine, or in other words, what is considered instability of the spine? How do we know that we are promoting spine stability in the exercises we prescribe? Which muscles, planes of movement and directions of movement and types of strengthening do we address in therapeutic exercise to most efficiently obtain spine stability? The areas of anatomy, biomechanics, spine stability, and exercises researched with reference to the above will now be discussed.

Relevant Anatomy and Biomechanics of the Lumbar Spine and Pelvis

To discuss the biomechanics of spine stability and exercise, a brief overview of lumbar spine and pelvic anatomy is desirable. The discussion of anatomy will primarily be limited to the basics with respect to the functional roles of the spine.

Bony components

The lumbar spine is composed of 5 vertebrae composing a lordotic curve that connects the thoracic rib cage region with the pelvis. It functions to transfer the loads of the upper body, to provide the stability needed for the attached large muscles, and to allow its owner to position the body in space in order to carry out desired tasks. Each vertebra is typically divided into three functional components, (figure 2): the vertebral body (1), the pedicles (2), and the posterior elements (3).

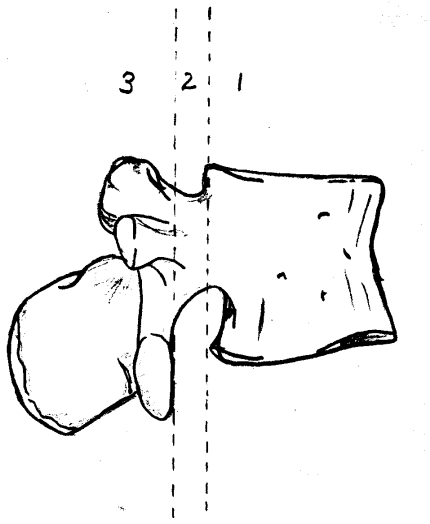


Figure 2 The parts of a typical lumbar vertebrae. The division of a lumbar vertebrae into its three functional components. (Adapted from Bogduk [49].)

The vertebral body is designed for weight bearing, promoting stability in the vertical direction, especially with its larger size in the lumbar spine. It has a shell of cortical bone that surrounds cancellous bone that is composed of vertical and transverse trabeculae. The compressive load is transferred from vertical pressure to transverse tension due to the architecture of the trabecular bone [49]. Because of this structure, the vertebrae are resilient but yet light.

The pedicles connect the body and the posterior elements. The pedicles transmit forces, both tension and bending, through the posterior elements. Tension in the pedicles arises from the locking of a superior vertebral body sliding on an inferior one, with the locking of the inferior articular processes of the superior vertebrae with the superior articular processes of the inferior vertebrae. These articulations are typically called facet joints. Bending forces occur because the pedicles act as levers. Since muscles are attached to the posterior elements of the vertebra, the transfer of the muscular action or pull is through the pedicles to the vertebral bodies.

As previously described, the posterior portion of the vertebrae includes the facet joints. These joints are load bearing, especially in extension, lordotic postures, and with decreased disc height as in degenerative disc disease [50]. The facets also restrict anterior glide of the superior vertebrae on its inferior one and thus resists shearing forces, as well as forces that would create rotatory instability. As intervertebral flexion occurs the inferior articular facet slides upward 5-8 mm along the superior articular facet [49]. The facets vary in angulation throughout the spine and there can be variation between individuals. However, in the lumbar spine they

are oriented closer to 90˚ from the coronal and transverse planes, thus they can limit rotation and promote stability.

The smallest functional unit of the spine is considered to be a motion segment comprised of two vertebrae and their intervening disc (see figure 3). The joints associated with this motion segment are the anterior joint between vertebral bodies at the disc, and the paired posterior facet or zygapophysial joints. In later discussions a term 'neutral zone' will be introduced which describes motion occurring at this level, primarily between the two vertebral bodies, restrained by the facets and associated soft tissue.

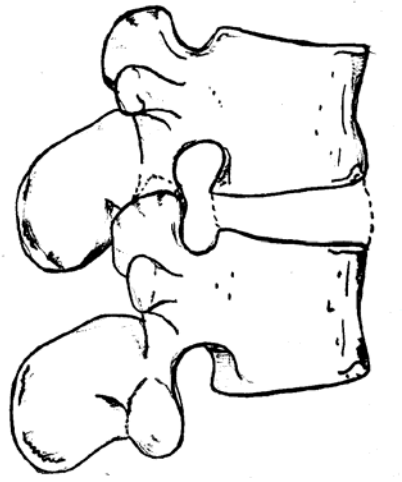


Figure 3 A lumbar spine motion segment.

Soft Tissue Components

The associated soft tissue structures of the vertebral motion segment are the intervertebral disc, joints capsules, ligamentous supports, and the muscular components. The intervertebral disc is composed of a nucleus pulposus and an annulus fibrosus. In a healthy individual the nucleus pulposus is a semi-fluid mass that can be deformed under pressure but not compressed, therefore transmitting any applied pressure in all directions. The annulus fibrosus is composed of highly ordered collagen fibers in concentrically arranged lamella, each layer with its fibers the same 65˚ from the vertical, but alternating directions from one lamella to the next. Under loads the radial expansion of the disc exerts a pressure on the annulus. In a healthy disc the tensile properties of the collagen lamellae are such that with a 40kg load to an intervertebral disc there is only one mm of vertical compression and 0.5 mm of radial expansion in the annulus [49]. The facet joints have a double layer capsule that is composed of collagen fibers and houses an adipose tissue pad and a meniscoid. These meniscoids have similar functions as the meniscus of the knee (protective, increase the contact surface area, and fill space), yet they range in structure from a small connective tissue rim to an adipose tissue pad to a larger fibro-adipose projection, all a thickening of the joint capsule [49]. The facets and capsule help restrain and control motion.

The spine has six primary ligaments: anterior longitudinal ligament, posterior longitudinal ligament, ligamentum flavum, interspinous ligament, supraspinous ligament, and iliolumbar ligament. Both the anterior and posterior longitudinal ligaments run the length of the lumbar spine and resist separation of the vertebral

bodies, especially the anterior longitudinal ligament. The ligamentum flavum is composed of a high amount of elastin and runs between lamellae of consecutive vertebrae. This ligament differs from all others in the lumbar spine in its fiberous makeup of 80% elastin and 20% collagen [49]. Due to its high elastin content, it does not buckle and create nerve root impingement in neutral or extension, but can stretch with flexion. The interspinous and supraspinous ligaments (named for their positions) oppose separation of the spinous processes and restrain flexion along with the facet joint capsules. The iliolumbar ligament connects the transverse process of the fifth lumbar vertebra with the ilium bilaterally. It restrains motion of L5 on the sacrum in twisting, bending, and in particular with anterior movement or shear of L5 on the sacrum.

The sacroiliac joint is at the base of the spine where the loads through the lumbar spine are subsequently transferred to the iliae. The sacroiliac joint is an irregular joint between the sacrum and the ilium, it is a load bearing joint but it also permits slight movement in gliding and rotation. The irregular surfaces which interlock, the wedge-like shape to the sacrum, and the network of ligaments anterior and posterior to the joint, all work together to keep the iliae locked against the sacrum and ensure stability. Mobility dysfunction at the sacroiliac joint affects the lumbar spine; similarly, mobility dysfunction at the lumbar spine affects the sacroiliac joint.

Spinal motion

The physiologic movements occurring in the lumbar spine are described in the three planes of flexion/extension, rotation, and lateral bending. This motion is described as range of motion (ROM) and is typically in degrees. Wong et al. [51] showed that the average terminal flexion was 53.0° ± 10.2° and that the average terminal extension was 23.4° ± 8.3° with a linear like pattern of the IVFE (intervertebral flexion-extension) curve, at all levels, with no significant differences between genders. This means that the motion recruited was more from L1/2 and decreased sequentially to L5/S1 (figure 4).

This seems to show a nice smooth recruitment of motion with the most at L1/L2 decreasing to the least at L5/S1 during flexion. However, in extension, the slope of the IVFE curves in different vertebral levels was found to be about the same. Thus, all levels seem to be contributing to the extension curve similarly.

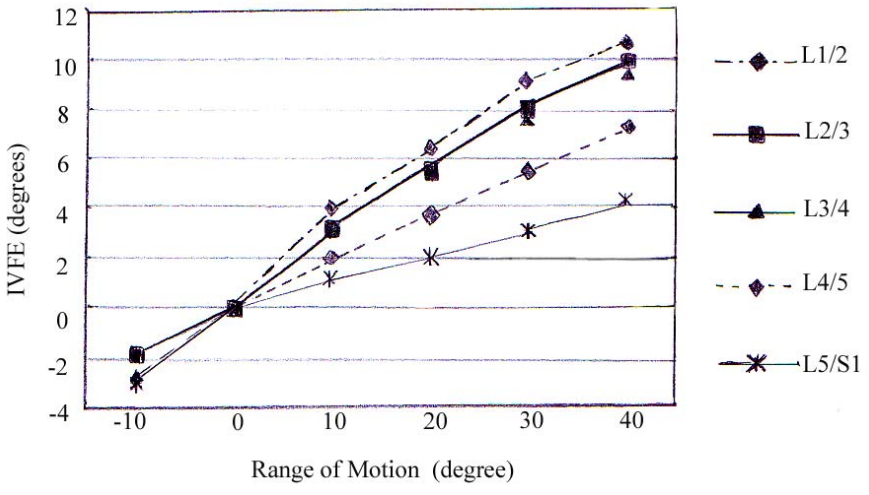


Figure 4 IVFE degrees per lumbar segment in 10˚ increments of ROM, for 100 healthy volunteers. (Adapted from Wong et al. [51])

At each vertebral motion segment (two vertebrae with the intervening disc) the sagittal plane motion can be described as the superior vertebrae on the inferior one in terms of rotation and translation with an instantaneous axis of rotation (IAR) around which motion occurs. This center of motion lies below the moving vertebrae, near the superior endplate of the inferior vertebrae, with the series of IARs at each 10 degrees of flexion normally falling in tightly clustered zones. Motion does not just occur in the sagittal plane in physiologic flexion and extension, as axial rotation and lateral flexion of about 1˚ accompany these motions [49]. Note in figure 5 the normal and abnormal IARs from cadaveric spines. The abnormal specimens were from spines exhibiting degenerative changes. This very displaced and erratic IAR demonstrates the increase in the amount of sagittal rotation and translation occurring during spinal flexion and extension. If this is the state of one's spine, how do you restore, if possible, control of this erratic and increased intervertebral motion?

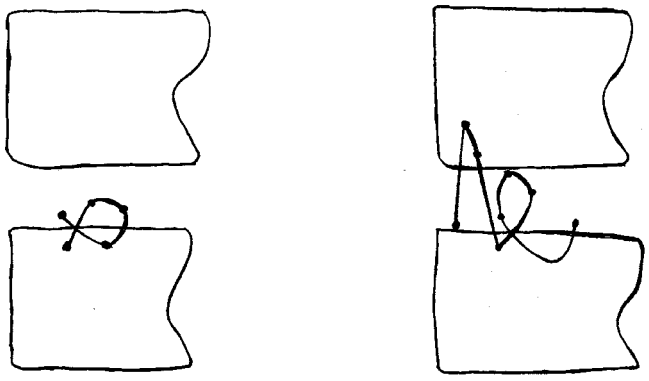


Figure 5 A. The IAR or centrodes of normal cadaveric intervertebral joints are short and tightly clustered. B. Degenerative specimens exhibit linger, displaced and seemingly erratic centrodes (adapted from Bogduk [49]).

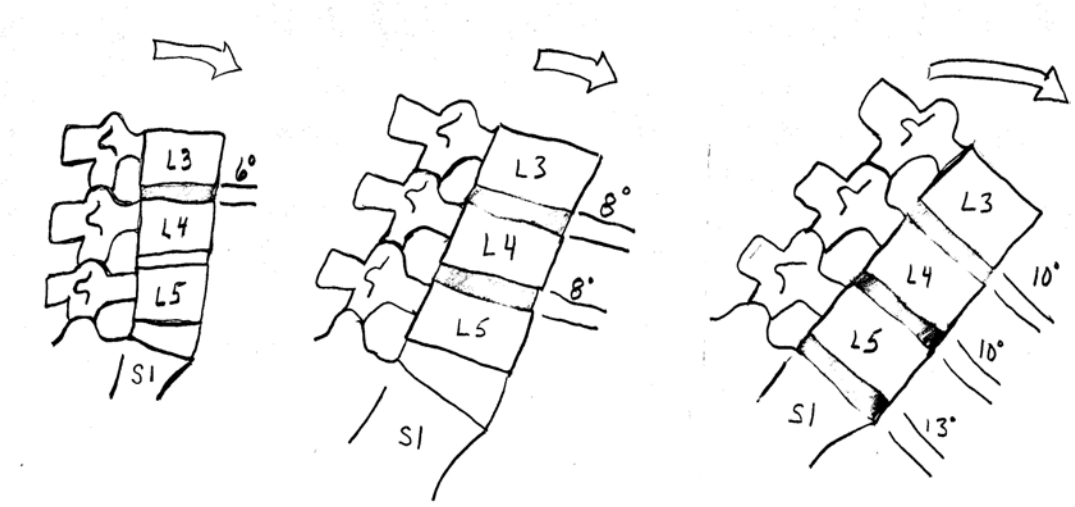


Figure 6 Lumbar intersegmental motion. (Adapted from Kanayama et al. [52])

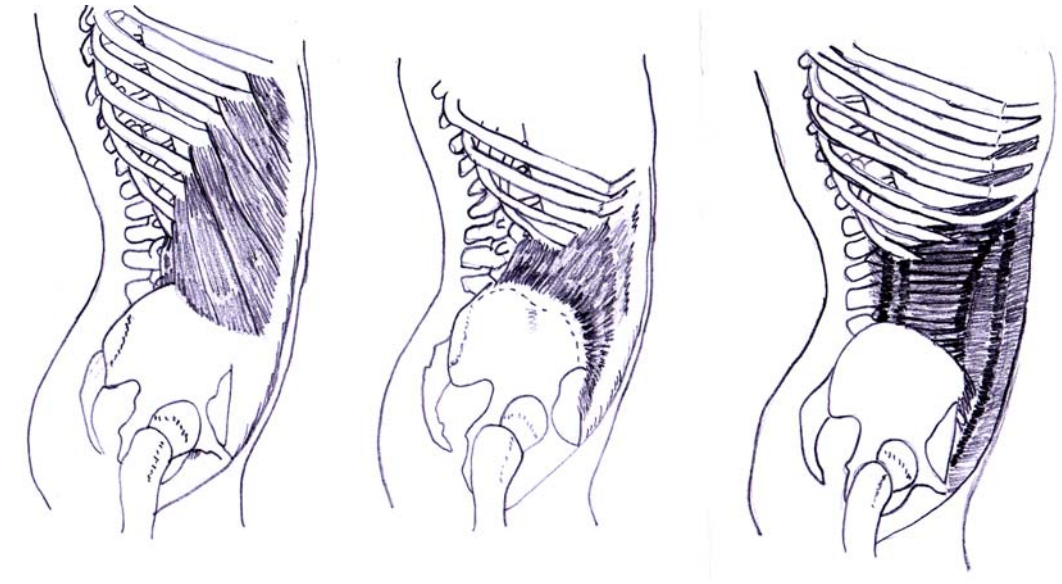
Kanayama et al. [52] investigated intervertebral segmental mobility of eight healthy male subjects in the segments L3-S1 using cineradiography during flexion and extension. Each trunk motion was carried out from the neutral position to the maximum position. Segmental rotation and translation were measured sequentially at the L3-L4, L4-L5, and L5-S1 motion segments. It was discovered that the motion (in flexion) occurred sequentially, in a stepwise fashion beginning at L3 and after an average of 6º of motion at L3/L4, L4/L5 motion began. After an average of 8º of motion at L4/L5, motion at L5/S1 began (figure 6).

Muscular Components

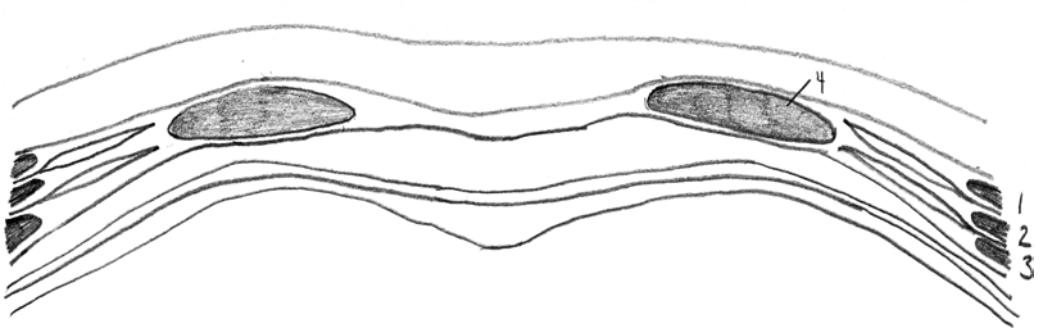
The muscular components of the spine can be described by location or by function, as the global and local stabilizing systems. The later description of function will be covered in the following sections, and below in terms of location.

The abdominal muscles include the rectus abdominis, the most superficial and primarily a trunk flexor in the sagittal plane, which is wrapped in the aponeurosis from the other three abdominal muscles (see figure 7). The internal and external obliques contribute to flexion but also act to provide a large turning moment. The obliques are positioned at 90˚ to each other on the ipsilateral side and work in tandem with their contralateral opposite (for example: left internal with right external) to produce a rotatory motion of the spine. The transversus abdominis is the deepest layer running across from the aponeurosis that covers the rectus to the thoracolumbar fascia posteriorly. It arises from the iliac crest and lower six ribs, and inserts into the thoracolumbar fascia and linea alba. Its function has been the subject of much recent inquiry into lumbar and sacroiliac joint stability [53-55] and will be discussed at length in subsequent sections.

The posterior trunk musculature includes the multifidus, longissimus, iliocostalis, quadratus lumborum, and psoas major; each has an attachment on the thoracolumbar fascia (see figure 8). The psoas major attaches to the anterior surface of T12 through L5 transverse processes, the discs and vertebral bodies. Bogduk [49] reports that its action of tending to extend upper lumbar segments and flex lower ones is weak due to a small moment arm. The psoas rather uses the lumbar spine as a base



A B C



D

Figure 7 The (A) external obliques, (B) internal obliques, (C) transversus abdominis (with rectus abdominis sheath), and (D) a cross section of the abdominal wall with the external obliques (1), internal obliques (2), transverses abdominis (3), and rectus abdominis (4) (adapted from Liemohn and Porterfield and DeRosa [56, 57]).

