Science, Theory and Clinical Application in Orthopaedic Manual Physical Therapy

Vol 3: Scientific Therapeutic Exercise Progressions (STEP): The Back and Lower Extremity

This long awaited textbook, and its companion texts, from The Ola Grimsby Institute provide decades of clinical experience and reasoning, with both historical and current evidence, with rationale for active treatments in orthopaedic manual therapy. Practical guidelines for exercise rehabilitation are presented with this logical and exciting work. Incorporating experience and science, this book provides new approaches and treatment principles to make what you already do more effective.

Look for the outstanding features:

Actual Exercise Pictures and Descriptions: Not just extensive theory, but hundreds of exercise pictures with descriptions and instruction on application and modification for both the novice and master clinician

Functional Integration: Exercise concepts outline training the low back, pelvis and lower quarter as a functional unit, not separate joint systems

Evidence: Extensively referenced in scientific and clinic research related to exercise rehabilitation

Exercise Design: Application of biomechanics, work physiology and different resistance sources for custom exercise design for the low back, pelvis and lower quarter

Exercise Dosage: Detailed description of specific exercise dosage for training goals on the continuum from tissue repair and mobilization to endurance, strength and power

Exercise Progression: Concepts for how to initiate a rehabilitation programs, with logical progressions back to full functional mobility and stability

Extensive Content: Over 371 pages and 705 illustrations, photographs and tables

Ola Grimsby and his co-authors have compiled a significant resource for the practicing physical therapist and manual therapist. Ideal for both the classroom and clinic, Science, Theory and Clinical Application in Orthopaedic Manual Physical Therapy (Volume 3): Scientific Therapeutic Exercise Progressions (STEP): The Back and Lower Extremity provides the application of the scientific and clinical literature to assist the practicing clinician in exercise design, dosage and progression. It is an essential addition to the clinical library for anyone studying and practicing in the field of exercise rehabilitation.
Science, Theory and Clinical Application in Orthopaedic Manual Physical Therapy

Scientific Therapeutic Exercise Progressions (STEP): The Back and Lower Extremity
Notice
Evidence and knowledge in rehabilitation is an ever-changing field. Standards safety precautions must be followed for the application of passive manual therapy intervention, exercise, medication, supplements and diet. As new research and clinical experience broaden our knowledge changes in treatment, drug therapy and diet supplementation may become necessary or appropriate. Readers are advised to check the most current product information provided (i) on procedures featured or (ii) by the manufacturer of each drug or diet supplement to be administered to verify the recommended dose or formula, the method and duration of administration and contraindications. It is the responsibility of the licensed practitioner, relying on clinical experience and knowledge of the patient, to determine dosage and the best treatment for each individual patient, and to take appropriate safety precautions. To the fullest extent of the law, neither the Publishers nor the Authors assume any liability for any injury and/or damage to persons or property arising from any use of the material in this publication.

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Scientific Therapeutic Exercise Progressions (STEP): The Back and Lower Extremity

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Resources

The Ola Grimsby Institute
Orthopaedic Manual Therapy (OMT) courses for evaluation, treatment, exercise and residency training.
www.olagrimsby.com

Nutrition and Health
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www.tissuerecovery.com

Exercise Equipment
www.lojer.com
www.rehabpropulleys.com
www.cardonrehab.com

Home Exercise Pulley Equipment
www.qtekproducts.com

Exercise Software
www.vhikits.com

Look for these companion texts:

Science, Theory and Clinical Application in Orthopaedic Manual Physical Therapy
Volume 1: Applied Science and Theory

Science, Theory and Clinical Application in Orthopaedic Manual Physical Therapy
Volume 2: Scientific Therapeutic Exercise Progressions (STEP): The Neck and Upper Extremity
Foreword

It has been my good fortune to have my physical therapy education complemented by an introduction to a broader paradigm of exercise rehabilitation. In the late 1980’s I attended a manual therapy course taught by Ola Grimsby. Presented with clinical application of scientific and clinical research, my rationale for all aspects of patient care changed significantly. Most traumatized was my belief system of how exercise was used in orthopedic rehabilitation and how it differed from research related to training healthy subjects. Ola Grimsby presented the fundamentals of Medical Exercise Therapy (MET) as taught in his home country of Norway. The MET curriculum originated in the 1960’s under the creative wings of Oddvar Holten. As a manual therapist, he combined his experiences as clinician, coach and athlete to bring training principles to patient care. MET laid out a foundation of exercise dosage and progression that began with tissue repair, joint mobilization, pain inhibition and resolution of edema. Specific training dosage was described for influencing motor function as it relates to coordination, timing, endurance, speed, volume strength and power. Being exposed to such a wide range of specific training parameters to influence such a larger list of potential training goals inspired me to better understand training principles as they relate to patient care.

My manual therapy education, under the guidance of Brad Jordan and Ola Grimsby, included training in exercise from several of the MET instructors from Norway. One of these MET instructors, Anders Myklebust, provided my first clinic training in MET through The Ola Grimsby Institute’s (OGI) residency program. Though he overwhelmed my capacity to absorb and digest information, I was nonetheless inspired to seek out more training in this exercise specialty. Another MET instructor, Ronnie Stensnes, not only progressed my exercise instruction through his involvement in residency teaching for the OGI, but was also kind enough to allow me to assist him with teaching weekend seminars in MET. His gentle approach with such a young mind help nurture me through the frustrating years of becoming clinically proficient. I continued to be a student of MET classes for many years. Finally having the opportunity to take a class directly from Oddvar Holten was not only an inspiration but a privilege. Rolf Leirvik must also be acknowledged as an instructor for this course, demonstrating applications of the MET principles for both the spine and extremities.

The OGI eventually began teaching exercise courses outside the MET banner. The courses were renamed Scientific, Therapeutic, Exercise Progressions, or STEP. Becoming an instructor for these courses, I apprenticed not only under Ola Grimsby, but also under Rick Hobusch, one of only a few US born MET certified instructors, and Torhild Kvarekval, a Norwegian born and trained manual therapist instructing for the OGI. This mentorship as a clinician and instructor was invaluable. As most educators understand, learning is just beginning when you start to teach. Continuing to instruct STEP courses with Ola Grimsby has taken me all over the United States and to 10 other countries. His grasp on the principles of STEP continue to broaden my understanding. Despite my best efforts as an instructor, each class seemed to end with a sense of learning more than I taught. Each student brings a clinical and life experience that, when applied to the principles of STEP, creates and ever growing set of exercises, modifications and applications. I am grateful to the countless residency and course participants that continue to teach and serve as my inspiration to remain a student for life. Leading the battle for the
removal of modalities for pain control as the primary form of orthopaedic physical therapy in the early 1970’s, Ola Grimsby has been a driving force in shaping the face of orthopedic manual therapy. He fought for the incorporation of histology and tissue repair with exercise in the late 1970’s, the inclusion neurophysiology for motor facilitation and pain inhibition in the early 1980’s, the use of diet and supplementation for tissue maintenance/repair in the late 1980’s and the push for residency training in manual therapy in the early 1990’s as one of the Founding Fellows of the American Academy of Orthopaedic Manual Physical Therapists. Attempting to capture Ola’s words in print, and to capture the clinical examples of STEP that have evolved with each course, has been the driving force behind the creation of Volumes 2 and 3 in this text series. The impact that the experiences of decades of clinical instructors, students and patients have been poured onto these pages is immeasurable.