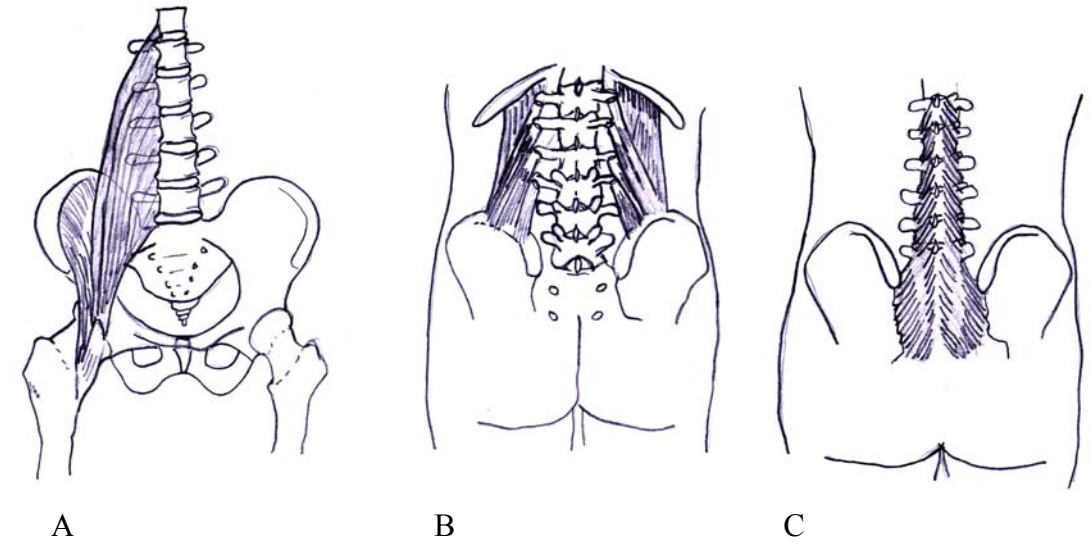


Figure 8 (A) Multifidus, (B) Quadratus Lumborum, (C) Psoas Major (adapted from Porterfield and DeRosa [57]).

from which to create motion at the hip joint. It therefore can add a compressive load to the lumbar discs. It is reported that upon bilateral maximum contraction as in sit-ups, the psoas can be expected to exert on the L5-S1 disc a compressive load equal to 100kg of weight [49]. It is interesting to note however, that Barker et al. [58] found evidence of coexisting atrophy of psoas and multifidus on the symptomatic side in LBP patients, suggesting a role yet not understood of the psoas.

The quadratus lumborum is a rectangular muscle that extends laterally a few centimeters from the tips of the lumbar vertebral transverse processes [49]. It also attaches to the 12th rib, the iliolumbar ligament and the iliac crest. The fibers of this muscle are oriented in three directions [57], and work in helping to maintain stability of the lumbar spine in the frontal plane.

The multifidus is the largest, most medial posterior lumbar muscle and has been recently recognized as a predominant spine stabilizer [47]. It fills the area between the spinous and transverse processes in the lumbopelvic region. This muscle consists of repeating bundles of fibers that stem from the lamina and spinous process of one vertebra and inserts caudally typically two to three levels down. Some of the fibers attach to the facet capsules thus protecting its impingement during motion.

The multifidus appears to be designed to act on a single spinous process. It is very interesting to note that all the fibers arising from a particular vertebrae are innervated by the medial branch of the dorsal ramus that arises from below that same vertebrae [49]. The muscle's line of action is two-fold, with a horizontal and vertical vector. Bogduk [49] reports that even though this horizontal vector suggests a primary role in rotation, electromyographic studies have shown the multifidus to be active in both ipsilateral and contralateral rotation, thus acting as a stabilizer in rotation instead of the primary mover for one direction.

The longissimus and iliocostalis are part of the lumbar erector spinae and lie laterally to the multifidus. These muscles form the bulk of the mass seen in the low back region, although each has both a thoracic and lumbar component (pars thoracis and pars lumborum). These muscles have an excellent lever arm with respect to the lumbar spine and primarily work eccentrically to control forward flexion of the spine (at full flexion, they are electrically quiet); they contract concentrically to extend the spine and isometrically to stabilize the thorax on the pelvis [57]. These muscles differ, however, if contracting unilaterally, by producing lateral flexion. Bogduk [49] reports that the lower fibers of the iliocostalis lumborum, due to their rotatory

moment arm when contracting unilaterally, appears well suited to cooperate with the multifidus to oppose the flexion effect of the abdominal muscles when they rotate the trunk.

Stability of the Lumbosacral Spine: Biomechanics

The Neutral Zone

Before investigating what promotes stability of the spine, the definition of what constitutes a stable or unstable spine must be clear. The human spine stripped of its musculature is incapable of carrying loads. The osseous structure with its ligamentous and discal components provide some restraint of motion, but not near enough to account for mitigating loads of daily life. Spinal loads associated with occupational and recreational activities have been described as ranging from 6000 to 18,000 N [48]. Panjabi et al. [59] report that an isolated fresh spine from below T1 with the sacrum fixed can only carry a load of 20N (4.4 pounds) before it buckles. These researchers investigated simulated intersegmental muscular forces on sequentially damaged cadaveric spines to observe the resultant intervertebral range of motion (ROM) and the neutral zone (NZ). Two important findings were that they felt the neutral zone was a better indicator of spinal instability than range of motion, and that the neutral zone decreased with increasing muscle forces for moments (e.g., damage) they induced on the spines. The application of 60 N of muscle force restored the neutral zone to the spines (most severe injury induced) from a 50% (of neutral zone) increase from normal. They concluded that the intersegmental muscles

act to maintain or decrease intervertebral motion after injury, and due to their locations close to the rotation centers of the vertebrae, are better suited as spine stabilizers. Thus Panjabi defines the neutral zone as a region of intervertebral motion around a neutral position where there is little resistance provided by the passive system [59, 60]. This neutral zone can be measured in the three planes: flexion/extension, lateral bending and axial rotation. Panjabi [60] also defined another parameter of intersegmental motion, the elastic zone, where stiffness to motion begins to increase (see figure 9).

Panjabi [60, 61] found, however, that injuries induced (in vitro) caused the greatest increase in the neutral zone as compared with the elastic zone, and thus concluded that the neutral zone was the most sensitive motion parameter in defining the onset and progression of spinal injury (versus range of motion from radiographs). With the injury threshold reached, the neutral zone showed an overall increase by 566% while the increase in range of motion was only 94% [61]. This increase in neutral zone was also found to occur in patients with disc degeneration [62].

Kirkaldy-Willis [64] suggested that there is an increase in intersegmental motion in the second or intermediate stage of the degenerative process. Tears in the disc annulus reduce torsional stiffness, degeneration of the cartilage of the facet joints leads to changes in the tensile forces on the facet capsule facilitating joint disruption and laxity, often resulting in instability at a segmental level [65]. It is thought that the neutral zone may also increase with muscle weakness as well, which may result in instability or LBP [60, 66], and it decreases with ostephyte formation, fusion, or muscular stabilization [60].

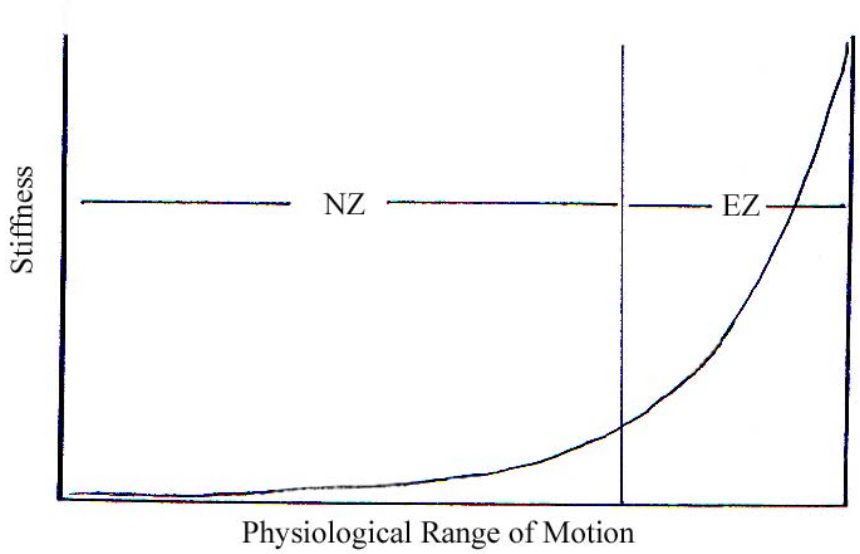


Figure 9 Plot of segmental ROM and stiffness (resistance to motion) for a typical lumbar motion segment demonstrating the bi-phasic nature of segmental motion. The segment experiences little resistance to motion early in range and sharply increased resistance later in range. These phases or partitions of the overall ROM are known as the neutral zone (NZ) and elastic zone (EZ). (Adapted from Jemmett et al. [63]).

The Passive Subsystem

Panjabi [59, 67] divides spinal stability into the passive, active and neural subsystems. The passive or osseo-ligamentous system is primarily comprised of bones, ligaments, joint capsules and intervertebral discs. The non-contractile structures resist motion only when the limit of their flexibility or stiffness is reached. Thus, they do not provide substantial support in neutral joint positions. These structures adapt to stresses placed on them and behave along a stress/strain curve. When the end of the elastic range is reached and the plastic phase is reached by microtrauma or injury, deformation of the structure may occur and with it a subsequent increase in the neutral zone associated with that level. This may lead to a

reduction in the passive structure's ability to limit the motion necessary to keep the integrity of the spinal segment. Translation (forward/backward) and rotation at the lumbar vertebrae occurs with flexion and extension as well as with lateral flexion and axial rotation in coupled motions. The facet joints limit translation [68], anterior sagittal rotation is limited by tension in the facet capsules, shear created by translation is resisted by the discs, and axial rotation is restrained by the facet joints and the disc annulus [49]. The health of the passive structures is integral to a functionally stable spinal unit.

The Active Subsystem: Global and Local divisions

The second of the subsystems theorized by Panjabi [59, 67] is the active or muscular portion. The muscular component of spinal stability may be the weak link or conversely compensate for another components' dysfunction. The muscular system is the force generating system which provides the active mechanical stability to the spinal segment, particularly in neutral. The muscular system has the potential to increase the stiffness of the lumbar spine and decrease the size of the neutral zone, thus improving overall spinal stability [48, 67, 69]. Therefore, if the neutral zone in 'spinal instability' can be reduced or moderated by the dynamic contribution of muscular forces, knowledge of what muscles contribute to spinal stability is essential in designing training regimens most appropriate for those with LBP and/or instability.

Bergmark [70] classifies the trunk musculature into a global and local system based on anatomy and function (see table 2). The local system consists of muscles having origins and/or insertions on the lumbar vertebrae. The local system's role in stabilizing the trunk is to be supportive of the trunk segmentally and control motion in

Table 2 Categorization of muscles used in trunk stabilization into global and local systems. (Adapted from Bergmark [70].

Local Stabilizing System	Global Stabilizing System
• Intertransversarii (intersegmental)	• Longissimus thoracis (pars thoracis)
• Interspinales (intersegmental)	• Iliocostalis lumborum (pars thoracis)
• Multifidus	• Quadratus lumborum (lateral fibers)
• Longissimus thoracis (pars lumborum)	• Rectus abdominis
• Iliocostalis lumborum (pars lumborum)	• External oblique
• Quadratus lumborum (medial fibers)	• Internal oblique
• Transversus abdominis	
• Internal oblique (fiber insertion into lateral raphe of thoracolumbar fascia	

the neutral zone. These muscles have shorter lengths, are closer to the center of rotation of the spinal segment and are therefore ideal in controlling motion at the segmental level [59]. They are typically small and balance the load at the segmental local level but are also responsible for proprioception. Specifically, the small intersegmental muscles, including the intertransversarii and the interspinales (both have a high density of muscle spindles) [49, 71, 72] and the multifidus have an important role in proprioception [73].

The global stabilizing system includes the larger more superficial muscles of the lumbopelvic region; they have the ability to produce larger torques and to control motions of the trunk and balance external loads in a way to minimize the resultant forces on the spine. Strength and endurance training of the global muscles can ensure that less force is transferred to the spine itself, where the control of forces is handled by the smaller local muscles [74].

Core-stability therapeutic exercise intervention primarily addresses the active and neural subsystems. The local active (and neural) system includes the transversus abdominis, intertransversari, interspinales, medial fibers of the quadratus lumborum, part of the internal obliques, and the multifidus. Panjabi [59, 60, 67] states these deep local muscles, including the multifidus and transversus abdominis, mainly contribute to spinal stability. Panjabi's research aligns well with noted studies in terms of demonstrating the trunk musculature most important in spine stability, specifically the transverses abdominis, internal obliques and multifidus [55, 75, 76]. Therefore, when designing a therapeutic exercise treatment approach for patients with LBP and/or instability, one might seek to include exercises which effectively train both the active local spinal musculature and the neural subsystem initially, then progress to the global musculature to bear external loads.

The Neural Subsystem

The third subsystem of the stabilizing system theorized by Panjabi [67] is the neural component. The central nervous system, peripheral nerves and the mechanoreceptors located in the ligaments, muscles and joint capsules comprise this portion that monitors and directs input into the active muscular system. This subsystem is huge in its influence for many factors play a role in its ability to function most efficiently. Pain can disturb the body's ability to correctly assess and adapt to spinal stability. An increase in afferent input increases muscle tone (spasm) leading to a change in the physiological properties in the tissue, thus increasing pain or at least continuing the cycle. The change in muscle tone affects the ability of the muscular system to stabilize the vertebral segments adequately without overload or

fatigue. Mechanical injury or impingement to neural structures as well as pain may cause adaptive neural patterning that promotes poor stability in the lumbar spine. Hodges and Richardson's, Hungerford et al., O'Sullivan et al., and Ferreria et al. research [75-78, 85] shows inappropriate motor patterns, including a delayed onset of contraction of the transverse abdominis, internal obliques, and multifidus in patients with LBP/sacroiliac pain. This indicates a deficiency in motor control and they hypothesized this resulted in inefficient muscular stability of the spine. Hodges et al. [79] experimentally induced LBP to healthy subjects and monitored the onset and amplitude of the transversus abdominis with upper extremity elevation. The induced pain produced changes in the motor control of the trunk muscles and consistent impairment of transversus abdominis activity. O'Sullivan et al. [80] found those with instability related LBP had an inability to reposition the lumbar spine accurately into a neutral spine position while seated. This points to a possible deficit in the neural subsystem, or proprioceptive awareness in this population.

Panjabi [67] states that a dysfunction in any of the three subsystems may lead to one or all of the following: 1) an initial compensation in one of the other systems, 2) a long-term adaptation in that other system, and 3) an injury to a component of any of the systems. For example, suppose a person is involved in a motor vehicle accident and had a significant shear force to the lumbar region straining some of the ligamentous supports (passive system). The neural system must recognize this subsequent increase in motion (neutral zone) while functioning in a likely swollen and muscularly guarded condition due to the injury and pain, and then add increased active subsystem or muscular control to the area that may be already in spasm. The

adaptation may persist even when the injured tissue has healed, leaving the person with a less than ideal adaptive pattern resulting in fatigue, spasm or poor recruitment of the active component.

A patient needs to re-educate their neural sub-system and override the adaptive patterns in order to regain optimal spinal stabilization. This component may be easily overlooked, and needs particular attention in teaching the spinal stabilization exercises. An aside is that although this is not a typically addressed issue in spine stability, one may question the impact of emotional and psychological states affecting the function of the spine, because the central nervous system is a component of the neural system.

Dynamic Stability of the Lumbosacral Spine: Clinical Research

Specific exercises and spine stability

Kavcic et al. [81] used data from eight different stabilization exercises typically prescribed. EMG, kinematic and external force measures were input into a biomechanical model to quantify lumbar spine stability and L4-5 compression. They reported that it was evident that abdominal bracing leads to an increase in lumbar spine stability but that it also increases compression at L4-5 as well. They provide a figure (see figures 10 and 11) that represents the trade of in each exercise of increase stability with increase of compression.

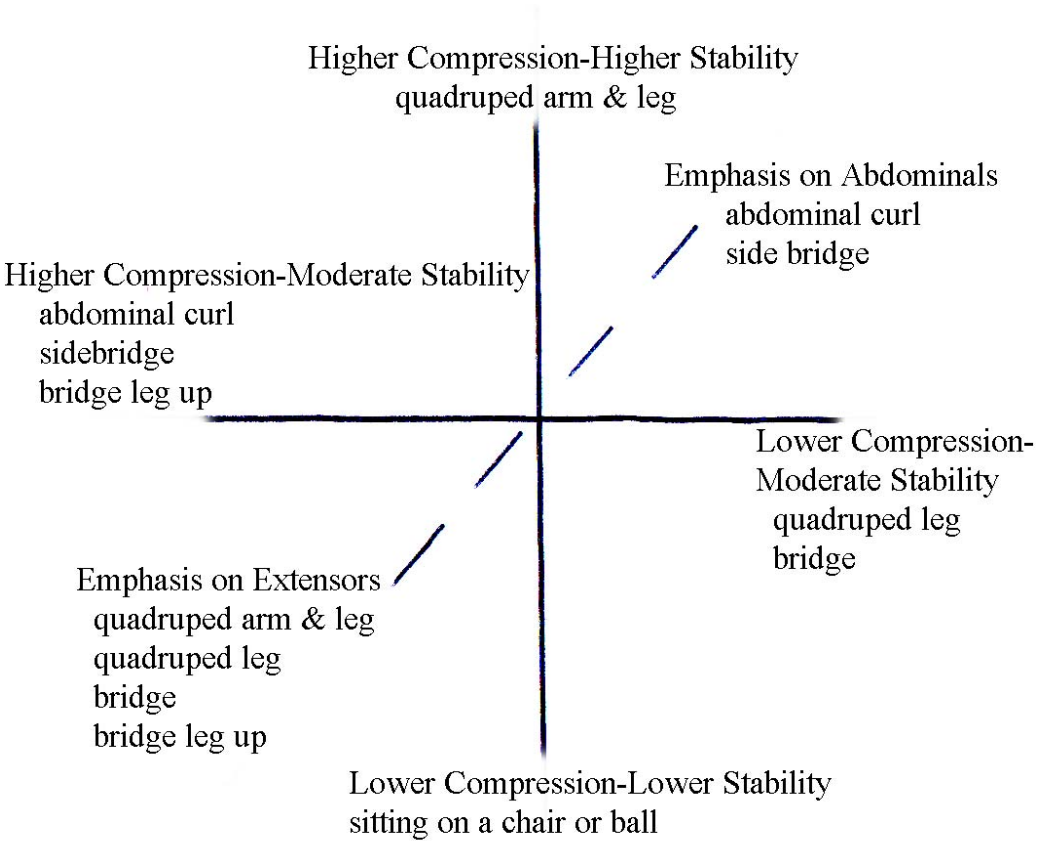


Figure 10 Exercise recommendations for specific goals (Adapted from Kavcic et al. [81]).