Exercise rehabilitation remains one of the most difficult aspects of patient care for the orthopaedic manual physical therapist. The main thrust of these texts is to provide a scientific foundation for exercise design, dosage and progression. With this foundation exercises can be customized to each patient, to train a specific issue with an exact dosage. The exercises themselves are not as important as the concepts behind their design, dosage and progression. It is my hope that we have laid out a thought process, with specific dosage parameters, to arm the clinician with the ability to create, rather than to simply attempt to fit their patient into the design of a certain exercise, protocol or research article. These books should not only provide new and exciting exercise examples for the spine and extremities but also enhance the design and dosage of all exercises. New research continues to sharpen the focus of these concepts and we look forward to the continued evolution of this material.

— Jim Rivard
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Every book has two stories; one on the page and one unseen. As a work of non-fiction, the story in this book is easy to understand. However, the untold story involves students, teachers, clients, therapists and that relentless quest for knowledge that so invigorates the human mind. For many years, in classrooms and clinics and training sessions, those connected to the STEP curriculum have asked for such a book. Students from around the globe have sought such a publication. Their energy, desire, and emerging commitment to their work provided inspiration for all. Gratefully, we acknowledge the countless thousands of individuals that have in one way or another contributed to this publication. Those whose experience, knowledge, study, research and wisdom have enabled this book to evolve into a publication that has long-term value, inherent meaning and practical applications. Thanks to all who were involved with the books, course books and lectures from which this text is drawn. A token reference at the end of a sentence seems to fall short of acknowledging the time, dedication and inspiration of each author(s) of the hundreds of references cited in this text. Each articles represents the efforts of so many people, including subjects in the studies. Without the contributions of the Norwegian Medical Exercise Therapy (MET) group, in creating the foundation and sharing their knowledge and experience, this text would not have been possible. We also wish to thank the following for their insights and assistance with writing and editing this text: Torhild Kvaerekval, Ben Grotenhuis, Laura Markey, Brian Power, Robin Schoenfeld, Asha Hossain and Dana Grant. Also of note is the exercise models and patients that provided their time to be photographed for this text. Thanks to all those who gave of their time simply because they cared. Thanks to those who shared their ideas because they believed. Thanks to those who saw the promise of so many possibilities. And most of all, thanks to those who will make the ink on these pages come to life.
Preface

Volume 3 of this text series is just that, Volume 3. This textbook can stand-alone as a reference for evidence related to motor dysfunction and exercises to restore function. Hundreds of examples for each joint system—from the cervical spine, thoracic spine and TMJ, to the shoulder, elbow and wrist—are demonstrated. But a deeper meaning of the text is lost if the reader simply thumbs through the pages searching for an interesting looking exercise to apply to a patient. This textbook is a companion text for Volume 1 (Science, Theory and Clinical application in Orthopaedic Manual Physical Therapy: Applied Science and Theory), which covers the integration of research in basic sciences and work physiology. Prior to initiating exercise a basic understanding of how to incorporate the fundamentals of—histology, neurophysiology, work physiology, exercise dosage and exercise progression—is required. It is not the exercises themselves but the design, dosage and progression chosen that determines the outcome.

This text, in a general way, will discuss the concepts of exercise dosage and progression with application to specific joint systems. More in depth discussions are provided in Volume 1 on all aspects of exercise design. References for cellular and tissue responses to mechanical stimulus are given, providing more clarity to early stage exercises shown. Descriptions of exercise equipment and types of exercise assist in making choices for exercise design. Detailed chapters on dosing exercise to achieve specific outcomes are provided, arming the clinician with the knowledge to modify almost any exercise to achieve almost any result. Knowing where to start is one thing, but understanding when and how to progress is another. Also outlined in Volume 1 is a logical approach to progressing exercise from the earliest stages of tissue repair all the way to returning to normal function.

The reader is encouraged to keep Volume 1 handy to review detailed discussion on the fundamentals of exercise design, dosage and progression. The following pages provide a limited summary of this information to assist with the dosage and progression parameters discussed in each chapter of this textbook, but this information cannot replace the contents of Volume 1.
# STEP Principles: Summary of Resistance Training Recommendations

<table>
<thead>
<tr>
<th>Quality</th>
<th>Muscle Action</th>
<th>Selection</th>
<th>Sequence</th>
<th>Resistance</th>
<th>Volume</th>
<th>Rest Intervals</th>
<th>Velocity</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tissue Repair</strong></td>
<td>ECC &amp; CON</td>
<td>SJ</td>
<td>Away from pain, or not</td>
<td>From assisted, to 0% of 1RM, up to</td>
<td>1–5 set, 10–60</td>
<td>≥1 minute</td>
<td>S</td>
<td>1–5x daily</td>
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<tr>
<td><strong>Pain &amp; Edema Reduction</strong></td>
<td></td>
<td></td>
<td>into pain</td>
<td>50% of 1RM</td>
<td>reps</td>
<td>S/weekly</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tendinopathy</strong></td>
<td>ECC only</td>
<td>Tendon specific</td>
<td>Mid to shortened range</td>
<td>As heavy as is pain free progress to</td>
<td>1 set, 8–15 reps</td>
<td>None</td>
<td>S</td>
<td>1–2x daily</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mild soreness</td>
<td></td>
<td>S/weekly</td>
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<tr>
<td><strong>Mobilization</strong></td>
<td>ECC into restriction</td>
<td>SJ</td>
<td>Distraction then glides</td>
<td>Assisted to 50% of 1RM</td>
<td>1–5 set, 10-60 reps</td>
<td>None</td>
<td>S</td>
<td>1–3x daily</td>
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<td></td>
<td>3–5 reps if a stretch</td>
<td>50–70% of 1RM</td>
<td>S/weekly</td>
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<tr>
<td><strong>Coordination</strong></td>
<td>CON emphasis</td>
<td>SJ &amp; MJ ex</td>
<td>Balance/Vestibular Planar</td>
<td>Assisted or 0%–50% of 1RM</td>
<td>2–5 sets, 30–50 reps</td>
<td>1 min.</td>
<td>S/weekly</td>
<td>1–3x daily</td>
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<td></td>
<td>ECC</td>
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<td>Tri-planar/PNF</td>
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<td>S/weekly</td>
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<tr>
<td><strong>Vascularity</strong></td>
<td>CON emphasis</td>
<td>SJ &amp; MJ ex</td>
<td>Into guarded pattern first</td>
<td>Pathology: 55% to 65% of 1RM</td>
<td>1–3 sets, 25–30 reps</td>
<td>Acute: Until respiration returns to steady state</td>
<td>S</td>
<td>1x daily</td>
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<tr>
<td></td>
<td>ECC</td>
<td></td>
<td>then opposite</td>
<td>Normal: 50–70% of 1RM for 10–15 reps</td>
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<td>Subacute: &lt;30 sec.</td>
<td>S</td>
<td>6–7x/week</td>
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<td>(Kraemer)</td>
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<td>Respiratory rate</td>
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<td><strong>Endurance</strong></td>
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<td>1x daily</td>
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<tr>
<td><strong>Novice</strong></td>
<td>ECC &amp; CON</td>
<td>SJ &amp; MJ ex</td>
<td>A variety in sequencing is</td>
<td>50–70% of 1RM</td>
<td>1–3 sets, 24–30 reps</td>
<td>For all groups:</td>
<td>For all:</td>
<td></td>
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<td></td>
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<td></td>
<td>recommended</td>
<td>50–70% of 1RM</td>
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<td>1–2 min. for high rep sets</td>
<td>S–MR</td>
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<td></td>
<td>30–80% of 1RM—PER</td>
<td>Multiple sets, 24–30</td>
<td>&lt;1 min. for 10–15 reps</td>
<td>2–3x/week</td>
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<tr>
<td><strong>Intermediate</strong></td>
<td>ECC &amp; CON</td>
<td>SJ &amp; MJ ex</td>
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<td>For all:</td>
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<td>S–MR</td>
<td>±-6x/week</td>
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<td><strong>Advanced</strong></td>
<td>ECC &amp; CON</td>
<td>SJ &amp; MJ ex</td>
<td></td>
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<td>M–HR</td>
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<td></td>
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<td>SJ &amp; MJ</td>
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<td>2–4x/week</td>
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<td><strong>Hyptertrophy</strong></td>
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<td>SJ &amp; MJ ex</td>
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<td>4–6x/week</td>
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<td><strong>Novice</strong></td>
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<td>SJ &amp; MJ ex</td>
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<tr>
<td><strong>Advanced</strong></td>
<td>ECC only</td>
<td>SJ &amp; MJ ex</td>
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<td><strong>Strength</strong></td>
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<td>SJ &amp; MJ ex</td>
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<td><strong>Novice</strong></td>
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<td><strong>Power</strong></td>
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<td>SJ &amp; MJ ex</td>
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</table>
| **Correlation**             | Eccentric, CON, concentric, SO, isometric, SJ, single-joint; MJ, multiple-joint; ex., exercises; HI, high intensity; LI, low intensity; 1RM, 1-repetition maximum; PER, periodized; VH, very heavy; L–MH, light-to-moderately-heavy; S, slow; M, moderate; US, unintentionally slow; F, fast; MR, moderate repetitions; HR, high repetitions. Modified from: Kraemer et al. (2002), Kraemer and Newton (2000) and Deschenes and Kraemer (2002).
STEP Concepts: Stage 1

- 3–5 Exercises
- Many repetitions/Minimal resistance, primarily for coordination, but also for:
  - < 50% of 1RM (mobilization).
  - < 60% of 1RM (local endurance).
  - < 50% of 1RM (tissue repair, edema reduction and range of motion).
  - < 40% of 1RM if atrophy (hypertrophy)
- Low speed (for improved coordination):
  - Deformity of collagen with slow stretch.
  - Concentric facilitation improved.
- Range of training:
  - Hypomobile joint: train in the outer range of available normal physiological motion.
  - Hypermobile: train in the mid to inner range of available normal physiological motion.
- Selective tissue training (STT): provide the optimal stimulus for repair of bone, muscle, collagen, cartilage, disc, etc.
- Neurophysiological influences of training: pain inhibition and coordination.
- Normalization of breathing patterns and posture.

Options

- Joint in resting position, start contraction from length tension position.
- Pure Concentric work for improved vascularity:
  - Use a pulley with specific wheel to remove the eccentric phase.
  - Weight stack rests between repetitions.
  - Avoid isometric work.
- Joint locking may be required to avoid motion around a non-physiological axis.

STEP Concepts: Stage 2

- Increased repetitions with an increased number of exercises (5–10 exercises).
- Increase repetitions with additional sets (endurance).
- Increase speed/not weight (strength/endurance).
- Combined concentric and eccentric work for further tissue tension accommodation.
- Isometrics to fix strength in shortened position of muscles that work eccentrically into the pathological range of motion.
- Body/limb position changes from recumbent to more dependent.
- Integration of balance training and normalization of ocular reflexes.
- Planar motions with exercise to full range/partial range tri-planar (diagonal patterns).
- Remove locking or change to less aggressive type.
- Histological influence of increased lubrication with increased speed.

STEP Concepts: Stage 3

- Increase weight (60–80% of 1RM), decrease repetitions (strength).
- Change work order: eccentric to concentric work to stabilize into the newly gained range.
- Isometrics to fix strength in gained range closure to the pathological range.
- Tri-planar motions in available range (diagonal patterns).
- Progression toward more functional motions and exercise application.

STEP Concepts: Stage 4

- Tri-planar motion through full range of motion around the physiological axis (coordination, endurance, strength and hypertrophy).
- Endurance, hypertrophy, speed, strength and power (80–90% of 1RM).
- Functional exercises for retraining of activities of daily living, sport and job activities.
Exercise Rehabilitation of the Ankle and Foot

Introduction

The intent of this chapter is but to provide a logical treatment model for progression and dosage of exercise in the rehabilitation of common foot and ankle pathology. It is assumed the reader is familiar with anatomy, biomechanics and pathology associated with the lower limb. In a basic sense, the foot and ankle provide the stable contact points of the lower extremities to allow normal weight bearing and locomotion functions to occur. This stability is required not only to provide weight bearing support but also to provide leverage for propulsion; however, these are not the only functions of the foot and ankle. They also function to provide the lower extremity with shock absorption capability and an ability to adapt to different surfaces during gait. For these two latter functions, mobility is needed. For these purposes the foot and ankle need to be stable and mobile at the same time to allow for a normal gait pattern. The complexity of the foot and ankle is indicated by the number of bones and joints involved: 26 bones, two to five or even more sesamoid bones, seven principal joints and a number of lesser joints.

As with all joint systems, the source of pain can come from a multitude of tissues. Acute tissue injury in the ankle complex will alter the distal lower extremity’s ability to perform, affecting entire body function. Joint restriction will limit mobility and function. Hypermobile joint motion will allow excessive motion, further stressing tissue. Even with non-injured tissue and normal joint mobility, muscles need to coordinate and control motion to attenuate ground reaction forces transmitted into joint structures. Without proper motor control from the lumbar spine to the foot, motions at the foot and ankle can occur through too far a range and/or too fast. Biomechanical restriction for any reason in the chain of joints from the lumbar spine to the foot needs to be addressed.

Segmental dysfunction in the lower lumbar spine can lead to inhibition, or altered motor patterns, of muscles innervated at these levels. For example, gluteal weakness from a pain free lumbar segmental dysfunction at L4 can alter force attenuation at the hip.
Per Henrik Ling (1776–1839) recognized that exercise was necessary for all persons. He maintained that exercise programs should be devised based on individual needs and that physical educators must possess knowledge of the effects of exercise on the human body. He used science and physiology to better understand the importance of fitness.
Exercise Rehabilitation of the Knee

Introduction

The knee is one of the most researched joints in the human body. From anatomy and biomechanics to exercise design, studies have attempted to learn more about this complex region. Discussions have focused on open chain, closed chain, concentric, eccentric, isotonic and isokinetic exercise programs, as well as combinations of these. Emphasis on evidence-based practice can guide treatment, but should not be limited to these techniques alone, as they may not be adequate for a comprehensive rehabilitation program of the individual patient.