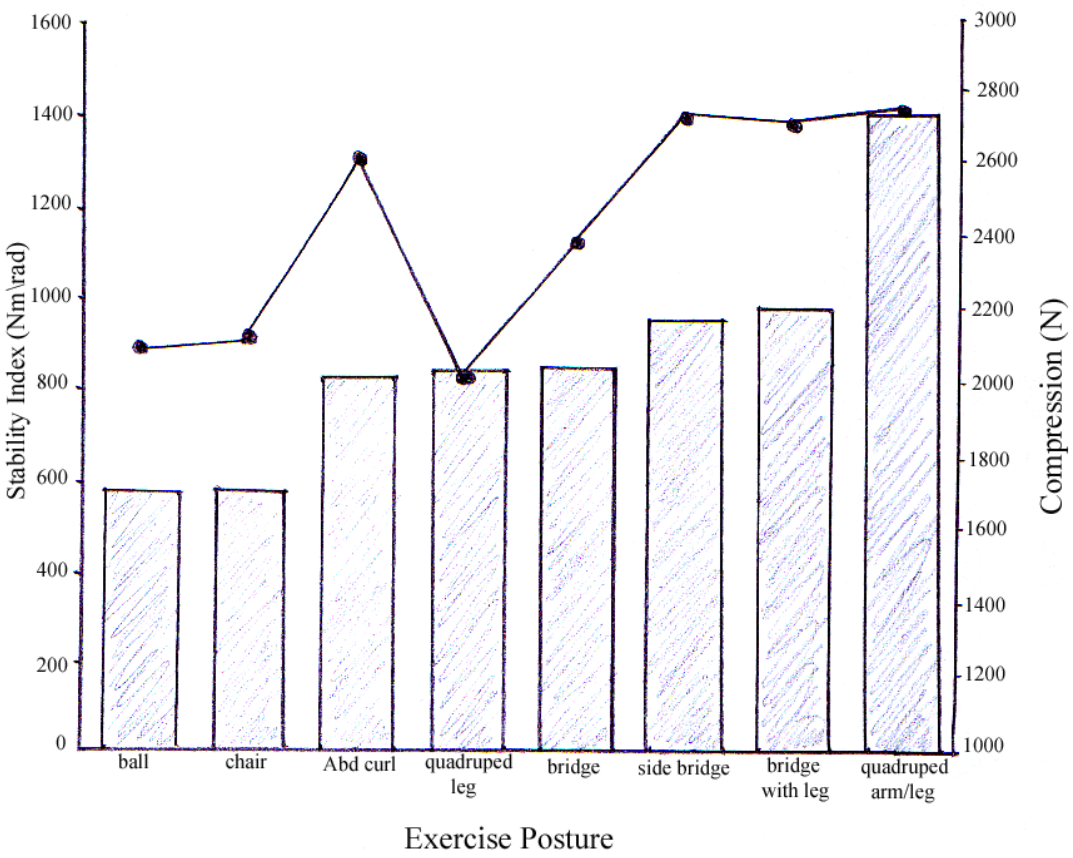


Figure 11 Stability index versus L4-L5 compression for each exercise posture. The exercises are ordered in terms of increasing spine stability. (Adapted from Kavcic et al. [87]).

Specific Muscular Contributions

Recently specific exercise therapy addressing deep abdominal musculature has been shown to be very effective in reducing recurrences of LBP in patients to 30% after one year and 35% at 2-3 years [11]. Much research addresses the question of which musculature should be specifically addressed in therapeutic exercise in rehabilitation for LBP [47, 53-55, 58, 69, 73, 75-77, 82-87]. Kavcic et al.[87] used data from normal subjects performing lumbar stabilization exercises to determine muscular roles in stabilizing the spine. They concluded that no single muscle dominated and that their individual roles were continuously changing across tasks. Although Cholewicki and VanVliet [83] compared the relative contribution of 12 major trunk muscles to overall spine stability and concluded that no single muscle could be identified as the most important for spine stability, a few specific muscles have the been the focus of recent research.

An in vivo porcine study [55] indicated that elevated intraabdominal pressure, and contraction of the diaphragm and transversus abdominis increased control of spinal intervertebral stiffness. Numerous studies now show a change in the recruitment timing and intensity of the transversus abdominis in those with LBP [54, 75-78, 85, 88]. Hodges and Richardson [77, 78] have shown that patients with LBP have impaired motor control of the transversus abdominis and multifidus. The transversus abdominis and internal obliques have been found to have a delayed onset of contraction in patients with LBP in some upper extremity movements (Hodges and Richardson [78]). Ferreira et al. [85] used ultrasound and EMG to assess muscle activity in subjects with LBP as compared with normals. They assessed the thickness

of the transversus abdominis during contraction with ultrasound and used EMG to show activity levels. They reported that subjects with LBP had less transversus EMG activity with leg tasks than normals, but that there was no difference between groups for EMG activity for the obliques. Hungerford et al. [76] found that in males with sacroiliac pain the internal oblique and multifidus were delayed in contraction, as compared with normal subjects, on the supporting leg during hip flexion in standing on both the symptomatic and nonsymptomatic sides. The onset of contraction of the internal obliques and multifidus was first of all the seven muscles tested in normal subjects and preceded initiation of the task of hip flexion. In the symptomatic individuals the onsets occurred more than 20ms after initiation of the task. This initiation of contraction before the task is termed feed-forward and appears to be a component of the Panjabi's neural subsystem [67]. Cowan et al. [84] found a delayed contraction of the transversus abdominis in those subjects with groin pain, as compared with normal subjects, during an active straight leg raise. Since LBP can coincide with sacroiliac joint dysfunction, it is interesting to note that contraction of the transversus abdominis has been shown to significantly reduce the laxity (thus increase stiffness) of the sacroiliac joint [53]. The transversus abdominis was more effective at decreasing laxity at the sacroiliac joint than the other lateral abdominal muscles or the rectus abdominis muscle. O'Sullivan et al. [89] found that the abdominal recruitment pattern for healthy individuals was different that that of individuals with LBP during the 'drawing in' exercise (some refer to this as 'hollowing'), which activates the transversus abdominis. Drysdale et al. [90] found that abdominal-hollowing exercises in healthy subjects can be performed with

minimal activation of the larger global muscles such as the rectus abdominis and the external obliques. An inability for individuals to activate the most effective abdominal musculature may play a role in LBP. O'Sullivan et al. [88] reported however, that those with LBP could have the automatic patterns of abdominal recruitment changed with specific exercise intervention.

In a review by a leading researcher on spinal stability, Hodges [54] concludes that several points need to be considered with respect to training the transversus abdominis (TA) in management of LBP:

> 1) The TA is controlled independently of the other trunk muscles and should be trained separately from the other trunk muscles.
> 2) The TA is the principle abdominal muscle affected in LBP…should be trained separately from the other trunk muscles.
> 3) The TA should be trained to contract tonically, but not at a constant level.
> 4) The TA loses its tonic ability in LBP and needs to be retrained to regain this function.
> 5) The interaction between TA, diaphragm and pelvic floor muscles should be considered.

Fryer et al. [91] performed a MEDLINE and CINAHL search on the latest literature relating to the change in musculature in those with LBP. They concluded that there is evidence of changes in muscle fiber composition and localized selective multifidus atrophy. In the Hides et al. study [47], the multifidus did not show spontaneous recovery concurrent with the remission of LBP without specific exercise intervention. However, subjects who received exercise including isometric multifidus contraction and co-contraction with the deep abdominal muscles, had restoration of

cross sectional area reaching symmetry. The researchers suggest this lack of spontaneous recovery of multifidus without specific exercise intervention leads to the high recurrence rate of LBP and that the inhibition of multifidus firing can be reversed. Barker et al. [58] also noted that there was an association between decreased cross sectional area of the multifidus (and psoas) on the side of pain in subjects with LBP. Arokoski et al. [92] showed that some traditional lumbar stabilization exercises in quadruped, prone and standing are effective in activating the lumbar paraspinal muscles, specifically the multifidus; however, in a subsequent study with the same exercises they reported that the LBP subjects had difficulty in contracting the multifidus independently of the external obliques [93]. This suggests that the typical lumbar stabilization exercises as used by Arokoski et al. [92] do not ideally train the local muscular system (multifidus) without activating the global system (e.g., external obliques).

Cholewicki et al. [82] demonstrated that antagonistic trunk muscle co-activation (trunk extensors and flexors) is present in healthy individuals in a neutral spine position. Granata et al. [94] designed a biomechanical model to assess antagonistic co-contraction of spinal musculature. Co-contraction was associated with a 12% to 18% increase in spinal compression and a 34% to 64% increase in stability. These previously noted studies are among many that suggest that therapeutic exercise intervention for effective short and long-term treatment of LBP include training of the transversus abdominis and multifidus. Together these studies point to the transversus abdominis, the multifidus and the internal obliques as the primary dynamic stabilizers of the lumbar spine, particularly in the role of co-

contractors or co-stabilizers. O'Sullivan [95], Lee [34], and Richardson, Hodges and Hides [35] cover specifically some techniques to avoid recruiting the global muscles and to appropriately train the local deep ones, such as the transversus abdominis, the multifidus and the internal obliques. The aim is co-contraction of the deep local muscles and then re-coordination with the global system.

Traditional Dynamic Lumbar Stabilization Exercises

The San Francisco Spine Institute seems to be one of the first to term and promote dynamic lumbar stabilization exercises as a component of rehabilitation for those with LBP (San Francisco Spine Institute [96]). These exercises typically have as a basis 'abdominal bracing' or co-contraction of trunk flexors and extensors. Saal and Saal [18] used exercises protocols with a stabilization component and had a high rate (85%) of success for return to work in those with herniated discs. O'Sullivan et al. [19] used a bracing-like exercise as the base of their exercise protocol. They trained the patients to perform an isometric co-contraction, at low levels of maximum contraction, of the deep abdominal muscles and lumbar multifidus with minimal use of global system muscles by using the abdominal drawing in maneuver as described by Richardson and Jull [46]. They reported it was difficult to achieve because of the substitution of the rectus abdominis, external oblique, and the long back extensors. They also reported that patients had difficulty controlling breathing with this 'bracing'. Therefore, they allowed patients to advance only when the isolated contraction could be held for 10 seconds for 10 times. It was then incorporated into holding and dynamic tasks. They felt that this was necessary to reinforce a new

engram of motor control, so that this stability control occurred automatically. This form of bracing in the exercise protocol described above produced a statistically significant reduction in pain intensity and functional disability levels at a 30 month follow-up.

Many current texts typically used to train physicians, physical therapists and exercise physiologists in rehabilitation techniques for LBP have incorporated exercises that include core strengthening and/or dynamic lumbar stabilization exercises, as well as flexibility, cardiovascular training, and/or functional tasks to meet the patients goals ([13, 31, 33-37]. Some of the typical lumbar spine stabilization exercises are:

- Abdominal Bracing and/or hollowing
- Dead bug with or without upper and lower extremity movement
- Bridge series with a march and/or leg extension, adduction against a ball or abduction against a belt
- Prone series of trunk extension, prone upper extremity and/or lower extremity alternating lifts
- Quadruped upper extremity and/or lower extremity alternating lifts
- Trunk curl series
- Side lying leg lifts
- Kneeling progressions to standing
- Lunges or wall squats
- Horizontal side support on the elbow and feet

Some of the currently used exercises based on the dynamic lumbar stabilization models presented by the San Francisco group have been adapted to the exercise ball [36]. Most of the above mentioned exercises can be adapted to the exercise ball for an additional neural input and challenge from the ball motion, thus addressing the neural system retraining Panjabi [67] speaks of as a component of spine stability.

The focus and goal of these exercises are to retrain, strengthen and promote use of the local muscular system to stabilize the spine to promote good control of the neutral zone, thus protecting the motion segments of the spine against repeated microtrauma, thus decreasing strain to any injured tissues. The global muscular system is addressed in the more advanced stabilization activities when the extremities become involved. The aim is to promote return to the activities of daily living and athletic/recreational goals with a stabile spine, appropriately controlled at the local segmental level, and with an ability to control the external forces from the global muscular system.

Arokoski et al. [97] demonstrated that some of the basic traditional exercises (bridge, bridge variation and prone exercises) provided sufficient activation of the rectus abdominis, external obliques, and in particular the multifidus muscles at L5 to provide training to promote stability of the lumbar spine. McDonald and Lundgren [98] report on many very specific dynamic lumbar stabilization exercises (a twelve phase program) for patients with LBP. Unfortunately, these were case studies, but McDonald and Lungren do provide clear descriptions of a complete program of the traditional type lumbar stabilization exercise typically prescribed. Stanton et al. [99]

report an increase in core stability in the athletes they trained over 6 weeks with exercise ball stabilization exercises.

Pilates Exercises

The pilates form of exercise is named after the man who originated the roughly 500 movements used in these exercises in the early 1900's, Joseph Pilates. He was born in Germany (1880-1967) and suffered from a multitude of illnesses which left him experiencing muscle weakness. Pilates studied yoga, martial arts, Zen Meditation, Greek and Roman exercises, worked with physicians and his wife (a nurse) in developing his method [40]. He used a variety of techniques including springs and devices to change the body's orientation to gravity to break down faulty movement patterns, and to apply altered loads. In theory, this is accomplished by reducing the degrees of freedom that the nervous system must control, and reducing the overall load applied. Pilates' exercises vary from mat work to reformer, barrels, spine reformers, and stability chairs (see appendix A). Pilates immigrated to the United States and brought his exercise practices with him in 1923. He attracted the attention of the dance community and many famous chorographers and dancers in the 30's and 40's such as Martha Graham and George Balanchine embraced Pilates' methods [40]. These exercises become a method of improving dance technique and rehabilitating dancers after injuries.

Pilates did little writing and no research, so his material was predominately passed on via students, many of whom were dancers, and in his writings [45]. After his death his students continued following and developing his ideas; however as the

trademark ended in 2000 [41, 100], Pilates unfortunately became a generic description of exercise as is yoga or karate. Many practitioners have studied his work intensely and established thorough training and certification programs (for example Stott™ Pilates). However, Pilates is open for a wide style of training, certifications and interpretations, and Pilates instruction is now even available on videos, in books, and in gym programs.

A worrisome aspect of this surge of Pilates usage and certification is that it is commonly used as treatment in rehabilitation facilities without clinical research and general standards for certification. As noted previously a variety of sources report Pilates is helpful in treating LBP; these include MayoClinic.com, Medic8® Family Health Guide @medic8.com, spine-health.com, backcare.org, and 56 books listed on Amazon.com for Pilates and LBP (as of 2/5/2005). The number of hits on Google was remarkable at 74,600 for 'physical therapy Pilates clinics' and at121,000 for 'Pilates and LBP'. There has also been a recent growth in the continuing education courses available for physical therapists in Pilates exercises for spine rehabilitation. Many state boards are now recognizing these courses as meeting continuing education requirements, including Tennessee's.

In theory the Pilates form of exercise appears appropriate to address the goals of effectively training both the active and neural local spinal musculature with progression to training the global musculature to bear external loads. It even addresses the addition of breathing patterns and recruitment of local trunk musculature while inhibiting global musculature in the initial stage of training as suggested by O'Sullivan [95] and Lee [34]. Core stability and posture are

emphasized in the Pilates regimen, with all exercises beginning with 'setting' the abdominals (e.g., co-contraction of the transversus abdominis and multifidus). There is an association of the pelvic floor and abdominals in healthy subjects [101] and when taught correctly, Pilates emphasizes the role of the pelvic floor in stabilizing the spine.

The spine is kept either in a neutral position or 'imprint' in which the local or deep spinal musculature is thought to be engaged at a more intense level (transversus abdominis, internal obliques, and multifidus). The focus and specific verbal cueing on deep breathing structured into the exercises themselves helps to facilitate the contraction of the transversus abdominis and multifidus, that is reported in the literature to improve spine stability at the local level [55], improve control over the neutral zone on intervertebral motion [60, 67], and stabilize the sacroiliac joint [53]. Richardson et al.[53] report that contraction of the transversus abdominis significantly reduced the laxity (or increased the stiffness) of the sacroiliac joint at $P < 0.0260$ over using all lateral abdominal muscles. Thus, the focus of Pilates on retraining and engaging the TA, and internal obliques while maintaining neutral spine, in theory sounds ideal to treat instability and LBP.

The primary goal of the Pilates exercises is alignment as well as core control. This is taught, for example, in the Stott™ Pilates technique [102] by incorporating five principles of alignment to be addressed for each exercise performed. This includes breathing patterns to more deeply engage the deep local musculature, rib placement, scapular girdle placement and engagement, and cervical spine and pelvic alignment. Pilates can be taught in a manner in which progression from beginning

exercises (which are based on mastering correct spinal alignment of these five principles and transversus abdominis-multifidus co-contraction) is not allowed until core control is established. When one can stabilize the spine position in the basic exercises, movement of the extremities can be progressively added further from the center, thus engaging the global muscular system. This training pattern in Pilates is the same as suggested by Lee in the progression from local to global muscular retraining [34]. Many researchers [76-79, 84, 86] have shown a feed-forward disruption in activity of the transversus abdominis in patients with LBP, while performing extremity movements, which shows the necessity for proper retraining of the transversus abdominis before adding the more complicated extremity motions. The risk is if the progression is made too soon and loads are applied to the spine via the global musculature that the local system cannot control. Thus, it is important to note here that qualified clinicians are needed to teach Pilates to those with LBP.

Pilates movements are typically multi-plane ones that require coordination; with the exercises being geared toward overcoming faulty movement patterns. As previously noted, one of the stabilizing components is the neural sub-system. Because these exercises are so focused on control of alignment with correctly timed usage and recruitment of muscles, and are multi-plane and utilize breathing, one would theorize that the neural system is being more deeply engaged and retrained.

The Pilates style of exercise and rehabilitation for those with LBP has some promise with respect to transferring smoothly from the clinic to a home program that patients will want to continue as part of their lifestyle. The mat exercises may be continued at gyms classes or Pilates studios, performed while following one of the

many videos available, or transferred to a home program without equipment; all of the aforementioned if done appropriately provide less risk of LBP recurrence and therefore less utilization of health care resources. The importance of continuing a home exercise program was noted by Manniche et al., [20] in that the patients who continued their home program of exercises once a week were still better at one year, as compared with those who did not. If patients feel it is easier to transfer to a popular form of exercise that is easily accessible (versus a page of 'physical therapy' exercises), they may actually continue with the suggestions of a continued exercise program to prevent the recurrence of LBP.

An additional interesting and possible secondary benefit of participating in a Pilates based exercise program is the overall effect on one's being. Pilates exercises integrate movement of the extremities in multi-plane functional positions and correct spinal alignments with breathing and core centering. The centering and 'quiet' stress-relieving aspect of this type of movement may have deep-reaching effects not yet known, beyond the biomechanical ones examined in this study. It would be quite interesting to investigate the outcomes of performing Pilates exercise with stress-related tools or depression scales.

Current published research on the use of Pilates in rehabilitation is mostly descriptive in nature, for example Cozen [39] presents some options in ankle and foot rehabilitation using Pilates; Anderson & Spector [40] discuss the theoretical reasons Pilates should be utilized in rehabilitation; Galeota-Wozny [103] and Dacko [104] discuss Pilates training for dancers; Segal et al. [105] observed participants in a community Pilates class for changes in flexibility and body composition; and Smith

and Smith [106] discuss the appropriate use of Pilates with an older population. A few of the studies were quantitative but they do not address the use of Pilates mat exercises in the treatment of LBP (e.g., reformer analysis of dancers [43], and Pilates used in jumping programs for gymnasts [42]). Two different case studies were found; one of treatment for scoliosis using Pilates exercises as therapeutic intervention shows promising results [44], and another case study contrasting Pilates with ultrasound usage in re-training the multifidus [41].

One concern is that when Pilates is so broadly disseminated, without mandatory standards of training certification and a huge variety of sources available to the average person with LBP, it can be misused and poorly represented, and may actually cause LBP. One would hope that if research is conducted and brings to light productive objective findings in the use of Pilates exercise in rehabilitation there may be some standards for Pilates usage. One aim of this study is to begin objective research into the area of using Pilates mat exercises in the treatment of patients with LBP, and to present a base line approach to safe usage of Pilates exercises in rehabilitation from LBP.