From a biomechanical perspective, the knee joint has the contrary requirements of providing stability in weight bearing and mobility for dynamic function. Stability derives from the powerful ligamentous system, the menisci, a complex capsular design and the supporting musculature. The neurological system, via mechanoreceptor afferent feedback in ligaments such as the anterior cruciate ligament (ACL) and joint capsule, also significantly contribute to the regulation of muscular stiffness and dynamic stability around the knee (Johansson et al. 1990). The knee requires proper biomechanical alignment and adequate mobility to allow for the necessary re-orientations of the foot in response to irregularities of the ground during walking and running. The myokinetic portion that governs knee motion is a combination of synergistic motor patterns and muscle performance that encompasses the entire lower quarter kinematic chain including the hip and ankle. More proximal, the lumbar spine has implications on knee stability, both biomechanical attachment to the lower quarter chain and neurological influence for complex movement patterns. Passive treatment to normalize soft tissue and joint mobility cannot be over looked prior to exercise rehabilitation, but is beyond the scope of this text. This chapter will outline the stages of knee rehabilitation exercise including treatment design guidelines, dosage and progressions with reference to specific pathologies. A thoughtful application of the best evidence for treatment will be applied using a foundation of the knowledge of anatomy, biomechanics, neurophysiology, exercise physiology, pathology and clinical experience.
Section 1: Stage 1
Exercise Progression
Concepts for the Knee

Training Goals

Exercise prescription is one of the keys to a successful rehabilitation program. It is not always the specific exercise chosen, but the dosage and design that will determine the outcome. Intervention not only focuses on the knee, but on any joint that has an adverse effect on the function of the lower limb. Training for the initial functional qualities of range of motion, pain inhibition, tissue repair and resolution of edema are all addressed with high numbers of repetitions and minimal resistance. The high number of repetitions will also serve to improve coordination of basic movement patterns. The lighter resistance allows for proper motor unit recruitment and sequencing that results in the restoration of functional movement patterns.

Minimal resistance in the beginning phases is also important to increase tissue tolerance to stress and strain. When attempting to train tissue tolerance, over exertion is avoided to allow energy for protein synthesis after training. Properly dosing resistance, repetitions and rest breaks are also necessary to avoid abnormal tissue stress and further collagen breakdown. Pain and compensatory movement patterns are hallmarks of abnormal joint loading and must be avoided. Proper rest breaks can be determined based on the respiration rate. If it exceeds the steady state due to oxygen debt, a longer rest is needed after the set to allow for recovery.

Delayed onset tissue soreness (DOTS) and delayed onset muscle soreness (DOMS) can also be indications of over training and are associated with higher level muscle training, specifically eccentric work. Exceeding tissue tolerance should be avoided, as it can produce inflammatory responses leading to increased tissue soreness, stiffness and reflexive muscle guarding. DOTS should be avoided in initial training programs focused on tissue repair. The utilization of thermal agents and medication can reduce the pain associated with DOTS, but the tissue has still been over trained and the overall recovery will be delayed. Ice after exercise should not be necessary, as pain and inflammation should be reduced with training, not aggravated. Thermal agents may be more appropriate prior to exercise, along with soft tissue work and joint mobilization, to reduce symptoms and muscle guarding allowing for a higher level of function and training.

Stage 1—Dosed Functional Qualities

- Optimal stimulus for tissue repair and tolerance to activities of daily living: collagen, cartilage, bone, muscle, disc and nerve.
- Edema reduction: venous pump
- Range of motion: osteokinematic motion
- Joint mobility: arthokinematic motion
- Vascularity to guarded muscles
- Facilitation: recruitment patterns
- Coordination: neurological adaptation

Joint / Myofascial Mobilization

Normalizing joint mobility (arthokinematic motion) and range of motion (osteokinematic motion) are a necessary first step prior to training for muscular qualities such as endurance, strength and power. The instantaneous axis of motion in a hypomobile joint shifts toward the restriction creating abnormal tissue stress that can lead to additional trauma and compensatory movement patterns. Achieving full passive motion ensures proper force distribution through the knee to avoid these consequences. For example, limited end range extension during weight bearing activity creates abnormal compression through the patellofemoral and tibiofemoral joints. Passive articulations may be necessary to restore arthokinematic motion prior to an active exercise approach.

Mobilization of the knee can be addressed through translatory glides or distraction forces. The techniques are best performed manually by a trained physical therapist, but basic techniques can be
performed as mobilization exercises in the clinic and at home. As arthrokinematic joint motion improves, high repetition and low load active exercises can be safely employed to improve osteokinematic joint motion. Arthrokinematic mobilization forces can be achieved in non-weight bearing positions utilizing a pulley and straps to replace the mobilizing hands of a therapist. Mobilizations should begin with distraction, as it is typically the safest and best tolerated direction, deforms the greatest amount of collagen, and fires the greatest number of mechanoreceptors for pain inhibition and muscle facilitation. The closed packed position (full extension) should be avoided with all mobilization techniques and may occur much earlier in the range of motion under pathological conditions. A common clinical error is to attempt to mobilize a translatorial glide at the end of the available range, which is the new relative closed packed position, resulting in increasing joint compression and not improving gliding movements.

These mobilization examples follow the normal arthrokinematic motions of the knee complex. The force moment from the strap should always be parallel to the joint surface to achieve a translatorial glide. More classic exercises attempt to mobilize via osteokinematic torque, rather than arthrokinematic gliding translations. The former technique may initially improve range of motion, but can lead to intracapsular swelling and increased muscle guarding that ultimately increases joint stiffness.

For example, the prone knee hang is a popular technique used to help improve knee extension. A weight is placed around the ankle and the lower leg is dangled over the edge of a table. The combination of the long moment arm, represented by the tibia, and resistance from ankle weight create a rotary force at the tibiofemoral joint that places abnormal compression on the cartilage and tension on the joint capsule and ligaments. This may be an effective technique for a total knee arthroplasty that is devoid of these structures, but it will be problematic for a normal joint with traumatised tissue or surgically repaired tissues (i.e., post ACL or PCL repair).

Supine knee hanging is another common approach to early mobilization to post-surgical knees.
The above supine knee hang has been used for improving knee extension. The patient lies supine, with the heel placed on a pad. A weight is placed on the knee to push it into extension and providing tension on the posterior structures. This approach is not recommended, as a torque moment is created at the knee, rather than an anterior arthrokinematic glide of the tibia on the femur. Even for joint replacement, when no cartilage is present to be irritated from an abnormal torque, a sustained stretch is not recommended for the capsule. Mobilization should focus on previous examples of distraction or translatory gliding. If a sustained stretch for an arthrokinematic glide is performed, the hold time is 10–15 seconds to deform collagen, consistent with previous discussions on collagen mobilization. This approach avoid pain from abnormal tissue stress and the potential for an increase in intracapsular edema from abnormal joint compression forces.

Rather than placing a torque on the joint to improve osteokinematic motion, mobilizing exercises should focus on improving arthrokinematic motion. The external mobilizing force (the strap or roll) should be placed as close to the joint line as possible to produce a pure translation, rather than a rotatory torque moment. Muscle activity can be used to help influence the mechanics and coordinate motion.