Outcome Measurement Tools

Visual Analogue Scale (VAS)

The VAS is one of the most frequently used pain measurement scales in both the clinic and research, especially with respect to LBP [1, 24, 93, 107-109]. It is one of the measures that the World Health Organization [110] suggests be used for

outcomes measures of LBP. The VAS is a 100mm line on a blank piece of paper with the following descriptors at each end; no pain at all at the left end and worst pain possible at the right end (see appendix B). The patient marks the spot that best corresponds to his or her level of pain at that moment in time. It has been shown that the horizontal is preferred over the vertical for measurement of LBP due to higher sensitivity [111]. The measure in centimeters from the left side of the line to the location of the mark on the line is the score. Kovacs et al. [108] suggest, based on their study of correlation of pain and disability, that these variables should be assessed separately when evaluating the effect of any form of treatment for low back pain.

Revised Oswestry Disability Index (ODI)

The Revised Oswestry Disability Index (ODI) is currently a commonly used tool in assessing outcomes of LBP [14, 23, 25, 93, 109, 112, 113]. The original Oswestry index was designed by Fairbank and his colleges in 1980 [114, 115]. The questionnaire consists of 10 items addressing different aspects of function. Each item is scored from 0 to 5, with higher values representing greater disability. The patient marks the statement(s) in each section that best describes his/her state. The total score is multiplied by two and expressed as a percentage for disability ratings, however the raw score will be used in this study. A modified version [115] which is used in this study (see appendix C) with the change of replacing the sex life section with a question related to fluctuations in pain intensity, demonstrated superior measurement properties compared with the Quebec Back Pain Disability Scale (CLUE) and comparable to the Roland-Morris Disability Questionanaire [114].

Bombardier [112] performed a review of the available tools to assess outcome measures of spinal disorders. The key recommendations from the review were that a core set of measures should include back specific function of which the Oswestry Disability Index was one of the two recommend in the area of function. Fairbank and Pynsent [116] reviewed versions of the ODI, its uses and power calculations in uses in managing spinal disorders. They concluded that the ODI remains a valid and vigorous measure. The World Health Organization [110] includes the ODI in its list of recommendations for outcome measures for LBP.

Dual Inclinometer Technique

The current edition of the *AMA Guides* [117] recommends the use of dual inclinometers (DI) to measure lumbar spine range of motion in assessing disability due to LBP. Saur et al. [118] showed the noninvasive inclinometer technique to be highly reliable and valid for flexion as compared with radiography. One fluid goniometer is placed on the T12 –L1 interspace and the other on the base of the sacrum. The difference between the two is the range of motion (ROM) measurement for that particular movement. This measurement and particular tool was chosen because ROM measurements in the clinic are commonly reported in a physical therapy evaluation and discharge, as well as its inclusion in the AMA's guidelines for disability evaluation [117].

Stability Platform

The stability platform, model 16030, is a very sensitive instrument developed by LaFayette Instrument Co. for the measurement of standing balance (see appendix D). Although there are numerous ways to measure core strength [33, 119-121], this particular activity (stability platform testing) was chosen as an outcome measure to test core strength and stability because it integrates muscular strength and endurance (active subsystem), and balance/coordination (neural subsystem). Cosio-Lima et al.[122] used a balance test (unilateral standing) to indicate core stability. However, in this current study the specific position was chosen from the four tested in previous research [123] and was selected in part due to the results reported by Hodges and Richardson [78]. They found a delay in the transverses abdominis and internal obliques during upper extremity elevation in subjects with LBP. Of the four core stability tests from Liemohn et al. [123], the kneeling with alternating unilateral arm raise was thought to possibly show the most change in core stability/strength after treatment, in part due to the noted feed-forward problem with the transversus abdominis in those with LBP [78].

Liemohn et al. [123-125] used this instrument in assessing core stability in normal subjects. Liemohn et al. [123] showed both internal and stability reliability measures for the test used in this study (i.e., kneeling on knees while alternately lifting an arm). The scores (number of seconds out of balance) were recorded from normal subjects in four positions over 4 days, for 5 trials each day. Means were calculated for each day. Based on the means observed of the first day's trial and the first test of each day's trial (which were markedly worse), it was decided to consider

the trial (all 5 tests) of day 1 and each trial's first test a practice test. Thus, days 2 – 4 and tests 2-5 of each day were analyzed. The reliability of the scores within a day (internal consistency reliability) for tests 2–5 was high, especially for the kneeling arm raise, at 0.95, 0.94, and 0.95 for days 2–4. In order to decide how many trials (days) of testing were necessary to produce a reliable score between days (stability reliability), reliability scores were estimated using an intraclass reliability coefficient formula from Baumgartner et al. [126]. The data used for this were from days 2 and 3, 3 and 4 and 2-4. The reliability scores for the kneeling arm raise for days 2 and 3 were low at 0.52, but high for days 3 and 4 at 0.94. Thus, the learning curve for normal subjects appeared to be two full test sessions (days or trials 1 and 2), and one practice each test time. The scores were stable from day (trial) 3 forward for tests 2-5 each trial.

Because of their interest in prior research from our lab [123-125], Lafayette Instrument Co. made for us a prototype of the Stability Platform. The platform size of the prototype is 127cm by 137cm; the size of their standard marketed model is 66cm by 106cm. The prototype version was utilized in this study (see appendix D).

Byl & Sinnott [127] found that increased body sway occurred in patients with LBP during specific tasks. If one is unable to maintain balance in a position, the center of gravity has moved outside the base of support. Theoretically, if a person is kneeling on the Stability Platform and alternatively lifts an arm rhythmically, his or her stability of the spine will be reflected in how well he or she maintains balance. Loss of balance may be a pure strength or endurance issue combined with a loss of proprioception or the ability to adapt and reposition the spine in an appropriate

balanced posture. Brumagne et al. [73] found patients with LBP to have a less refined lumbosacral position sense than non-patients, and Parkhurst and Burnett [128] noted that impaired proprioception (awareness of position) of the lumbar spine may degrade lumbar function after injury to the low back. O'Sullivan et al. [80] assessed lumbar spine proprioception in a population of both normal subjects and those with LBP, specifically clinical spinal instability. The LBP patients demonstrated greater repositioning error in obtaining neutral spine. If assessing and maintaining a neutral spine posture is necessary for maintaining balance and readjusting to obtain balance once lost, then the stability platform may be the ideal way to clinically, functionally and non-invasively test core stability.

Chapter III

Research Methods

Subjects

The subjects were recruited from Tennessee Sports Medicine Group (TNSMG), an outpatient orthopedic physical therapy rehabilitation facility in Knoxville, TN. The recruitment occurred over a 5 month period. All patients presented for physical therapy treatment with a prescription from a medical doctor, chiropractor, or osteopath. Exclusion criteria included positive neural signs, any serious pathology preventing exercise, age < 18, referring physician's request on the prescription desiring a specific rehabilitation technique that would limit the randomization process to either group, workers compensation or motor vehicle cases, and those attending physical therapy elsewhere. All patients with LBP attending TNSMG for their initial evaluation (with one of the two participating physical therapists) in the 5-month period were presented the opportunity to participate; only five patients declined.

The method of recruiting occurred in the following order: 1) the patient presented for the physical therapy initial evaluation with a prescription, 2) the patient was evaluated by one of the two treating physical therapists participating in the study 3) the therapist then decided if the patient was appropriate for inclusion in the study (no exclusion criteria), 4) the subject was approached by the principal investigator

(PI) and was presented with the informed consent form that was approved by the Institutional Review Board at the University of Tennessee # 6401 B (see appendix E), was allowed to ask questions concerning the study, 5) upon acceptance the subject was randomly assigned to group A (traditional lumbar stabilization) or B (Pilates exercises) was provided with the information packet (see appendix) and began testing.

Research Design

All subjects received what was deemed medically necessary by the treating physical therapist and referring physician. Every subject was treated by their physical therapist at each visit but support personnel were utilized for components of the treatment. The treating team included physical therapists (3), a chiropractor, athletic trainers (3), exercise physiologists (2), Stott™ Pilates certified instructors (3), a licensed massage therapist (who is also one of the exercise physiologists), and a physical therapy technician. The physical therapy evaluation and treatment was provided by one the physical therapists who managed the subject's case throughout their treatment.Treatments included for all subjects were designated as medically necessary by the physical therapist and included those normally chosen in treatment of LBP at TNSMG: (1) use of modalities (heat, ultrasound, electrical stimulation, ice, etc.), (2) manual therapy, (3) patient education, (4) and management of lower extremities biomechanical issues (orthotics). The exercise portion of the subjects' treatment was dictated by group assignment. Flexibility programs, and home exercise

programs (HEPs with compliance journals – see appendix) based on the in-clinic exercise program was provided to each subject. Thus, all subjects received what was deemed medically necessary for their treatment, but the exercise portion (clinic and HEP) was assigned to the protocols of either group A or B.

Patients were randomly placed in one of the two groups: Traditional therapeutic exercise group (A) or Pilates group (B). The randomization was a coin flip, 40 sequential times with a list compiled of subject numbers from heads = A and tails = B. The group protocols were as follows: Group A exercises included mat lumbar stabilization, under the direction of the athletic trainers, exercise physiologists and the physical therapist (see appendix F). Group B received the treatments deemed necessary by the physical therapist and instead of the traditional therapeutic exercise program, Group B participated in Pilates mat exercises (see appendix G). The Pilates exercises were taught by a certified Pilates instructors (the main exercise clinician who worked with all subjects in both groups is both an exercise physiologist and Stott™ Pilates trained). See appendix for the specific exercises included in these protocols of group A and B. The specific guide of exercises to be chosen from for each group was provided to the physical therapist, exercise physiologists, athletic trainers and Pilates instructors. There was clear documentation of each exercise performed including type and repetitions performed in the subject's medical chart and in the HEP manual provided to the subject. The subjects participated in these exercises during their regular treatments in the clinical gym setting where the exercise physiologist, athletic trainer, or Pilates instructor guided anywhere from 1 - 4 patients simultaneously. Individual attention was available, yet a social setting or sense of

being in a group setting was present. The exercise sessions at each treatment lasted from 30 – 45 minutes.

The subjects were measured at the evaluation before their first treatment, and subsequently after every 4th treatment. The number of the subjects' treatment sessions were dictated by medical necessity, thus the treating physical therapist and physician decided when the patient was ready for discharge. When it was decided that a patient was ready for discharge, the tests were performed once more even if it was not a 4th treatment, thus it was considered the discharge test.

Research Procedures

The patients presenting for physical therapy evaluation and treatment of LBP at TNSMG were initially evaluated by one of the two participating physical therapists. If the patients were deemed appropriate for the study (no exclusion criteria), the PI addressed the patient, inviting them to participate as a subject in the study. The PI is a certified Stott™ Pilates mat instructor and a currently licensed and practicing physical therapist at TNSMG but was neither the treating therapist nor an instructor for any of the exercises for the subjects. The patients were presented with the informed consent form and upon acceptance of inclusion were assigned the next subject number and corresponding randomly assigned group. The subject and treating physical therapist were then provided with the appropriate materials for the group assignment; namely the HEP folder, and chart materials of the protocol for the exercise portion of their treatment.

At each testing session the subject filled out the written outcome measures, was measured in spine motion and trunk stability with the tools listed below.

Outcome measurements:

1) The Revised Oswestry Disability Index
2) Visual Analogue Scale
3) Lumbar spine mobility/ROM measured with double inclinometers for flexion and extension: The fluid goniometers were placed by the athletic trainers on the skin over the interspace of T12/L1 and at the sacral base. The patient then asked to bend forward to maximum range possible and leaned backwards to the maximum possible. These measurements were taken by two of the athletic trainers, who followed the suggested method in using this technique.
4) Stability platform measurements: The subjects maintained a kneeling position as described previously (see picture in appendix) while lifting one arm then the next in time with a metronome set to 60 beats per minute. The measurements taken were of time (in msec) in balance/control on the platform in the 6° arc and # of times out of 6° arc to each side, right or left. See appendix for sample measurement form.

The testing protocol was as follows:

- the device was checked for being level, and all parts in working order.
- the subject was provided a demonstration of the kneeling balance position, was allowed to practice for 30 seconds, and allowed to ask questions.

- The test began of 30 seconds balance, and 30 seconds rest, for 5 trials. The subject was allowed to get off the stability platform and rest 3 – 4 minutes before the second round. There was an audible marker of the 30 second intervals. The initial test included five 30 second balances. This counted as the learning curve portion. As noted earlier, previous research [123] showed the measures for sets 2 – 5 were stabile by the third trial test time; however, that research was on healthy subjects without LBP. As the pilot subjects were tested it was discovered that patients with LBP had scores that began changing dramatically by the third trial in the opposite direction as reported in Liemohn et al. [123]. Due to this possible fatigue factor in patients with LBP, only a second and not third trial of 5 was used. To obtain a true pre-test, both tests had to be done in one day – before treatment. After 2 tests of 5 trials were conducted the subject was returned to the treating physical therapist and had the evaluation and treatment portion of their visit completed.

Pilot Testing

Previous research [123-125] on the Stability Platform was discussed earlier with respect to its test-retest stability and reliabilities. Based on this previous testing on non-patient and often athletic university students, it was initially decided that 3 tests of 5 trials were necessary for the subjects to appropriately learn the device [123]. However, as noted above, the subjects with LBP tended to fatigue and reverse the test score by the third test (i.e., balance less well), thus showing a learning curve interruption secondary to fatigue. It was then decided to use only two tests for this

study of symptomatic individuals to account for the learning curve and it would protect the subjects from over-fatiguing and risking injury while performing the test. The previous study did show internal consistency reliability was acceptable on testing day two on the kneeling test [123].

The first four subjects recruited were pilot subjects with respect to the stability platform testing. The first four were considered pilot subjects for the stability platform for the following reasons:

1) A newly constructed and larger stability platform was constructed for and delivered to the University of Tennessee by Lafayette Instrument Co. after 4 subjects had been tested on the smaller original platform. Due to the improved recording device associated with this new and larger device, the decision was made to switch to the larger stability platform and the first four subjects were considered pilot subjects with respect to the stability measures.

2) The first four subjects had been tested for all sessions on campus with electromyography (EMG) as well, for the study was originally designed to investigate the changes in rectus abdominis, internal and external oblique and multifidus firing patterns in response to the Pilates training and the Stability Platform. Because the EMG equipment was not available for use at the clinic and as travel was cumbersome to the subjects, the EMG component was dropped for

this current study, and only the new Stability Platform was moved to the clinic.

3) The decision was also reached by the time of testing subject five to consider only the 2nd test instead of the 3rd test as the pre-test initial measurement.

Data Analysis

A two – way analysis of variance for repeated measures (2 X 3 ANOVA) was used to determine the effects of Pilates mat exercise on patients with LBP over time. The two factors in this 2 X 3 design are type of therapeutic intervention and time. The design is mixed: between groups of A or B and within groups for repeated measures over time. There were seven outcome measurements analyzed statistically: the VAS scores, Revised Oswestry scores, AROM of lumbar flexion and extension, total time in balance and number of times out of balance to right and left on the Stability Platform. Statistical analysis was performed using SPSS, version 13.

Chapter IV

Research Findings

Summary Statistics

A total of 21 (of 26 patients) who passed the exclusion criteria (positive neural signs, any serious pathology preventing exercise, age < 18, referring physician's request on the prescription desiring a specific rehabilitation technique that would limit the randomization process to either group, workers compensation or motor vehicle cases, and those attending physical therapy elsewhere), signed the consent form to participate in the study. These 21 were randomly assigned to either group A or B and initial measures were taken (12 group B, 9 group A). Only 12 of these completed their prescribed physical therapy treatments, with six to each group. The remaining 9 subjects began with the evaluation/first treatment as did the 12 in the study, but had insufficient data to be included. They either did not return at all for physical therapy, or attended too few times (< 4) to be re-tested at the 4^{th} visit. All 9 were contacted for re-testing and chose not to participate either by reporting reasons or not returning the call. Some typical reasons for not participating in physical therapy were work and/or family commitments preventing treatment at that time, holiday schedule not permitting time for treatment (recruitment was over the winter holidays), and 'feeling better' not needing physical therapy after all. No one reported

dropping out secondary to problems with the physical therapy treatments, and all who dropped out did not attend any other form of physical therapy at the clinic.

Subject's diagnoses' are included in figure 12. Summary statistics for age, chronicity of LBP (chronic ≥ 3 months), treating physical therapist, gender, and pre-test levels for all variables tested are listed in table 2 and 3 for the 12 subjects who participated. These subject characteristics and variables were compared at baseline (before treatment) for the two groups, traditional exercise and Pilates, to establish whether the randomization process was successful. Independent sample t-tests were performed for the dependent variables and age (Table 3), and Chi-Square tests were performed for chronicity, gender, and treating physical therapist (Table 4).

Diagnoses – per subject
LBP with L5/S1 radiculopathy, L5 Laminectomy
LBP with Pelvic Obliquity, Myofascial LBP
LBP with Sacroiliac Joint Dysfunction
LBP with mild Retrolisthesis L5/S1, Myofascial Pain
Lumbago
LBP
LBP with Pelvic Asymmetry, Myofascial Pain
LBP with Sacroiliac Joint Dysfunction
LBP, Bilateral hip pain, Pelvic pain
LBP (history of HNP)
LBP with Sacroiliac Joint Dysfunction
LBP

Figure 12 Specific diagnoses.

Table 3 Summary Statistics for age, pre-test variables, A n=6 and B n=6.

	group	Mean	Std. Deviation	P value
Age	A	30.33	12.40	0.430
	B	36.00	11.43	
VAS pre	A	3.85	2.52	0.183
	B	2.07	1.72	
Oswestry pre	A	17.17	6.11	0.658
	B	15.83	3.71	
Flexion pre	A	42.33	19.20	0.594
	B	35.50	23.57	
Extension pre	A	15.83	12.84	0.765
	B	17.67	6.98	
Stability pre	A	19.61	3.08	0.257
	B	22.33	3.92	
Stability Left	A	5.70	2.43	0.724
	B	6.35	3.14	
Stability Right	A	5.55	2.95	0.851
	B	5.20	2.74	

Table 4 Percentages per group for gender, LBP chronicity, treating PT.

	Group A	Group B	Fishers Exact Test P value
Chronicity: < 3months	16.7 %	33.3 %	1.00
> 3 months	83.3 %	66.7 %	
Gender: Male	33.3 %	16.7 %	1.00
Female	66.7 %	83.3 %	
Treating PT: # 1	66.7 %	66.7 %	1.00
# 2	33.3 %	33.3 %	

There were no significant differences for age (group A # = 30.33, S.D. = 12.4 and group B: # = 36.00, S.D. = 11.4, P = 0.430), chronicity of LBP with group A at 83.3% and group B at 66.7% for chronic LBP (Fisher's exact test P=1.00), gender with group A at 66.7% and group B 83.3% female (Fishers exact test P=1.00), or differences with the number of subjects assigned to each of the two participating therapists. There were also no significant differences between the two groups on any of the dependent variables (see Table 3) at pre-treatment.

Outcome Measures

A 2 X 3 (exercise group X time) analysis of variance for repeated measures was used to assess the effect of exercise treatment over time, using the outcomes of VAS, Oswestry Disability Index, Lumbar spine AROM measures in flexion and extension (Table 5). Not all subjects had an 8th treatment test because not all subjects needed eight treatments, therefore, only pre, four and post treatment measures were used for these variables. Assumptions of sphericity were considered with the use Mauchley's test of sphericity and showed P values of VAS p=0.828, ODI p=0.115, F-AROM p=0.977, and E-AROM p=0.994. Thus, the condition of sphericity does exist. A 2 X 2 (exercise group X time) analysis of variance for repeated measures was used to assess the effect of exercise treatment over time, using the outcomes of central balance time on the stability platform, and deviations left and right (table 5). The measures from pre and post were used in this analysis because two subjects had 4th treatment measures missing and two pilot subjects included in the final 12 subjects

Table 5 Scores by Group over Time for the Interaction Effect using a repeated measures 2 X 3 ANOVA (n=6 per group) for VAS (visual analogue scale), ODI (Oswestry disability index), F-AROM and E-AROM (lumbar spine flexion and extension active range of motion), and 2 X 2 ANOVA (n=5 per group) for stability platform measures of STAB-C (central balance in seconds), and STAB-L and STAB-R (number of times deviated to either the left or right).

	Pre-treatment				**4th visit**				**Post treatment**				**P value time * group**	**P value time**	**P value group**
	A		**B**		**A**		**B**		**A**		**B**				
	#	**SD**	**#**	**SD**	**#**	**SD**	**#**	**SD**	**#**	**SD**	**#**	**SD**			
VAS	3.85	2.52	2.01	1.72	2.00	1.60	1.20	1.71	1.53	1.77	0.98	1.71	0.300	0.004*	0.308
ODI	17.17	6.11	15.83	3.71	11.00	6.36	8.00	6.30	9.17	7.50	7.00	5.90	0.804	0.004*	0.499
F-AROM	42.33	19.20	35.50	23.57	41.33	19.20	41.17	16.33	40.67	18.87	35.33	14.23	0.698	0.733	0.686
E-AROM	15.83	12.84	17.67	6.98	12.83	9.99	18.00	7.18	19.33	12.60	20.50	10.15	0.873	0.538	0.477
STAB-C	19.61	3.08	22.33	3.92	-	-	-	-	22.95	2.75	24.05	4.56	0.403	0.013*	0.340
STAB-L	5.70	2.43	6.35	3.14	-	-	-	-	4.80	2.54	6.10	5.40	0.591	0.458	0.617
STAB-R	5.55	2.95	5.2	2.74	-	-	-	-	2.9	1.91	2.40	1.51	0.830	0.004*	0.709

did not having any stability platform measures (as previously noted).

There was no interaction of group over time on any of the outcome measures (table 5). However, all subjects independent of group showed significant improvements in the VAS (p=0.004), ODI (p=0.004) and stability platform measures of central balance (p=0.013) and the number of times deviating to the right (p=0.004). No changes over time occurred in the range of motion measures or the deviations to the left on the stability platform. See Figures 13–15 for graphical representation of the measures that changed over time.

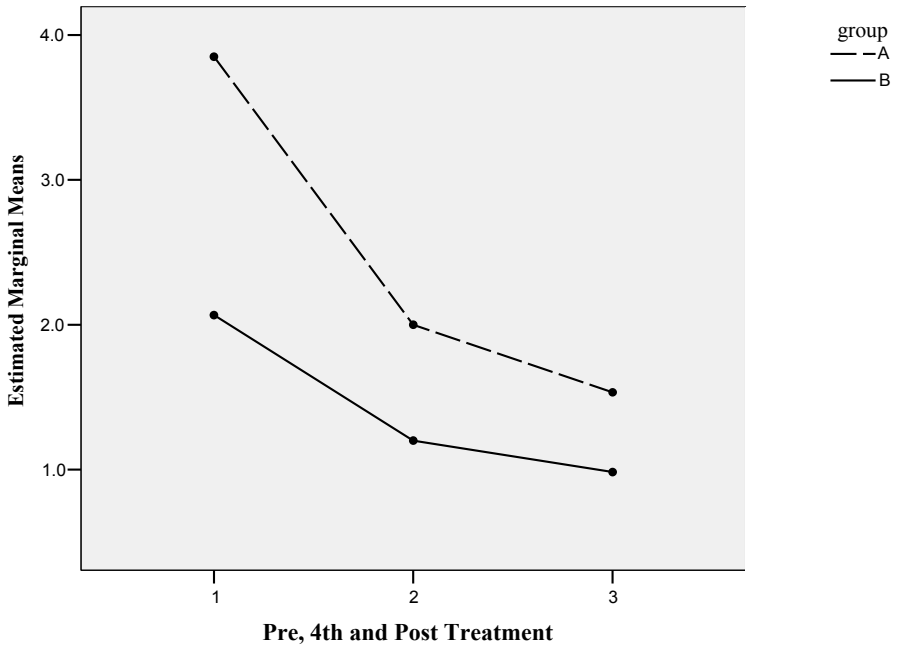


Figure 13 VAS measures. Means presented are in centimeters (from the 10 cm length scale). A - pre #=3.85 SD=2.52 & post #=1.53 SD=1.77; B - pre #=2.01 SD=1.72 & post #=0.98 SD=1.71.

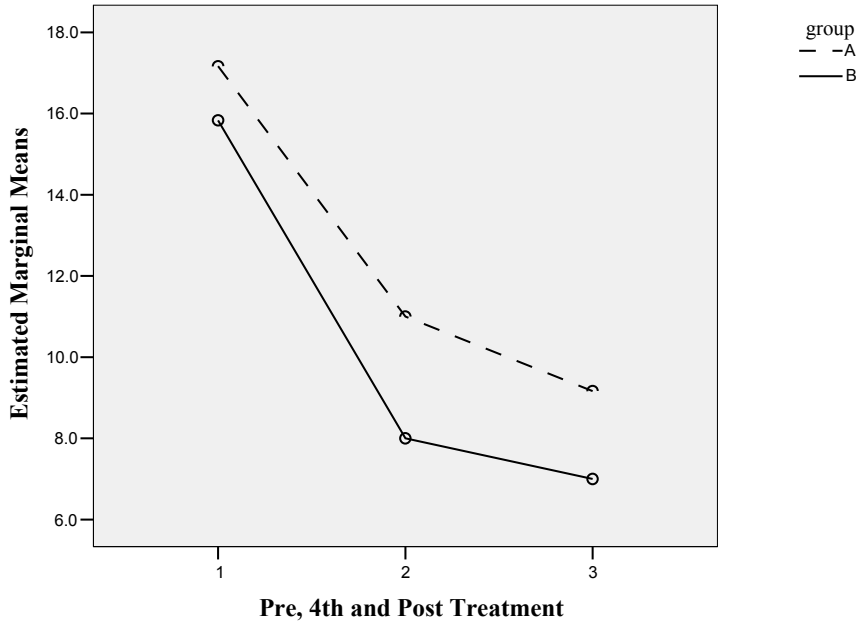


Figure 14 ODI measures. Means are presented as raw scores, out of a possible score of 50. A - pre #=17.17 SD=6.11 & post #=9.17 SD=7.50; B - pre #=15.83 SD=3.71 & post #=7.00 SD=5.90.

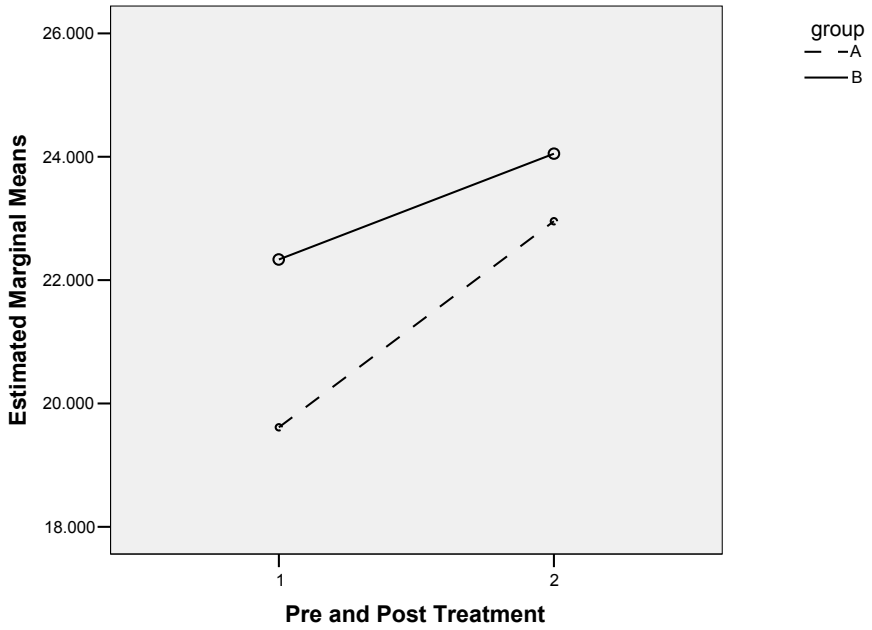


Figure 15 Stability platform measures of seconds in balance in 6° central range. A - pre #=19.61 SD=3.08 & post #=22.95 SD=2.75; B - pre #=22.33 SD=3.92 & post #=24.05 SD=4.56.

Analyses were performed on other possible confounding variables such as number of treatments subjects needed per group, length of treatment time per group, and specific additional physical therapy interventions used in the treatments of subjects in each group. Independent sample t-tests were performed on the number of weeks and treatment length for each group (table 6). Chi-Square tests (table 7) were performed for the specific treatment interventions each patient received as part of their regular physical therapy treatments, including HP/ES (hot packs with electrical stimulation), US (ultrasound), STM (soft tissue mobilization), MT (manual therapy or joint mobilization), and ORTHO (orthotics). No differences existed between the two groups for number of treatments with a mean of 9.67 for the traditional group and 10.50 for the Pilates group. The length of treatments were not significantly different either between the two groups at 6.6 weeks for the traditional group and 7.3 for the Pilates group. The other treatments provided to patients as their physical therapist and physician saw necessary to include, were not significantly different for the two groups.

Table 6 Treatment summary statistics

	Group	N	Mean	SD	P value
Number of Treatments	A B	6 6	9.67 10.50	3.44 2.66	0.649
Treatment length in weeks	A B	6 6	6.58 7.33	2.50 3.56	0.682

Table 7 Percentages of types of treatments other than therapeutic exercise (group A or B) provided to the subjects as part of their physical therapy treatments.

	Group A	Group B	Fishers Exact Test p value
HP/ES	66.7 %	83.3 %	1.00
US	66.7 %	33.3 %	0.567
STM	100 %	83.3 %	1.00
MT	100 %	100 %	1.00
ORTHO	50.0 %	50.0 %	1.00

Chapter V

Conclusions

Discussion

According to many authors, retraining spine musculature (in strength and proprioception) is essential in rehabilitating those with LBP to restore function and prevent recurrence [22, 27, 35, 47, 58, 67, 73, 85, 88, 98]. Traditional lumbar stabilization exercises are suggested for the purpose of retraining the local and global muscular systems and restoring function [18, 19, 31, 33, 35, 36]. The purpose of this study was to make a determination on the effectiveness of Pilates exercises as the therapeutic intervention with those with LBP. To investigate this recently touted form of rehabilitation for LBP (i.e., Pilates), it was decided to compare it with the typical lumbar stabilization exercises used for treatment of LBP. The null hypotheses was that there would be no differences between the two groups, traditional lumbar stabilization and Pilates exercises, in the measures of pain, function, motion and core stability.

All the subjects in this study progressed at a significant level with respect to lowering pain, improving function, and improving core stability. There were no significant differences between the two groups, traditional therapeutic exercise and Pilates exercises as taught at TNSMG, in the areas measured of pain, function, or core stability over the times measured in this study. There were also no differences in the length or number of treatments. Pilates, as provided to subjects at TNSMG, performed equally as well as the traditional exercises. Pilates did not cause harm or

prevent the typical progression seen with patients performing the traditional lumbar stabilization exercises.

The Stability Platform Measures

It was expected that at least in the stability platform measures a significant difference might be seen with the Pilates group. This was believed due to the focus with every Pilates exercise on engaging the transversus abdominis (with the breathing patterns integrated into every exercise facilitating an increase in transversus recruitment) and the reported role of this muscle in core stability. Some methodological improvements with respect to testing and the Stability Platform may allow a bigger difference to be seen between the two groups. The testing occurred in a busy out patient orthopedic clinic that was usually noisy and full of activity, and the subject pool was smaller than desired at five in each group. A quiet testing room may have been more ideal for the noise was seen to be distracting at times. A larger pool of subjects would provide a better basis for conclusions. Although the pre-test differences for the stability measure of central balance was at a P level of 0.257 (not significant), it suggests that a larger sample of subjects could result in less of a starting difference, and increase the chance of seeing a difference by post treatment. The Pilates group started with a higher balance mean, and thus had less room to improve. A power analysis was performed on the central stability measures due to the P value for interaction being one of the closer ones found ($p=0.340$). For a difference to be seen, with a power of 0.80, the subject sample size would need to be 42.

A previous study in our lab [123] investigated the stability reliability of the Stability Platform and showed that the mean balance in the center for asymptomatic university students was 27.2 seconds for day three and 28.00 for day four. This current study showed the subjects reached a mean of 22.95 for group A and 24.05 for group B. This may suggest that more treatment times were needed because the average normal times were not yet reached, or the exercise interventions were not continued either long enough or frequently enough for a training effect.

Nevertheless, the positive results of progress on the levels of pain, function and core stability for both groups is exciting. The use of the Stability Platform in measuring core stability appears to have many implications. Hodges et al. [79] showed a change in transversus abdominis recruitment with experimentally induced LBP. Did subjects get better at balancing on the stability platform because they had a reduction of pain or was it the training effect of the exercises, traditional and Pilates? Core stability, whether gained by strength, improved feed-forward due to decrease pain, improved proprioception, and/or increased endurance in trunk musculature might be better understood with the use of this device in future testing.

Treatment Frequency and Compliance

The average treatment length of time was 6.58 and 7.33 weeks (A and B), with an average of 9.67 and 10.5 treatments in that time, thus an average of 1.47 and 1.43 treatments a week. A significant difference between the groups may have been seen if the guided exercise sessions could have be provided on a more regular basis (3 times a week for at least 8-12 weeks). However, insurance exclusions prohibited the

continuation of patients through the 8 or 12 weeks originally proposed in this study. External funding would help to overcome covering extra costs associated with a longer exercise intervention time (i.e., extra visits past insurance allowance). This study did encompass the winter holidays which did not permit some subjects to attend the regular two times a week that is usual for our clinic. Compliance journals were provided for daily use, with some self- reporting performing their exercises 1–3 times a week at home, and some at 5–6 times a week. It was reported by the physical therapist that one subject in group B was not compliant, evidenced by an inability to reproduce the exercises at each treatment. Again, a larger sample size would help control for this influence.

A possible benefit from having one perform Pilates exercises as the therapeutic exercise intervention with LBP is the availability of post clinic motivation/sources to help compliance with the home exercise program. This study did not have follow up (at this point), so evidence of this is not yet available. It seems likely that patients might have a higher chance of continuing their exercises with the many sources such as videos (specific ones were suggested to our subjects), classes, and books so readily available. It has been noted that only those with LBP who continued with their exercise program were better at 12 – 14 months [20, 30].

Limitations

Limitations to this study are that it was performed with a relatively small sample size (12), in one physical therapy outpatient clinic. The two physical therapists were provided with a selection of exercises fitting either the traditional or

Pilates exercise conditions, however due to individual patient fitness levels and needs, not all exercises could be performed at the same point in treatment in each group. All subjects had exercises within each of their assigned groups, but were only progressed when they could appropriately stabilize their spine. This is the correct manner in which to progress patients, but due to the shorter treatment number lengths (~10) not all subjects got past the very beginning phases of Pilates. More treatment sessions, whether by times per week or in number of weeks, would solve this problem.

The medical diagnoses were quite varied (see figure 13). None of the patients had active herniated discs and most were considered chronic (see table 3) at 83.3% group A and 66.7% group B. Other treatments were provided simultaneously so as to not restrict treatments that were considered necessary, therefore the improvements noted of decrease in pain, improved function, and an increase in core stability cannot be solely attributed to the exercise interventions. However, it is important to note that it has been previously reported [47] that those with LBP, especially chronic, do not have a return of symmetry of the multifidus muscles without exercise intervention that includes co-contraction of the deep trunk musculature, so the exercise seems to be highly influential in outcome.

The Pilates portion of the exercise intervention was provided by Stott™ Pilates (mat) trained clinicians. The Pilates exercises used were chosen (from the group noted in the appendix) by the treating physical therapist and Pilates trained clinician and progressed according to the patient's ability to stabilize their spine and pelvis during the exercises. The results of this study do not mean that all Pilates provided from any source will have the same beneficial effect that the traditional

lumbar stabilization exercises provide. One must carefully select and progress Pilates exercises for those with LBP.

Suggestions for Future Research

There are many ways to improve on and answer many more questions concerning the use of Pilates in the treatment of LBP. A study with a larger subject pool, more sessions of the exercise intervention (at least twice a week and preferably over three months), and follow-up at measures of compliance and outcomes might provide valuable information. A future study might be one that includes the use of EMG, in particular viewing what is occurring with the transverses abdominis, and especially with those patients who suffer form sacroiliac joint dysfunction [53] while under treatment with Pilates. The reformer is a piece of equipment frequently used in Pilates and there would be value in investigating its role in rehabilitating those with LBP. Another future direction might be to look at psychosocial outcome measures for those with LBP and being treated with Pilates.

Summary

Subjects participating in Pilates exercises as provided as part of physical therapy treatment for LBP under the guidance of a physical therapist and Stott™ trained clinicians improved in measures of pain, function, and core stability equal to that of those performing traditional lumbar stabilization exercises as typically provided in rehabilitation for LBP. Given that there have been no clinical studies performed assessing the benefits suggested from performing Pilates exercises, this

study provides a legitimate and safe basis for inclusion of Pilates exercises, taught and progressed by appropriately trained clinicians, as therapeutic exercise intervention with patients who have LBP.