Knee flexion is improved by performing a posterior glide of the tibia on the femur. As in the previous examples, care is taken not to perform the mobilization at the end range of available flexion where the joint will be maximally compressed. It should be performed with the knee close to the resting position, or at least roughly 20 degrees from the end of available flexion range.
Exercise for the Knee

Figure 2.9: Sitting active mobilization for tibial internal and external rotation. Tibial rotation is required for knee motion. Internal rotation occurs with flexion, while external rotation occurs with extension. These motions can simply be performed as isolated rotation in sitting with the weight on the heel to improve arthrokinematic spin of the tibia for osteokinematic flexion and extension motions.

Selective Tissue Training (STT)

SST addresses issues of tissue repair, edema resolution and pain inhibition. Repetitive motion in the pain free range can assist in improving range of motion by reducing muscle tension and increasing collagen elasticity of the joint capsule. Muscle guarding of the quadriceps due to joint pain and/or inflammation can limit knee flexion, while extension may be limited by guarding in the hamstrings, adductors and gastrocnemius-soleus complex. Repetitive motion also provides...
a mechanical stimulus for repair of collagen, cartilage and bone. A thorough evaluation for differential diagnosis is an important step in exercise prescription so that the most effective stimulus can be applied to the dysfunctional tissue. For example, training collagen in a tendinopathy is different than addressing cartilage issues in patellofemoral syndrome. Progressive tensile forces can address collagen dysfunction, while progressive compression or loading exercises stimulate cartilage and bone repair. Surgical procedures, such as ACL reconstruction, can dictate the focus of a rehabilitation program. For instance, an exercise prescription for the donor site in a patellar tendon autograft will need to be considered along with protection of the graft fixation. Data from studies suggest that patellar tendon donor sites remodel over an 18–24 month period (Kiss et al. 1998). It is also common to have meniscal, articular cartilage and surrounding ligamentous damage that needs to be addressed concurrently, which can act to delay and complicate functional progression in the clinic.

Resolution of inflammation, when present, is a part of the initial phase of the rehabilitation program. Effusion management involves modifying tissue stress with manual techniques and exercise to avoid pain, which is of paramount importance in rehabilitating traumatized or post surgical tissues (Iles et al. 1990). Edema can be a cause for decreased range of motion, increased pain and altered motor function. It must be noted that inflammation is a complex interaction of cellular signals and responses and not all conditions are related to inflammation and respond to anti-inflammatory medication (Scott et al. 2004).

Muscle inhibition due to arthrogenic pathologies has been attributed to presynaptic neuronal reflex activity in which altered afferent input originating from the injured joint results in a diminished efferent motor drive to the quadriceps muscles (Palmieri et al. 2005). The effects of long-term effusions contribute to the loss of proprioception observed in some clinical conditions (McNair et al. 1995). Edema is better treated with active muscle pumping approaches rather than more passive modalities such as cryotherapy or compression (Wester et al. 1996). Stimulation of the venous pump via muscle contraction allows for active transport of fluid and exudate through the venous system and lymphatics. Elevation of the limb during training can further assist in decreasing edema by reducing the mean fluid pressure of the blood that is forcing fluid out of the capillaries and into the extracellular space. Reduction in intracapsular edema not only improves mobility but also will assist in normalizing the afferent feedback from the joint capsule, and increase motor facilitation. McNair et al. (1996) demonstrated a reduction in quadriceps facilitation after a 60 mL saline and dextrose injection into the knee joint, with torque measurements returning to normal after three to four minutes of submaximal exercise.

Repetitive mechanical loading of collagen in the line of stress stimulates fibroblasts to produce new collagen fibers and glycosaminoglycans (GAG). Miller et al. (2005) found that a single acute bout of strenuous, non-damaging exercise increased the rates of synthesis of tendon and muscle collagen, as well as muscle myofibrillar and sarcoplasmic protein that peaked after 24 hours and slowly decreased toward resting values by 72 hours. The level of strain to healing collagen is increased, as pain levels drop and coordination improves, in order to maximize the rate of protein synthesis for the reparative process. Exercise for osteoarthritis of the knee has been extensively researched. Bautch et al. (2000) disputed concerns that exercise for osteoarthritis (OA) would contribute to cartilage degradation. In a systematic review of randomized clinical trials (RCTs) of exercise therapy for patients with osteoarthritis of the hip and knee, van Baar (1999) found sufficient evidence for including exercise as a major component of rehabilitation. Roddy et al. (2005a) performed a systematic review of RCTs comparing aerobic walking to quadriceps strengthening for OA that showed evidence for improving disability and reducing pain in both cases. In an evidence-based review, recommendations included utilizing an individualized exercise approach consisting of
proprioceptive training and compliance with the program (Roddy et al. 2005b).

Prior to initiating exercise in a degenerative joint, arthrokineomatic motion needs to be restored to a sufficient level (Grimsby 1991). Passive joint mobilization may be necessary to improve joint motion, reduce pain, improve afferent input for motor facilitation and proprioception as well as lubricate avascular tissues. Deyle et al. (2000) found a combination of passive manual physical therapy treatments and supervised exercise to be beneficial for patients with OA of the knee, possibly delaying or preventing the need for surgical intervention. A comparison of patients receiving home exercise alone to those receiving both manual therapy (MT) and supervised exercise found the home exercise group only had about half the improvement compared to the MT and supervised exercise group after one month (Deyle et al. 2005). Long-term outcomes after one year were similar, as subjects continued similar home exercise programs through this period. Factors other than joint restriction that may impede outcome include quadriceps inhibition, obesity, passive knee laxity, poor alignment, fear of physical activity and a lack of self-efficacy (Fitzgerald 2005). In the presence of any of these variables, exercise design may need to be modified to a lower level with a slower progression to higher level training.

Vad et al. (2002) presented a five-stage program recommended for rehabilitation of athletes with early knee OA. Stage 1 related to the use of protected mobilization and pain control modalities. Medical intervention focused on pain medications, nonsteroidal anti-inflammatory drugs, chondroprotective agents such as glucosamine in some cases, and injection therapy including intra-articular injections of corticosteroids or viscosupplementation. Stages 2–5 involved progressive exercises consistent with the four stages outlined in this chapter. The initial stage focused on open kinetic chain exercises for resolution of edema, increasing range of motion, controlling pain and improving coordination. Progressive closed kinetic chain exercises were added in the next stage with an emphasis on tissue repair, and some functional retraining. This was followed by an increased focus on functional activities and training related to specific athletic performance. The final stage emphasized patient education for long term training to reduce the risk of re-injury, improve the overall training state of the knee joint and provide long-term activity to delay the progression of the disease.

Moderate exercise in patients at high risk of developing OA has been associated with symptom reduction and improved function, as well as an improvement in the GAG content of the knee cartilage. After 12 weeks of training no significant deleterious effects of the osteoarthritic joints were found, as reflected by chondroitin sulphate synovial fluid markers. Pain reduction is a consistent finding with exercise programs for OA. van Baar et al. (1998) reported positive outcomes for improvements in pain and range of motion after 12 weeks of exercise. Aquatic exercise has been shown to significantly improve knee and hip flexibility, as well as strength and aerobic fitness in subjects with hip or knee OA, but it did not improve self-reported physical functioning and pain (Wang et al. 2007). Both aquatic and land-based training have been shown to be effective in improving knee range of motion, thigh girth, subjective pain ratings, and time for a one-mile walk (Wyatt et al. 2001). Training can be effective in improving motor performance and providing a positive stimulus for cartilage repair. In the obese patient, benefits of exercise may be limited or slow due to constant overloading of cartilage. Weight loss through dietary intervention is beneficial in over weight patients with OA (Focht et al. 2005). Martin et al. (2001) were successful in reducing pain levels in obese women with OA of the knee with weekly nutrition classes and an exercise-walking program.