References

References

1. **Andersson, G.B.J., *Epidemiological features of chronic low-back pain.* Lancet, 1999. 354(9178): p. 581-585.**
2. **Hicks, G.S., et al., *Low back pain.* American Journal of the Medical Sciences, 2002. 324(4): p. 207-211.**
3. **Taylor, V.M., et al., *Low-Back-Pain Hospitalization - Recent United-States Trends and Regional Variations.* Spine, 1994. 19(11): p. 1207-1213.**
4. **Luo, X.M., et al., *Estimates and patterns of direct health care expenditures among individuals with back pain in the United States.* Spine, 2004. 29(1): p. 79-86.**
5. **Hart, L.G., R.A. Deyo, and D.C. Cherkin, *Physician Office Visits for Low-Back-Pain - Frequency, Clinical-Evaluation, and Treatment Patterns from a Us National Survey.* Spine, 1995. 20(1): p. 11-19.**
6. **Nachemson, A., *Chronic Pain - the End of the Welfare-State.* Quality of Life Research, 1994. 3: p. S11-S17.**
7. **Kelsey, J.L. and A.A. White, *Epidemiology and Impact of Low-Back-Pain.* Spine, 1980. 5(2): p. 133-142.**
8. **Khaltaev, N., et al., *Assessing the burden of musculoskeletal conditions: a joint World Health Organization-Bone and Joint Decade project.* Arthritis Research & Therapy, 2003. 5: p. S2-S2.**
9. **Woolf, A.D. and B. Pfleger, *Burden of major musculoskeletal conditions.* Bulletin of the World Health Organization, 2003. 81(9): p. 646-656.**
10. **Campello, M., M. Nordin, and S. Weiser, *Physical exercise and low back pain.* Scandinavian Journal of Medicine & Science in Sports, 1996. 6(2): p. 63-72.**
11. **Hides, J.A., G.A. Jull, and C.A. Richardson, *Long-term effects of specific stabilizing exercises for first-episode low back pain.* Spine, 2001. 26(11): p. E243-8.**
12. **Carey, T.S., et al., *Acute severe low back pain - A population-based study of prevalence and care-seeking.* Spine, 1996. 21(3): p. 339-344.**
13. **Kirkaldy-Willis, W. and J. Bernard, TN, *A Comprehensive Outline of Treatment*, in *Managing Low Back Pain*, W. Kirkaldy-Willis and J. Bernard, TN, Editors. 1999, Churchill Livingstone: Philadelphia. p. 265-283.**
14. **Frost, H., et al., *Randomised controlled trial of physiotherapy compared with advice for low back pain.* British Medical Journal, 2004. 329(7468): p. 708-711.**
15. **vanTulder, M.W., B.W. Koes, and L.M. Bouter, *Conservative treatment of acute and chronic nonspecific low back pain - A systematic review of randomized controlled trials of the most common interventions.* Spine, 1997. 22(18): p. 2128-2156.**
16. **van Tulder, M., et al., *Exercise therapy for low back pain - A systematic review within the framework of the Cochrane Collaboration back review group.* Spine, 2000. 25(21): p. 2784-2796.**

17. **vanTulder, M.W., et al., *Method guidelines for systematic reviews in the Cochrane Collaboration back review group for spinal disorders.* Spine, 1997. 22(20): p. 2323-2330.**
18. **Saal, J.A. and J.S. Saal, *Nonoperative Treatment of Herniated Lumbar Intervertebral-Disk with Radiculopathy - an Outcome Study.* Spine, 1989. 14(4): p. 431-437.**
19. **O'Sullivan, P.B., L.T. Twomey, and G.T. Allison, *Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis.* Spine, 1997. 22(24): p. 2959-2967.**
20. **Manniche, C., et al., *Intensive Dynamic Back Exercises for Chronic Low-Back-Pain - a Clinical-Trial.* Pain, 1991. 47(1): p. 53-63.**
21. **Manniche, C., et al., *Clinical-Trial of Postoperative Dynamic Back Exercises after 1st Lumbar Discectomy.* Spine, 1993. 18(1): p. 92-97.**
22. **Hansen, F.R., et al., *Intensive, Dynamic Back-Muscle Exercises, Conventional Physiotherapy, or Placebo-Control Treatment of Low-Back-Pain - a Randomized, Observer-Blind Trial.* Spine, 1993. 18(1): p. 98-106.**
23. **Kuukkanen, T. and E. Malkia, *Muscular performance after a 3 month progressive physical exercise program and 9 month follow-up in subjects with low back pain. A controlled study.* Scandinavian Journal of Medicine & Science in Sports, 1996. 6(2): p. 112-121.**
24. **Kankaanpaa, M., et al., *The efficacy of active rehabilitation in chronic low back pain - Effect on pain intensity, self-experienced disability, and lumbar fatigability.* Spine, 1999. 24(10): p. 1034-1042.**
25. **Brox, J.I., et al., *Randomized clinical trial of lumbar instrumented fusion and cognitive intervention and exercises in patients with chronic low back pain and disc degeneration.* Spine, 2003. 28(17): p. 1913-1921.**
26. **Rasmussen-Barr, E., L. Nilsson-Wikmar, and I. Arvidsson, *Stabilizing training compared with manual treatment in sub-acute and chronic low-back pain.* Manual Therapy, 2003. 8(4): p. 233-241.**
27. **Cleland, J., C. Schulte, and C. Durall, *The role of therapeutic exercise in treating instability-related lumbar spine pain: A systematic review.* Journal of Back and Musculoskeletal Rehabilitation, 2002. 16(2-3): p. 105-115.**
28. **Liddle, S.D., G.D. Baxter, and J.H. Gracey, *Exercise and chronic low back pain: what works?* Pain, 2004. 107(1-2): p. 176-190.**
29. **Mannion, A., et al., *Comparison of three active therapies for chronic low back pain: results of a randomized clinical trial with one-year follow-up.* Rheumatology, 2001. 40: p. 772-778.**
30. **Taimela, S., et al., *The role of physical exercise and inactivity in pain recurrence and absenteeism from work after active outpatient rehabilitation for recurrent or chronic low back pain - A follow-up study.* Spine, 2000. 25(14): p. 1809-1816.**
31. **Liemohn, W. and L. Gagnon, *Exercise (and diagnosis) protocols*, in *Exercise Prescription and the Back*, W. Liemohn, Editor. 2001, McGraw-Hill Medical Publishing Division: New York. p. 137-155.**

32. **Becker, B.E., *Aquatic exercise therapy*, in *Exercise Prescription and the Back*, W. Liemohn, Editor. 2001, McGraw-Hill Medical Publishing: New York. p. 197-213.**
33. **Fritz, J.M. and G.E. Hicks, *Exercise protocols for low back pain*, in *Exercise Prescription and the Back*, W. Liemohn, Editor. 2001, McGraw-Hill Medical Publishing Division: New York. p. 167-181.**
34. **Lee, D., *The Pelvic Girdle: An Approach to the Examination and Treatment of the Lumbopelvic-hip region*. 3rd ed. 2004, London: Churchill Livingstone.**
35. **Richardson, C.A., P. Hodges, and J.A. Hides, *Therapeutic Exercise for Lumbopelvic Stabilization: A motor control approach for the treatment and prevention of low back pain.* 2nd ed. 2004, London: Churchill Livingstone.**
36. **Jemmett, R.S., *Spinal Stabilization - The New Science of Back Pain*. 2001, Halifax: etc. Press Ltd.**
37. **Saunders, H.D. and R. Saunders, *Exercise*, in *Evaluation, Treatment, and Prevention of Musculoskeletal Disorders*. 1993, Educational Opportunities: Bloomington. p. 323-345.**
38. **Flannigan, K.P., et al., *The role of education in the management of low back pain*, in *Managing low back pain*, W. Kirkaldy-Willis, Editor. 1999, Churchill Livingstone: Philadelphia. p. 284-298.**
39. **Cozen, D.M., *Use of pilates in foot and ankle rehabilitation.* Sports Medicine and Arthroscopy Review, 2000. 8(4): p. 395-403.**
40. **Anderson, B.D. and A. Spector, *Introduction to Pilates-Based Rehabilitation.* Orthopaedic Physical Therapy Clinics of North America, 2000. September.**
41. **Kermode, F., *Benefits of utilising real-time ultrasound imaging in the rehabilitation of the lumbar spine stabilising muscles following low back injury in the elite athlete - a single case study.* Physical Therapy in Sport, 2004. 5(1): p. 13-16.**
42. **Self, B.P., et al., *Functional biomechanical analysis of the Pilates-based reformer during demi-plie movements.* Journal of Applied Biomechanics, 1996. 12(3): p. 326-337.**
43. **Hutchinson, M.R., et al., *Improving leaping ability in elite rhythmic gymnasts.* Medicine and Science in Sports and Exercise, 1998. 30(10): p. 1543-1547.**
44. **Blum, C.L., *Chiropractic and pilates therapy for the treatment of sdult scoliosis.* Journal of Manipulative and Physiological Therapeutics, 2002. 25(4): p. e3.**
45. **Anderson, B.D., *Pushing for Pilates.* The Interdisciplinary Journal of Rehabilitation, 2001. June/July.**
46. **Richardson, C.A. and G.A. Jull, *Muscle control - pain control. What exercises would you prescribe?* Manual Therapy, 1995. 1: p. 2-10.**
47. **Hides, J.A., C.A. Richardson, and G.A. Jull, *Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain.* Spine, 1996. 21(23): p. 2763-2769.**

48. **Cholewicki, J. and S.M. McGill, *Mechanical stability of the in vivo lumbar spine: Implications for injury and chronic low back pain.* Clinical Biomechanics, 1996. 11(1): p. 1-15.**
49. **Bogduk, N., *Clinical Anatomy of the Lumbar Spine and Sacrum*. 3rd ed. 1997, London: Churchill Livingstone.**
50. **Goel, V.K., et al., *A Combined Finite-Element and Optimization Investigation of Lumbar Spine Mechanics with and without Muscles.* Spine, 1993. 18(11): p. 1531-1541.**
51. **Wong, K.W.N., et al., *The flexion-extension profile of lumbar spine in 100 healthy volunteers.* Spine, 2004. 29(15): p. 1636-1641.**
52. **Kanayama, M., et al., *Phase lag of the intersegmental motion in flexion-extension of the lumbar and lumbosacral spine - An in vivo study.* Spine, 1996. 21(12): p. 1416-1422.**
53. **Richardson, C.A., et al., *The relation between the transversus abdominis muscles, sacroiliac joint mechanics, and low back pain.* Spine, 2002. 27(4): p. 399-405.**
54. **Hodges, P.W., *Is there a role for transversus abdominis in lumbo-pelvic stability?* Manual Therapy, 1999. 4(2): p. 74-86.**
55. **Hodges, P., et al., *Intervertebral stiffness of the spine is increased by evoked contraction of transversus abdominis and the diaphragm: In vivo porcine studies.* Spine, 2003. 28(23): p. 2594-2601.**
56. **Liemohn, W., *Anatomy and Biomechanics of the Trunk*, in *Exercise Prescription and the Back*, W. Liemohn, Editor. 2001, McGraw-Hill: New York. p. 3-35.**
57. **Porterfield, J.A. and C. DeRosa, *Mechanical Low Back Pain*. 1991, Philadelphia: W.B. Saunders Company.**
58. **Barker, K.L., D.R. Shamley, and D. Jackson, *Changes in the cross-sectional area of multifidus and psoas in patients with unilateral back pain - The relationship to pain and disability.* Spine, 2004. 29(22): p. E515-E519.**
59. **Panjabi, M., et al., *Spinal Stability and Intersegmental Muscle Forces - a Biomechanical Model.* Spine, 1989. 14(2): p. 194-200.**
60. **Panjabi, M.M., *The Stabilizing System of the Spine .2. Neutral Zone and Instability Hypothesis.* Journal of Spinal Disorders, 1992. 5(4): p. 390-397.**
61. **Panjabi, M.M., et al., *Graded thoracolumbar spinal injuries: development of multidirectional instability.* European Spine Journal, 1998. 7(4): p. 332-339.**
62. **Mimura, M., et al., *Disc Degeneration Affects the Multidirectional Flexibility of the Lumbar Spine.* Spine, 1994. 19(12): p. 1371-1380.**
63. **Jemmett, R.S., D.A. MacDonald, and A.M.R. Agur, *Anatomical relationships between selected segmental muscles of the lumbar spine in the context of multi-planar segmental motion: a preliminary investigation.* Manual Therapy, 2004. 9(4): p. 203-210.**
64. **Kirkaldy-Willis, S.H. and H.F. Farfan, *Instability of the lumbar spine.* Clinical Orthopedics, 1982. 165: p. 110-23.**

65. **Iatridis, J.C., J.J. MacLean, and D.A. Ryan, *Mechanical damage to the initervertebral disc annulus fibrosus subjected to tensile loading.* Journal of Biomechanics, 2005. 38(3): p. 557-565.**
66. **Panjabi, M.M., *Clinical spinal instability and low back pain.* Journal of Electromyography and Kinesiology, 2003. 13(4): p. 371-379.**
67. **Panjabi, M.M., *The Stabilizing System of the Spine .1. Function, Dysfunction, Adaptation, and Enhancement.* Journal of Spinal Disorders, 1992. 5(4): p. 383-389.**
68. **Twomey, L., J. Taylor, and B. Furniss, *Age-Changes in the Bone-Density and Structure of the Lumbar Vertebral Column.* Journal of Anatomy, 1983. 136(JAN): p. 15-25.**
69. **Gardner-Morse, M.G. and I.A.F. Stokes, *The effects of abdominal muscle coactivation on lumbar spine stability.* Spine, 1998. 23(1): p. 86-91.**
70. **Bergmark, A., *Stability of the Lumbar Spine - a Study in Mechanical Engineering.* Acta Orthopaedica Scandinavica, 1989. 60: p. 3-54.**
71. **Crisco, J.J. and M.M. Panjabi, *The Intersegmental and Multisegmental Muscles of the Lumbar Spine - a Biomechanical Model Comparing Lateral Stabilizing Potential.* Spine, 1991. 16(7): p. 793-799.**
72. **Nitz, A.J. and D. Peck, *Comparison of Muscle-Spindle Concentrations in Large and Small Human Epaxial Muscles Acting in Parallel Combinations.* American Surgeon, 1986. 52(5): p. 273-277.**
73. **Brumagne, S., et al., *The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain.* Spine, 2000. 25(8): p. 989-994.**
74. **Jull, G.A. and C.A. Richardson, *Motor control problems in patients with spinal pain: A new direction for therapeutic exercise.* Journal of Manipulative and Physiological Therapeutics, 2000. 23(2): p. 115-117.**
75. **Hodges, P.W. and C.A. Richardson, *Inefficient muscular stabilization of the lumbar spine associated with low back pain - A motor control evaluation of transversus abdominis.* Spine, 1996. 21(22): p. 2640-2650.**
76. **Hungerford, B., W. Gilleard, and P. Hodges, *Evidence of altered lumbopelvic muscle recruitment in the presence of sacroiliac joint pain.* Spine, 2003. 28(14): p. 1593-1600.**
77. **Hodges, P.W. and C.A. Richardson, *Delayed postural contraction of transversus abdominis in low back pain associated with movement of the lower limb.* Journal of Spinal Disorders, 1998. 11(1): p. 46-56.**
78. **Hodges, P.W. and C.A. Richardson, *Altered trunk muscle recruitment in people with low back pain with upper limb movement at different speeds.* Archives of Physical Medicine and Rehabilitation, 1999. 80(9): p. 1005-1012.**
79. **Hodges, P.W., et al., *Experimental muscle pain changes feedforward postural responses of the trunk muscles.* Experimental Brain Research, 2003. 151(2): p. 262-271.**
80. **O'Sullivan, P.B., et al., *Lumbar repositioning deficit in a specific low back pain population.* Spine, 2003. 28(10): p. 1074-1079.**

81. **Kavcic, N., S. Grenier, and S.M. McGill, *Quantifying tissue loads and spine stability while performing commonly prescribed low back stabilization exercises.* Spine, 2004. 29(20): p. 2319-2329.**

82. **Cholewicki, J., M.M. Panjabi, and A. Khachatryan, *Stabilizing function of trunk flexor-extensor muscles around a neutral spine posture.* Spine, 1997. 22(19): p. 2207-2212.**

83. **Cholewicki, J. and J.J. VanVliet, *Relative contribution of trunk muscles to the stability of the lumbar spine during isometric exertions.* Clinical Biomechanics, 2002. 17(2): p. 99-105.**

84. **Cowan, S.M., et al., *Delayed onset of transversus abdominus in long-standing groin pain.* Medicine and Science in Sports and Exercise, 2004. 36(12): p. 2040-2045.**

85. **Ferreira, P.H., M.L. Ferreira, and P.W. Hodges, *Changes in recruitment of the abdominal muscles in people with low back pain - Ultrasound measurement of muscle activity.* Spine, 2004. 29(22): p. 2560-2566.**

86. **Hodges, P.W. and C.A. Richardson, *Contraction of the abdominal muscles associated with movement of the lower limb.* Physical Therapy, 1997. 77(2): p. 132-142.**

87. **Kavcic, N., S. Grenier, and S.M. McGill, *Determining the stabilizing role of individual torso muscles during rehabilitation exercises.* Spine, 2004. 29(11): p. 1254-1265.**

88. **O'Sullivan, P.B., L. Twomey, and G.T. Allison, *Altered abdominal muscle recruitment in patients with chronic back pain following a specific exercise intervention.* Journal of Orthopaedic & Sports Physical Therapy, 1998. 27(2): p. 114-124.**

89. **O'Sullivan, P.B., L. Twomey, and G.T. Allison, *Altered patterns of abdominal muscle activations in chronic back pain patients.* Austrailian Journal of Physiotherapy, 1997. 43: p. 91-98.**

90. **Drysdale, C.L., J.E. Earl, and J. Hertel, *Surface electromyographic activity of the abdominal muscles during pelvic-tilt and abdominal-hollowing exercises.* Journal of Athletic Training, 2004. 39(1): p. 32-36.**

91. **Fryer, G., T. Morris, and P. Gibbons, *Paraspinal muscles and intervertebral dysfunction: Part two.* Journal of Manipulative and Physiological Therapeutics, 2004. 27(5): p. 348-357.**

92. **Arokoski, J.P.A., et al., *Back and hip extensor muscle function during therapeutic exercises.* Archives of Physical Medicine and Rehabilitation, 1999. 80(7): p. 842-850.**

93. **Arokoski, J.P., et al., *Activation of lumbar paraspinal and abdominal muscles during therapeutic exercises in chronic low back pain patients.* Archives of Physical Medicine and Rehabilitation, 2004. 85(5): p. 823-832.**

94. **Granata, K.P. and W.S. Marras, *Cost-benefit of muscle cocontraction in protecting against spinal instability.* Spine, 2000. 25(11): p. 1398-1404.**

95. **O'Sullivan, P.B., *Lumbar segmental 'instability': clinical presentation and specific stabilizing exercise management.* Manual Therapy, 2000. 5(1): p. 2-12.**

96. **Institute, S.F.S., *Dynamic Lumbar Stabilization Program*. 1989, San Francisco: San Francisco Spine Institute.**
97. **Arokoski, J.P., et al., *Back and abdominal muscle function during stabilization exercises.* Archives of Physical Medicine and Rehabilitation, 2001. 82(8): p. 1089-1098.**
98. **McDonald, J.C. and K.L. Lundgren, *The progressive dynamic lumbar stabilization program for the treatment of musculoskeletal dysfunctions that contribute to mechanical low back pain.* Journal of Sports Chiropractic & Rehabilitation, 1998. 12(2): p. 55-64.**
99. **Stanton, R., P.R. Reaburn, and B. Humphries, *The effect of short-term Swiss ball training on core stability and running economy.* Journal of Strength and Conditioning Research, 2004. 18(3): p. 522-528.**
100. **Carman, J., *Pilates trademark ruled unenforceable (Landmark decision a great victory for the public, pilates teachers and studios are free to say what they do).* Dance Magazine, 2001. 75(1): p. 28-29.**
101. **Sapsford, R.R., et al., *Co-activation of the abdominal and pelvic floor muscles during voluntary exercises.* Neurourology and Urodynamics, 2001. 20(1): p. 31-42.**
102. **Merrithew, M., *Comprehensive Matwork*. 2003, Toronto: Merrithew Corp.**
103. **Galeota-Wozny, N., *Pilates: Ripe for reforming? (The workout of choice for dancers).* Dance Magazine, 2004. 78(6): p. 29-29.**
104. **Dacko, K., *Stretching to new heights - Marjorie Thompson brings Pilates, and more, to Pittsburgh-Ballet-Theatre-School.* Dance Magazine, 2002. 76(3): p. 68-69.**
105. **Segal, N.A., J. Hein, and J.R. Basford, *The effects of pilates training on flexibility and body composition: An observational study.* Archives of Physical Medicine and Rehabilitation, 2004. 85(12): p. 1977-1981.**
106. **Smith, K. and E. Smith, *Integrating pilates-based core strengthening into older adult fitness programs implications for practice.* Topics in Geriatric Rehabilitation, 2005. 21(1): p. 57-67.**
107. **Broadhurst, N.A., N. Simmons, and M.J. Bond, *Piriformis syndrome: Correlation of muscle morphology with symptoms and signs.* Archives of Physical Medicine and Rehabilitation, 2004. 85(12): p. 2036-2039.**
108. **Kovacs, F.M., et al., *Correlation between pain, disability, and quality of life in patients with common low back pain.* Spine, 2004. 29(2): p. 206-210.**
109. **Gluck, N.I., *Passive care and active rehabilitation in a patient with failed back surgery syndrome.* Journal of Manipulative and Physiological Therapeutics, 1996. 19(1): p. 41-47.**
110. **Ehrlich, G.E., *Low back pain.* Bulletin of the World Health Organization, 2003. 81(9): p. 671-676.**
111. **Ogon, M., et al., *Chronic low back pain measurement with visual analogue scales in different settings.* Pain, 1996. 64(3): p. 425-428.**

112. Bombardier, C., *Outcome assessments in the evaluation of treatment of spinal disorders - Summary and general recommendations.* Spine, 2000. 25(24): p. 3100-3103.
113. Kuukkanen, T.M. and E.A. Malkia, *An experimental controlled study on postural sway and therapeutic exercise in subjects with low back pain.* Clinical Rehabilitation, 2000. 14(2): p. 192-202.
114. Roland, M. and J. Fairbank, *The Roland-Morris Disability Questionnaire and the Oswestry Disability Questionnaire.* Spine, 2000. 25(24): p. 3115-3124.
115. Fritz, J.M. and J.J. Irrgang, *A comparison of a modified Oswestry Low Back Pain Disability Questionnaire and the Quebec Back Pain Disability Scale.* Physical Therapy, 2001. 81(2): p. 776-788.
116. Fairbank, J.C.T. and P.B. Pynsent, *The Oswestry Disability Index.* Spine, 2000. 25(22): p. 2940-2952.
117. Association, A.M., *AMA Guidelines to the Evaluation of Permanent Impairment*. 2001.
118. Saur, P.M.M., et al., *Lumbar range of motion: Reliability and validity of the inclinometer technique in the clinical measurement of trunk flexibility.* Spine, 1996. 21(11): p. 1332-1338.
119. Graves, J.E., M.L. Pollock, and C.X. Bryant, *Assessment of muscular strength and endurance.*, in *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription.*, J.L. Roitman, Editor. 2001, Lippincott Williams & WIlkins: Baltimore. p. 448-455.
120. Ito, T., et al., *Lumbar trunk muscle endurance testing: An inexpensive alternative to a machine for evaluation.* Archives of Physical Medicine and Rehabilitation, 1996. 77(1): p. 75-79.
121. Leetun, D.T., et al., *Core stability measures as risk factors for lower extremity injury in athletes.* Medicine and Science in Sports and Exercise, 2004. 36(6): p. 926-934.
122. Cosio-Lima, L.M., et al., *Effects of physioball and conventional floor exercises on early phase adaptations in back and abdominal core stability and balance in women.* Journal of Strength and Conditioning Research, 2003. 17(4): p. 721-725.
123. Liemohn, W.P., T.A. Baumgartner, and L.H. Gagnon, *Measuring Core Stability.* Journal of Strength and Conditioning Research, 2005. 19(2) (in press).
124. Liemohn, W.P., T.A. Baumgartner, and K.A. Kelly, *Core Stability: The genesis of a test battery.* Medicine and Science in Sports and Exercise, 2003. 5 Supplement: p. S275.
125. Liemohn, W.P., et al., *Measuring core strength and stability: A pilot study.* Medicine and Science in Sports and Exercise, 2002. 5 Supplement: p. 153.
126. Baumgartner, T.A., et al., *Measurement for Evaluation in Physical Education and Exercise Science.* 7th edition ed. 2003, Madison, WI: McGraw-Hill.

127. Byl, N.N. and P.L. Sinnott, *Variations in Balance and Body Sway in Middle-Aged Adults - Subjects with Healthy Backs Compared with Subjects with Low-Back Dysfunction.* Spine, 1991. 16(3): p. 325-330.

128. Parkhurst, T.M. and C.N. Burnett, *Injury and Proprioception in the Lower Back.* Journal of Orthopaedic & Sports Physical Therapy, 1994. 19(5): p. 282-295.

Appendices

Appendix A

Rehab Reformer

(from Stott Pilates @www.stottpiulates.com)



Cadillac

(from Stott Pilates @www.stottpiulates.com)



Ladder and Arc Barrel

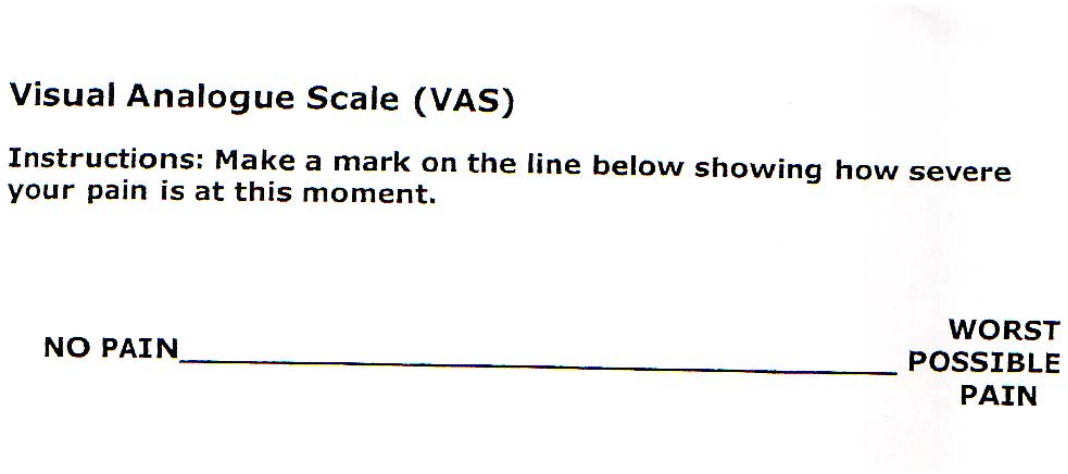
(from Stott Pilates @www.stottpiulates.com)





Appendix B

Visual Analog Scale



Appendix C

Revised Oswestry Disability Index

Please Read: This questionnaire is designed to enable us to understand how much your low back has affected your ability to manage everyday activities. Please answer each Section by circling the **ONE CHOICE** that most applies to you. We realize that you may feel that more than one statement may relate to you, but Please **just circle the one choice which closely describes your problem *right now*.**

SECTION 1–Pain Intensity
A. The pain comes and goes and is very mild.
B. The pain is mild and does not vary much.
C. The pain comes and goes and is moderate.
D. The pain is moderate and does not vary much.
E. The pain is severe but comes and goes.
F. The pain is severe and does not vary much.

SECTION 2–Personal Care
A. I would not have to change my way of washing or dressing in order to avoid pain.
B. I do not normally change my way of washing or dressing even though it causes some pain.
C. Washing and dressing increase the pain, but I manage not to change my way of doing it.
D. Washing and dressing increase the pain and I it necessary to change my way of doing it.
E. Because of the pain, I am unable to do any washing and dressing without help.
F. Because of the pain, I am unable to do any washing or dressing without help.

SECTION 3–Lifting
A. I can lift heavy weights without extra pain.
B. I can lift heavy weights, but it causes extra pain.
C. Pain prevents me from lifting heavy weights off the floor.
D. Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently positioned, e.g. on the table.
E. Pain prevents me from lifting heavy weights , but I can manage light to medium weights if they are conveniently positioned.
F. I can only lift very light weights, at the most.

SECTION 4 –Walking
A. Pain does not prevent me from walking any distance.
B. Pain prevents me from walking more than one mile.
C. Pain prevents me from walking more than one mile.
D. Pain prevents me from walking more than 1/2 mile.
E. I can only walk while using a cane or on crutches.
F. I am in bed most of the time and have to crawl to the toilet.

SECTION 5–Sitting
A. I can sit in any chair as long as I like without pain.
B. I can only sit in my favorite chair as long as I like.
C. Pain prevents me from sitting more than one hour.
D. Pain prevents me from sitting more than 1/2 hour.
E. Pain prevents me from sitting more than ten minutes.
F. Pain prevents me from sitting at all.

SECTION 6–Standing
A. I can stand as long as I want without pain
B. I have some pain while standing, but it does not increase with time.
C. I cannot stand for longer than one hour without increasing pain.
D. I cannot stand for longer than ½hour without increasing pain.
E. I can't stand for more than 10 minutes without increasing pain.
F. I avoid standing because it increases pain right away.

SECTION 7–Sleeping
A. I get no pain in bed.
B. I get pain in bed, but it does not prevent me from sleeping.
C. Because of pain , my normal night's sleep is reduced by less than one-quarter.
D. Because of pain, my normal night's sleep is reduced by less than one-half.
E. Because of pain, my normal night's sleep is reduced by less than three-quarters.
F. Pain prevents me from sleeping at all.

SECTION 8–Social Life
A. My social life is normal and gives me no pain.
B. My social life is normal, but increases the degree of my pain.
C. Pain has no significant effect on my social life apart from limiting my more energetic interests, e.g., dancing, etc.
D. Pain has restricted my social life and I do not go out very often.
E. Pain has restricted my social life to my home.
F. Pain prevents me from sleeping at all.

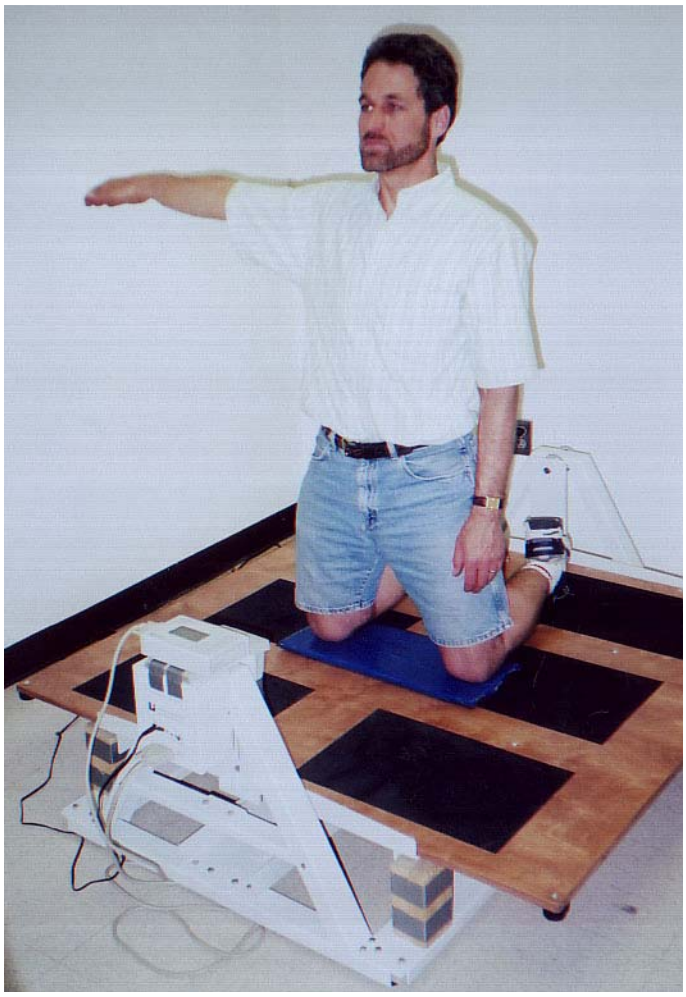
SECTION 9–Traveling
A. I get no pain while traveling.
B. I get some pain while traveling, but none of my usual forms of travel make it any worse.
C. I get extra pain while traveling, but it does not compel me to seek alternative forms of travel.
D. I get extra pain while traveling which compels me to seek alternative forms of travel.
E. Pain restricts all forms off travel.
F. Pain prevents all forms of travel except that done lying down.

SECTION 10–Changing Degree of Pain
A. My pain is rapidly getting better.
B. My pain fluctuates, but overall is definitely getting better.
C. My pain seems to be getting better, but improvement is slow at present.
D. My pain is neither getting better nor worse.
E. My pain is gradually worsening.
F. My pain is rapidly worsening.

DISABILITY INDEX SCORE: ____%

Appendix D

Stability Platform



Appendix E

Informed Consent Form

INFORMED CONSENT FORM

Effectiveness of Pilates Exercises as Therapeutic Intervention In Treating Patients with Low Back Pain

You are invited to participate in a research study. The purpose if this study is to assess the effectiveness of Pilates mat work exercises as the therapeutic exercise intervention in the clinical treatment of patients with LBP (low back pain). The goals include objectively demonstrating the treatment effects of Pilates exercises in terms of: 1) pain, 2) function in activities of daily living, 3) strength and endurance of back and abdominal musculature, 4) lumbar spine range of motion, and 5) the possible associations with noted clinical tests used by physical therapists for evaluation of sacroiliac joint dysfunction.

INFORMATION

1) You will receive your prescribed physical therapy (PT) including evaluation and treatments (number and type) deemed necessary by your physician and physical therapist. Some participants will receive traditional exercise (group A) in the course of treatment, while others will participate in Pilates mat exercises (group B). You will attend your regular PTsessions including the traditional therapeutic exercise if in group A. You will attend your regular PTsessions and Pilates exercise sessions at your convenience if in group B. The Pilates sessions will be roughly 30 –45 minutes in length and replace the traditional exercise typically in PT treatments. Whether in group A or B, you will attend at total of 16 sessions of exercise throughout the course of your treatment. No extra charges will be incurred by you if your formal therapy sessions are completed and you are completing the 16 exercise sessions only.
2) You will be asked to perform a home exercise program, which is prescribed in the usual course of physical therapy. You will be provided with a compliance journal to help facilitate documentation and adherence to home exercise.
3) The testing procedures will include filling out survey forms, pain scales, having range of motion and lumbar spine evaluation tests performed, which are usual in the normal course of physical therapy. You will be asked to balance in positions similar to those in therapeutic exercise on a platform to test your trunk muscle strength. The platform or Stabilometer^{R} is roughly a 3 foot X 4 foot platform 4 inches from the ground, that rocks side to side. You will have sticky electrodes like those used in usual physical therapy treatments attached to some back and abdominal muscles to read your muscle activity. Testing sessions will be before treatment, and at 4,8,12, and 16 sessions. Testing on the Stabilometer^{R} may need to take place in Gym 136, HPER Bldg., at the University of Tennessee.
4) Approximately 40 persons (males and females) will be participating in this research.

RISKS

Participants will be not be exposed to any risks other than that of normal physical therapy treatment in the course of receiving Pilates exercises. These may include sore and achy muscles. Minimal risks are present with the testing procedures which may include a slight sense of loss of balance on the Stabilometer^{R}. If a participant becomes concerned with the sense of loss of balance, they may choose to end the testing.

BENEFITS

One main benefit from this study is the documentation of the effectiveness of Pilates mat exercises in treating LBP. The incidental benefits to the participants will likely be those gained in traditional physical therapy treatments: decrease pain, and increase strength, motion and function.

CONFIDENTIALITY

The information in the study records will be kept confidential. Data will be stored securely and will be made available only to persons conducting the study unless you specifically give permission in writing to do otherwise. No reference will be made in oral or written reports which could link you to the study.

CONTACT

If you have questions at any time about the study or the procedures, (or you experience adverse effects as a result of participating in this study,) you may contact the researcher, Laura Horvath Gagnon, at TN Sports Medicine Group 1120 Weisgarber Rd., Suite 101 Knoxville, Tennessee 37909, or at (865) 584-1054. If you have questions about your rights as a participant, contact the Research Compliance Services section of the Office of Research at (865) 974-3466.

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at anytime without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed.

CONSENT

I have read the above information and agree to participate in this study. I have received a copy of this form.

Participant's name (print) _____

Participant's signature _____ Date _____

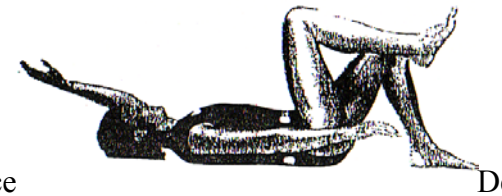
Appendix F

Traditional lumbar stabilization exercises

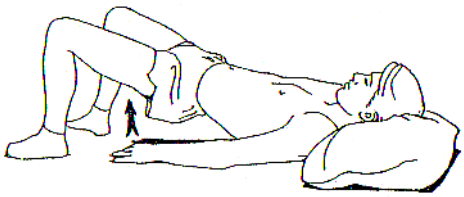
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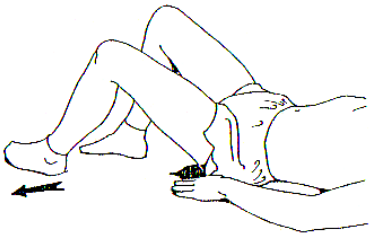
Brace



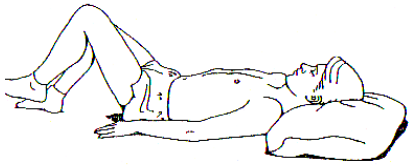
Dead Bug



Bridge



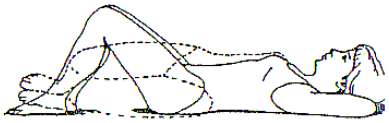
Heel slide



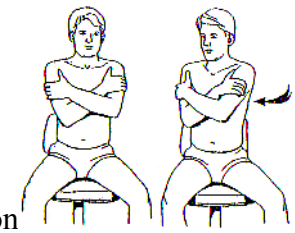
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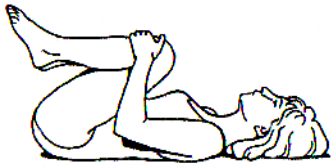
Press up



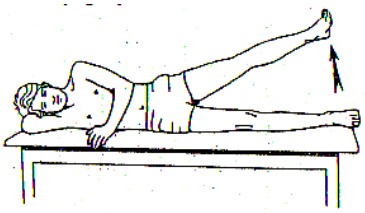
Trunk rotation



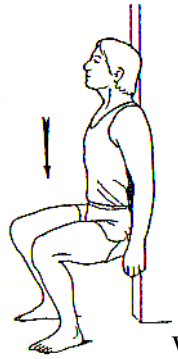
Seated rotation



Double knees to chest



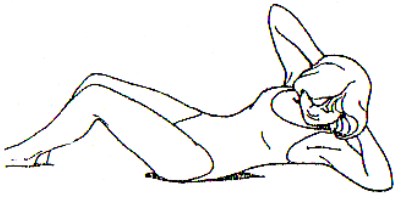
Abduction



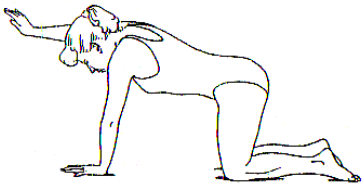
Wall slide



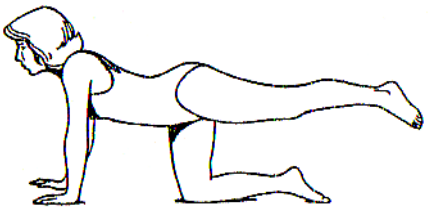
Curl



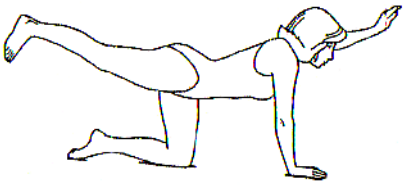
Diagonal



Quad arm



Quad leg

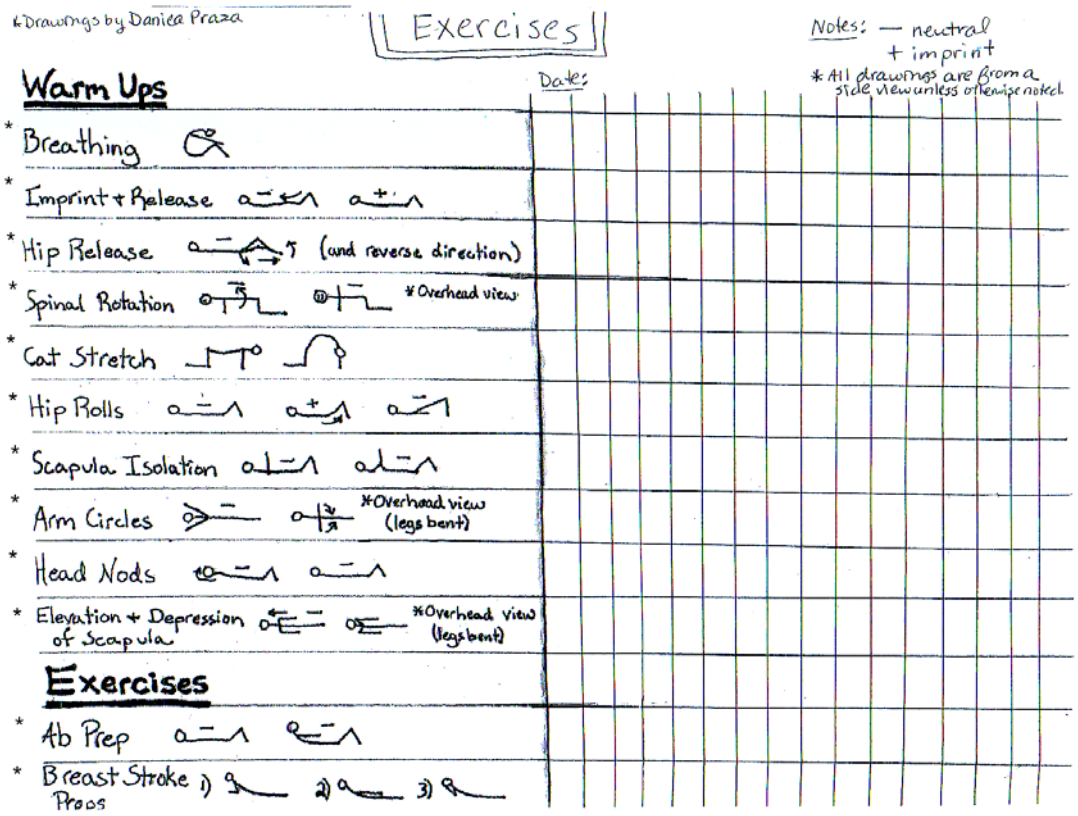


Quad arms and legs

Appendix G

Pilates Exercises

Pilates exercise sheets provided to patients: exercises that most patients were able to progress to performing are marked with an asterisk. Used with permission of Danica Praza, artist.