Active motion with minimal to no resistance allows for hundreds of repetitions to facilitate a muscle pumping action for fluid transport without associated fatigue or pain. The tension that is developed during the contraction with low resistance (<25% of 1RM) is not great enough to
The addition of a passive component to early rehabilitation. But these procedures can be costly and time consuming and may not significantly alter the end stage functional outcomes.

Figure 2.11: Sling training for knee flexion and extension. Two straps are placed on either side of the joint and attached to a fixed line. The axis of the knee joint is placed directly underneath the fixed line. Zero resistance in the sling suspension allows for pure concentric work of alternating knee flexion and extension. Hundreds of repetitions can be performed in the pain free range to positively influence pain, inflammation, tissue repair and early coordination. This is an excellent approach for acute post surgical knees that require a pain free safe environment for early high repetition training.

Beaupre et al. (2001) demonstrated that the addition of a CPM or slide board to a standard exercise program in the rehabilitation of total knee arthroplasty did not improve quality of life or outcome measures at both three and six months. Use of a CPM should be based on the individual situation and not a specific research study. Other variables such as pain levels, psychological motivation and general health may warrant the addition of a passive component to early rehabilitation. But these procedures can be costly and time consuming and may not significantly alter the end stage functional outcomes.

Figure 2.12a,b: Supine heel slides. Repetitive motion can be performed actively with heel slides in supine. Work emphasis is on the hamstrings and knee extension range. To reduce friction a sock can be worn with the foot on a sheet or vinyl. The knee is slowly flexed and extended in the pain free range. Forcing motion into the painful range will only reduce range by increasing muscle tension, as well as increase tissue irritation and inflammation.

Figure 2.13: Wall slides are performed as with the above heel slide, but work emphasis is on the quadriceps and knee flexion range.

Figure 2.14: Fitness ball knee flexion-extension. The patient is in supine with the calf resting on top of a fitness ball. The
knee is flexed rolling the ball toward the body, with contact transferring to the heel, then returned to an extended position. Work emphasis is on the hamstrings, range emphasis on knee extension.

Open chain low resistance knee flexion and extension exercises create a greater tissue stress and a higher motor demand for early coordination training than sling suspension training. A pulley assist can be used to reduce the weight of the lower limb to allow for 40–50 repetitions with resistance below 50% of 1RM. Pulleys provide an objective and consistent method of decreasing load.

Range of motion limitations from muscle guarding can be trained with repetitive concentric contraction of the involved muscles. Passive stretch is avoided in the acute stage when pain is present, as reduced flexibility is a function of neurological reflexive muscle guarding and not collagen restrictions. Repetitive motion at 60% of 1RM helps to increase circulation providing oxygen to tonic muscles in guarding. A slow eccentric phase can be added to allow for lengthening of the muscle to the end range for dynamic stretching. A sustained stretch on the last repetition of up to 30 seconds to improve flexibility can also be used. Pain is avoided at all times during the exercises, as a reflexive muscle guarding response will again limit range.

Protocols for open kinetic chain (OKC) quadriceps strengthening have been recommended in the range of 20 degrees to full extension, as this is deemed to be more effective due to the muscle effort of the quadriceps being the highest in this range (Wild et al. 1982, Escamilla et al. 1998). But muscle recruitment can be difficult toward the end range due to active insufficiency and patients with lateral subluxation or dislocation may need to avoid terminal extension to maintain stability of the patella in the trochlear groove. Also with end range extension the patella is superior to the femoral groove, so tissue repair may be reduced with lack of normal cartilage compression for a cellular stimulus. But, terminal knee extension has been recommended with PFPS to avoid cartilage contact in the trochlear groove (Alaca et al. 2002).

Lesions on the proximal aspect of patellar surface may be painful with closed kinetic chain (CKC) exercises with the knee flexed in the 60–90 degrees range due to compression of the lesion with the femoral trochlea (Ahmed et al. 1983, Huberti et al. 1984, Huberti et al. 1998). Training may be better tolerated in a 20–60 degrees range, in order to modify the amount of cartilage compression to a
pain free level. This mid range position also serves to stimulate both type I and II mechanoreceptors for maximizing quadriceps facilitation. Ultimately pain and coordination, along with the specific pathology, will determine the range and level of training that is most effective for each patient.

Knee extension training in the presence of patellofemoral subluxation initially avoids terminal knee extension to maintain the patella in the femoral groove. Full extension can lead to abnormal lateral motion of the patella and remove the cartilage stimulus for repair. These poor mechanics may also lead to abnormal forces during weight bearing, causing pain and limiting tolerance to weight bearing training. For weight bearing training the tibia can be placed in slight internal rotation during, creating a relative external rotation of the femur, serving to unload the lateral patellar facet enough to allow for pain free training. Unloading the body weight of the patient can also serve to decrease compression forces.

### Dosage for Stage 1 Functional Qualities

#### Tissue Repair, Pain Inhibition, Edema Reduction and Joint Mobilization

- **Sets:** 1–5 sets or training sessions daily
- **Repetitions:** 2–10 hours during the day
- **Resistance:** Assisted exercise up to 25% 1RM
- **Frequency:** Multiple times daily

#### Coordination

- **Sets:** 1–5 sets or training sessions daily
- **Repetitions:** 20–50 during the day
- **Resistance:** Assisted exercise up to 50% 1RM
- **Frequency:** 1–3 times daily

#### Vascularity / Local Endurance

- **Sets:** 2–3 sets or training sessions daily
- **Repetitions:** 25
- **Resistance:** Assisted to 50–60% 1RM
- **Frequency:** One time daily

#### Muscle in Atrophy

- **Sets:** 2–3 sets or training sessions daily
- **Repetitions:** 40 or more
- **Resistance:** Assisted to 30–40% 1RM
- **Frequency:** One time daily
Direction of Exercise

The initial direction of training can be influenced by the mobility restriction, tissue injury and/or functional deficits. Exercises may be selected simply to facilitate the muscles that govern basic tasks or motions or directly influence an injured muscle or tendon. Alterations in normal joint mobility have specific implications in exercise design, as it relates to direction and range of training. Initial training of hypomobile joints emphasizes restoring arthrokinematic joint play and osteokinematic range of motion. Repetitive eccentric work toward the restriction improves elasticity of collagen and muscle extensibility. The opposing pattern, or concentric work toward the restriction, ensures dynamic stabilization of the newly gained range.

Concentric Emphasis

Initial training for hypermobile joints involves a concentric emphasis within the beginning and mid ranges of motion away from the injury. Motion is performed in the same plane of tissue injury to provide modified tension in the line of stress for tissue repair. The end range, or pathological range, is avoided to prevent further tissue strain or injury. Concentric work away from the pathological range is performed to begin the process of gaining motor control of the muscles that provide stability. These same muscles are also eventually trained eccentrically toward the hypermobility to increase muscle spindle sensitivity and improve stability toward the hypermobile range.