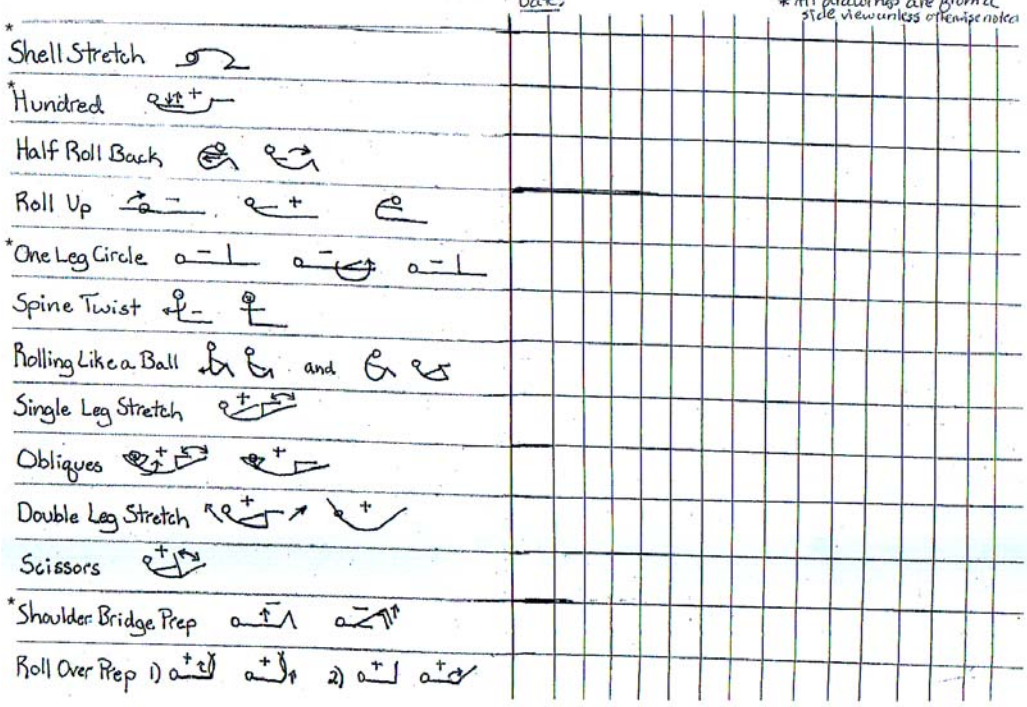


Drawings by Danica Praza

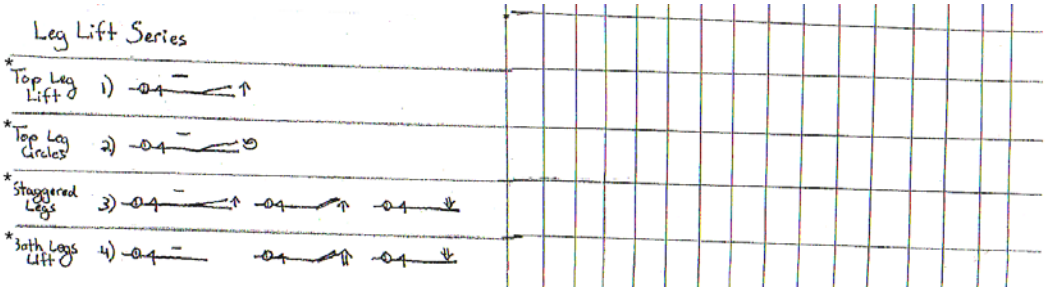
Exercises

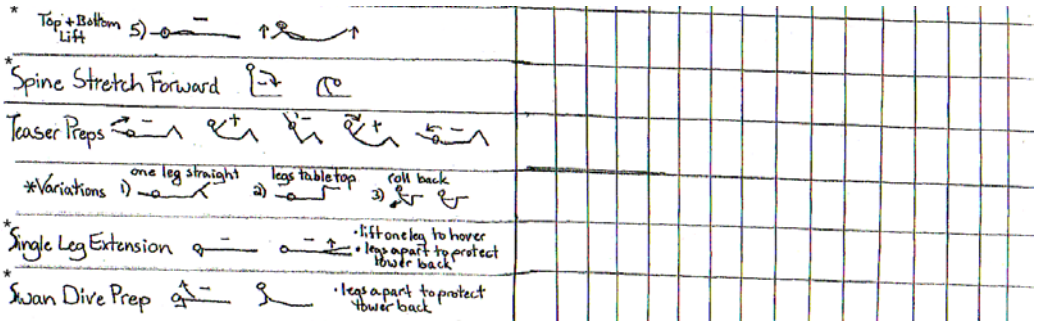
Notes: — neutral
+ imprint
* All drawings are from a side view unless otherwise noted

Date:



Leg Lift Series

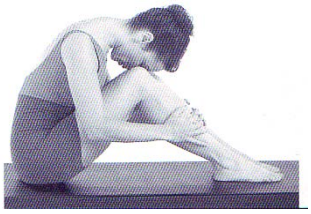




Pilates exercises as shown in Stott ™ Pilates matwork manual

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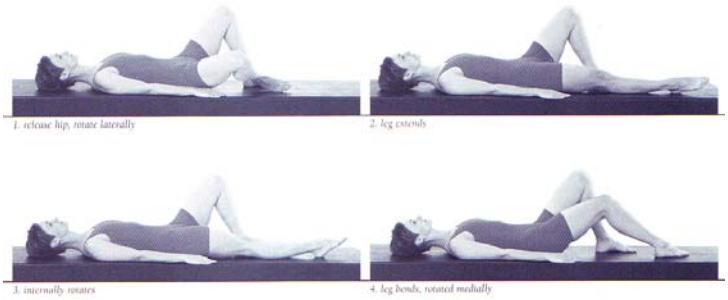
Warmup:



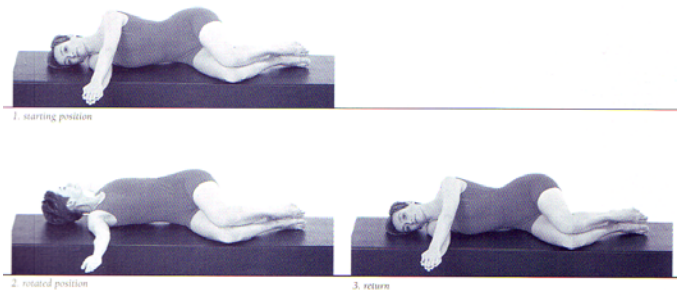
Breathing



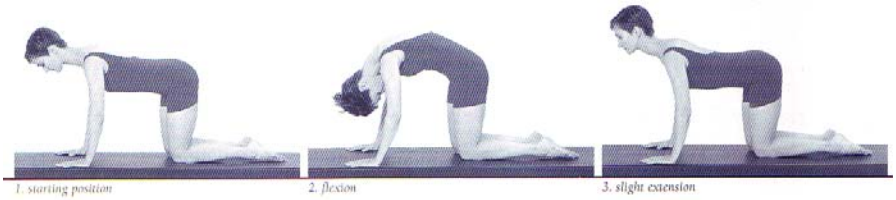
Imprint and release



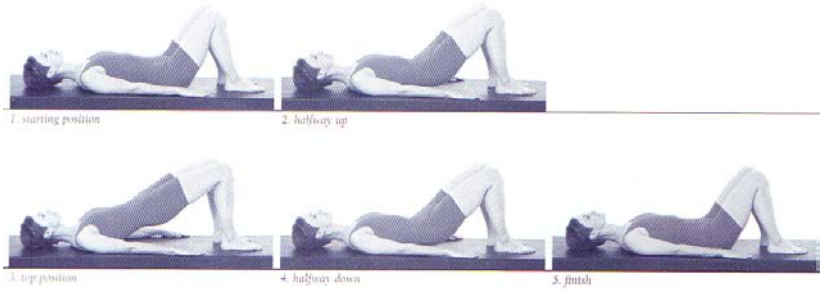
Hip release



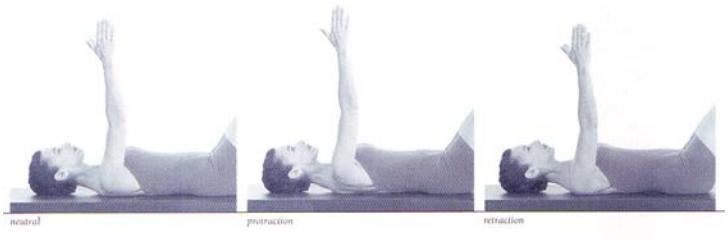
Spinal rotation



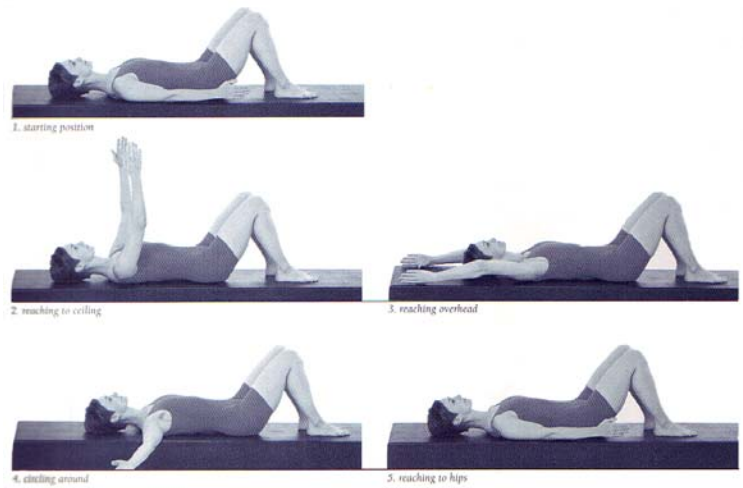
Cat stretch



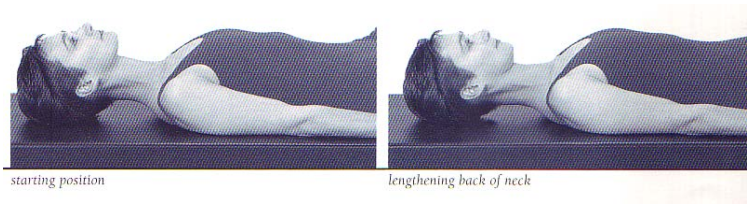
Hip rolls



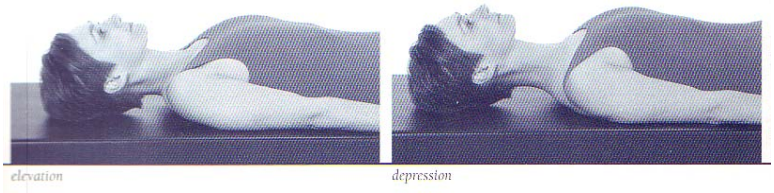
Scapular Isolation



Arm circles

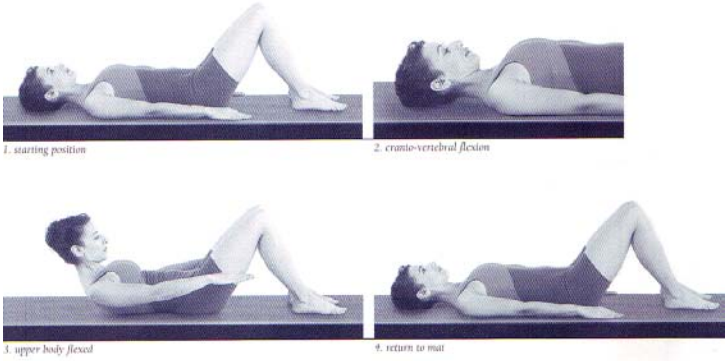


Head nods



Elevation and depression of scapula

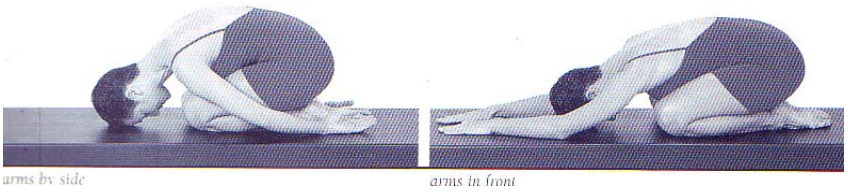
Exercises:



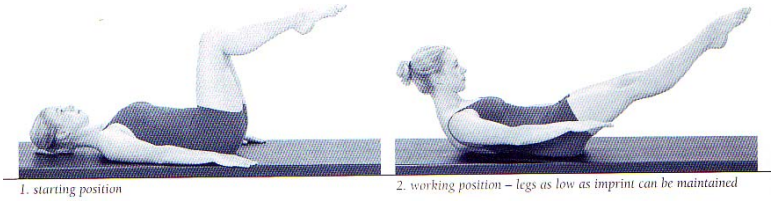
Ab prep

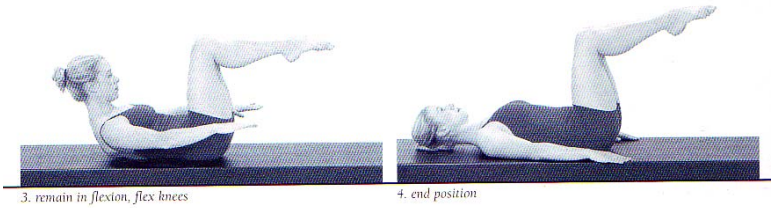


Breast stroke prep

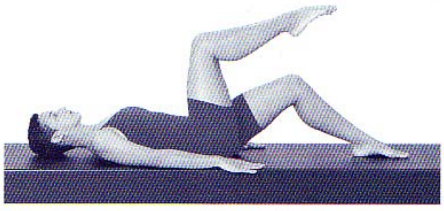


Shell





Hundred



Leg circle



Shoulder bridge prep

Exercise 1



1. starting position



2. top leg abducted



3. dorsiflex to lower leg



4. end position

Exercise 2



1. starting position



2. top leg abducted



3. end position

Leg lifts and leg circles

Exercise 3



1. starting position



2. top leg abducted

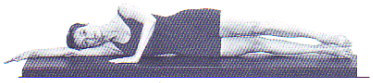


3. bottom leg meets top leg

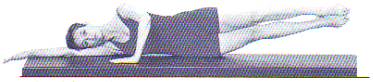


4. lower legs

Exercise 4



1. starting position



2. legs lift together

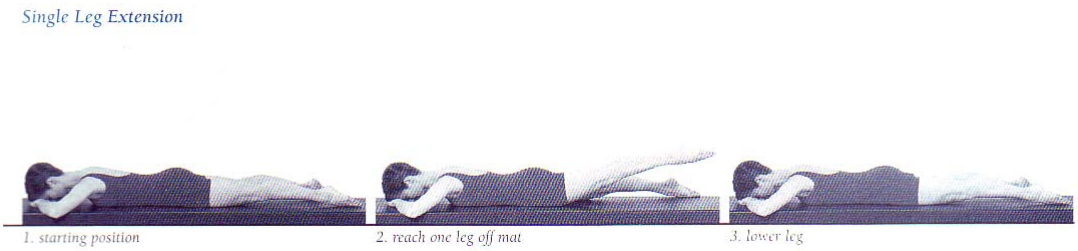


3. lower legs

Staggered and both legs together



Spine stretch forward



Leg extension

Vita

Laura Kathryn Horvath Gagnon was born in Memphis, TN on October 11, 1963. She was raised as one of five children in the suburbs of Atlanta, Ga. She attended Florida State University, receiving a Bachelor of Fine Arts degree in Dance in 1984, subsequently moving to New York City to pursue a career in dance. She was a member of the Martha Graham Dance Company, touring internationally and teaching as part of the Martha Graham School of Contemporary Dance faculty from 1989-1994. She also taught Graham technique at American Ballet Theatre's School. She attended Columbia University's College of Physicians and Surgeons receiving a Masters degree in Physical Therapy in 1995. As part of her Master's research, she developed and patented a device for measuring pelvic obliquity. Laura left NYC and practiced orthopedic physical therapy from 1995 to 1999 until she met her husband, Dan, while treating his mother. She subsequently moved to Maryville, TN to marry him and become a step-mom to Caitie and Amanda. In this transition she transferred pursuing her doctoral studies in biomechanics from Georgia State University to the University of Tennessee. Laura has received the following awards: Outstanding Freshman dancer at FSU, Excellence in Physical Therapy (student award for top academic, clinical and research work) at Columbia University, and a Citation for Extraordinary Professional Promise at the University of Tennessee. Laura currently teaches dance, choreographs and sets Martha Graham works for the University of Tennessee's dance program, practices orthopedic physical therapy at TNSMG, is certified by and teaches Stott™ Pilates classes, and enjoys her five cats and two dogs!