Eccentric Training for Tendinopathy and Collagen Repair

Patellar tendinopathies, patellar tendon repairs, hamstring and patellar grafts for ACL reconstruction, Osgood Schlatter’s disease, as well as hamstring and quadriceps strains represent impaired collagen states associated with a lowered ability to elongate and absorb tensile forces. All of these conditions can benefit from a specific tissue training program that focuses on repetitive modified tension in the line of stress for collagen repair.

Tendon is a metabolically active tissue that imposes an increased energy demand during exercise. Blood flow increases in the peritendinous tissue during exercise in humans (Boushel et al. 2000, Langberg et al. 1998, Langberg et al. 1999). Oxidative enzymes exist within fibroblasts and tenocytes of tendon (Joza et al. 1979, Kvist et al. 1987) and oxygen consumption increases during exercise (Boushel et al. 2000). A coupling exists between the exercise-induced drop in tissue oxygenation and increase in blood flow (Boushel et al. 2000). Glucose uptake has been shown to increase during exercise in the quadriceps tendon (Kalliokoski et al.

Stage 1 Direction of Exercise Concepts

<table>
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<tr>
<th>Joint Mobility/ Grade</th>
<th>Direction of Exercise</th>
<th>Hold Time</th>
<th>Histological Effect</th>
<th>Neurological Effect</th>
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| **Hypermobile** Grades 4, 5 and 6 | Concentric work away from the hypermobility – beginning to mid range only. | None | • Optimal stimulus for repair  
• Vascular effect on edema | • Sensitize spindles to stretch  
• Pain inhibition |
| **Hypomobile** Grades 1 and 2 | Eccentric work toward the hypomobility – end range training. | Slow speed with 10 second hold | • Improve elasticity and plasticity deformity  
• Optimal stimulus for repair | • Pain inhibition |
The increase in tendon glucose uptake is less pronounced and not correlated with that in muscle, as there is an unknown independent regulatory mechanism. Glucose uptake is more enhanced in the quadriceps tendon compared with the patella tendon in response to knee-extension exercise (Kalliokoski et al. 2005).

The pathology specifies the tissue in lesion while histology dictates the intervention and approach for rehabilitation. For example, overuse tendinopathies are aggravated and become chronic conditions if additional exercise and activity further contribute to oxygen and energy depletion. Typically it leads to the hallmark histopathological signs of tendinosis including collagen degeneration with fiber separation, increased mucoid ground substance and an absence of inflammatory cells often found in the Achilles, patellar, rotator cuff and extensor carpi radialis brevis tendons (Khan et al. 1999). The lack of inflammatory markers in these injured tendons is an essential point that alters the rehabilitation approach, as these conditions are often misdiagnosed as inflammatory issues rather than degenerative collagen disorders. Studies performed on chronic painful tendons, classically defined as tendonitis, have provided contrary evidence to assumed inflammatory responses following tendon injury. The evidence available suggests degenerative changes in type I collagen are the result of increased levels of matrix turnover affecting tendons that are exposed to higher levels of strain. Changes in cellular activity lead to a tendon that is mechanically weaker and more susceptible to damage (Riley 2004). Appropriate training in these cases, involves pure concentric work to the surrounding muscles in the area, except the one in lesion (Holten 1996). This indirect approach provides needed oxygen to the region, without placing an increased metabolic demand on the injured muscle/tendon complex. The tissue in lesion is then trained directly via pure eccentric work to stimulate collagen repair with little oxygen consumption, as the energy demand is only a third of that required for concentric work (Knuttgen et al. 1971). Eccentric exercise has been shown to lead to less fatigue, as well as lower lactate and ammonia reaction than concentric exercise at comparable work levels (Horstmann et al. 2001). The eccentric work phase also provides the necessary tension for collagen hypertrophy, where the concentric phase is more associated with vascularization via increased capillary density (Hather et al. 1991).

Application of eccentric training based on these histological concepts for patellar tendonitis is not new, as one of the first trials was performed by Cannell (1982). Several additional studies also assessed pure eccentric training for patellar tendonopathy (Jensen K, DiFabio 1989, Cannell et al. 2001, Young 2002, Stasinopoulos and Stasinopoulos 2004, Purdam 2004, Jonsson and Alfredson 2005, Young et al. 2005, Taunton 2006, Bahr et al. 2006). Visnes et al. (2005) did not find benefit with eccentric training for jumper’s knee in volleyball players, although subjects continued to train and compete during the trial treatment.

**Eccentric Training Options for Patellar Tendinopathy**

Figure 2.19a,b: Pure eccentric unilateral squat on an unloading slide board. The uninvolved left knee performs the concentric knee extension from a flexed position (top picture). The involved right knee performs the eccentric unilateral squat back to the start position. If the body weight cannot be reduced enough for pain free eccentric lowering unilaterally, then the uninvolved knee can assist with the eccentric performance as well.
Figure 2.20a,b: Seated open chain eccentric quadriceps knee extension using a wall pulley. The therapist raises the weight (a) and the patient fixes the joint position with a brief isometric contraction of the quadriceps. The knee is then slowly lowered eccentrically in the pain free range (b). Progression may include lying back in a supine position placing the hip in neutral to increase muscle lengthening of the proximal quadriceps. After increasing length, speed and finally resistance are increased.

Figure 2.21a,b: Door jam squats with upper limb support for eccentric phases. Weight is shifted to the involved knee for eccentric lowering, then shifted onto the uninvolved side for the concentric return.

Figure 2.22a,b: Step-downs with pure eccentric emphasis of the involved limb. Eccentric step-downs are performed by the involved limb while the uninvolved limb performs a concentric step-up, back up onto the step.

Dosage for pure eccentrics is not as specific as concentric training for specific muscle performance qualities. Vines and Bahr (2007) attempted to summarize the previous clinical trials for patellar tendinopathy training, but could not recommend one specific protocol. They did recommend including a decline board for squats and allowing some level of discomfort with training. These studies included training anywhere from three times per week to two times per day, with most exercises dosed at three sets of fifteen repetitions.

General guidelines can be used with pure eccentric training, but the patient will determine the starting level and speed of progression. The amount of resistance used is dictated by the integrity of the collagen. The general rule is to use as heavy a weight as possible without causing pain or losing coordination. The number of repetitions is initially limited to a range of eight to 15, with fewer repetitions in more significant collagen injuries. Warren et al. (1993) presented a material fatigue model for collagen assessing load versus repetitions for collagen breakdown. Findings included a significant increase in damage after eight repetitions. This study was performed in the laboratory on rattails, and does not exactly translate into the clinical setting, but the concept of initially limiting the repetitions and using a heavy load is otherwise utilized. The need for additional sets is another consideration as strain is important to stimulate cellular activity, but the added repetitions may contribute to material breakdown in the collagen. Generally only one or two sets is recommended, and progressed to multiple training sessions per day as tolerated. Rest, for oxygen recovery, between sets is not necessary when training collagen, but time for collagen production and bonding is necessary.

Range of motion should be progressed prior to increasing the resistance. Training through the full length of the tendon, the typical range of injury, is more important than increasing load tolerance in the shortened range. Speed is also increased before resistance is increased. Kubo et al. (2005) compared ballistic drop jumps with isometric
leg presses involving slow contractions lasting up to ten seconds. Ballistic drop jumps were more associated with muscle strengthening and delayed onset muscle soreness, while the slow prolonged work resulted in greater effects on the tendon. Initially, slower eccentric training will be more effective for stimulating tissue reparative responses in the tendon. Adding speed later is more related to simulating functional requirements. Once eccentrics can be performed at functional speeds through the entire range, resistance can be increased, which may require a slight and temporary drop in speed. Progression then continues by alternating increases in speed and weight.

Basic Patellar Tendinosis Rehab Concepts

- *Initial concentric training emphasis for vascularity for all motions in the region of the tendon, except the primary motion of the tendon (three sets of 24 at 60% of 1RM)*
- *Eccentric work one to two sets of eight to 15 repetitions with resistance as heavy as possible to allow for coordinated motion. Mild discomfort during the exercise is tolerated if coordination is not negatively affected and pain does not linger after completion of the exercise.*
- *Train through the full range of motion first, then progress by adding speed, followed by increasing resistance. Finally alternate progressions in speed and weight as appropriate.*
- *Avoid interventions that weaken collagen or slow repair: rest or immobility, stretching, NSAIDs, corticosteroids and heating the tendon with ultrasound.*

In more acute injuries or post surgical situations pure eccentrics are performed open chain, in non-weight bearing positions. Pulley resistance is preferred as consistent tension can be applied throughout the range. Free weights lose the force moment when parallel to gravity and elastic resistance decreases toward the lengthened range of muscle where tension is needed.

The hamstrings are frequently subjected to injuries due to eccentric forces developed when the leg is decelerating. The greatest tension develops immediately following toe off when there is an increase in the force moment during the transition between hip extension and flexion. This range is where the hamstrings need to have the greatest tensile strength so they have the ability to tolerate forces placed upon the collagen matrix. Pure eccentric training has been recommended for hamstring injury (Proske et al. 2004). Mjølnes et al. (2004) compared the effects of a 10-week training program on hamstring muscle strength among male soccer players with two different exercises. The first was a traditional hamstring curl (HC) that included both CW and EW. The second was a Nordic hamstrings (NH) exercise that involved a partner assisting the CW phase with emphasis on heavier resistance for the EW phase. After 10 weeks of training, the NH exercise was found to be more effective than the HC exercise in developing maximal eccentric hamstring strength. Improved training effects may be at least
Exercise for the Knee

Figure 2.25a,b,c,d: “The Hamstring Shuffle”—Unilateral dead lift for eccentric training emphasizing right proximal hamstrings (advanced eccentric training for hamstring strain). With the knees slightly flexed, weight is shifted to the involved side (a) and a slow eccentric lowering into hip flexion is performed (b). Weight is shifted toward the uninvolved side (c) for the concentric return (d).

Decline Squat

A decline squat protocol offers greater clinical gains during a rehabilitation program for patellar tendinopathy in athletes who continue to train and play with pain, as based on a study by Young et al. (2005). In this study a decline squat group was compared to a step-up group. The decline group was to perform single leg squats on a 25 degree decline board during a 12 week period. The step group performed single leg squats on a 10 centimeter step, exercising without pain and progressing by increasing speed then load. Similar findings were concluded in the study by Purdam et al. (2004). In this study eccentric training on a 25 degree slant board was performed twice a day at three sets of 15 repetitions for 12 weeks and compared to flat foot eccentrics. The group that trained with the decline board exhibited greater pain reduction and returned more quickly to

partially contributed to remodeling of endomysial type IV collagen after a bout of eccentric muscle contractions as suggested by Mackey et al. (2004).
previous levels of activity. Jonsson and Alfredson (2005) stopped halfway through their study due to pain and poor results concluding that eccentric, not concentric, quadriceps training on a decline board seemed to reduce pain in jumper’s knee.

**Myokinematics**

Basic motor function at the knee is commonly described in reference to open kinetic chain (OKC) dynamics with, the quadriceps extending the knee and the hamstrings flexing the knee. Dynamic function is actually more complicated than this simple description, as the knee primarily functions in closed kinetic chain (CKC) scenarios and also depends on muscles that act on the ankle, hip, pelvis and lumbar spine. This requires assessment of the entire kinetic chain from the lumbar spine to the foot including both non-weight bearing muscle testing and more functional weight bearing testing to assess motor performance.

In weight bearing, muscles of the lower limb work in synergy to resist the force of gravity. The hamstrings do not work antagonistic to the quadriceps, but in concert to support the lower limb. Isometric stabilization and eccentric deceleration help to prevent excessive valgus moments from occurring at the hip and knee as well as abnormal pronation at the foot and ankle. Pronation at the foot is classically described as a combination of dorsiflexion, abduction and eversion of the rear foot. The knee motion includes a combination of flexion, tibial internal rotation and abduction. The hip collapses into flexion, internal rotation and adduction. The hamstrings muscles contribute to concentric knee flexion and hip extension, as well as eccentric deceleration of knee extension and hip flexion in the swing phase of gait. The lateral hamstrings generate an external rotation moment at the tibia, that act to decelerate internal rotation during flexion of the lower limb. Tibial rotation in weight bearing is controlled primarily by passive structures of the tibia on the talus, but motor control is necessary for coordination of the movement pattern and absorption of ground reaction forces. The medial hamstrings generate an internal rotational moment on the tibia, and act to decelerate external rotation of the lower leg. The hamstrings, as a group, contribute to concentric hip extension and adduction as well. With a lateral lunge they act to eccentrically decelerate hip flexion and abduction.

Within the context of closed chain kinetics, the quadriceps can be described as knee extensors that also contribute to external rotation and adduction of the tibia, with opposing eccentric function. The rectus femoris portion of the quadriceps also contributes to eccentric deceleration of hip extension in the open chain swing through phase of gait. The quadriceps, as a group, also helps to dynamically control the axis of motion and tracking of the patellofemoral joint. The vastus medialis obliquus (VMO) imparts a medial vector proximally on the patella that is opposed by the lateral vector of the vastus lateralis and iliotibial band with a direct superior vector imparted by the rectus femoris and vastus lateralis muscles. Short arc extension exercises are commonly used for specific VMO strengthening as this muscle is often solely implicated in terminal knee extension deficiencies (Tria et al. 1992). This is a simplified view of motor performance, as muscles do not function in isolation. Lieb and Perry (1968) demonstrated that terminal knee extension involves the entire quadriceps complex, not only the VMO. Joint angles can play an important role for training of functional movement patterns. Mid range positions of the knee are more effective for muscle recruitment and may be favorable in early training sessions. For instance, VMO activation...
and contraction intensity has been measured to be greatest at 60 degrees of knee flexion (Tang et al. 2001). This information would suggest terminal knee extension quad sets for VMO training would be best performed closure to 60 degrees of flexion, rather than at full extension.

Quadriceps strengthening is an important component of a rehabilitation program for treatment of knee conditions ranging from jumper’s knee to post-operative ligament repair and total knee arthroplasty. The introduction of quadriceps exercises into rehab programs, particularly following ACL repairs, has been tentative secondary to the belief that contraction of the quadriceps would increase the anterior translation of the tibia on the femur and place unwanted tension on the ACL. Tagesson et al. (2005) showed that with the performance of cycling, heel raises and knee extension exercises did not increase tibial translation in healthy knees. Sagittal tibial translation was measured during Lachman’s testing, maximal isometric quadriceps contractions, one-legged squats and gait using the CA-4000 electrogoniometer. Electromyographic activity of the vastus medialis, vastus lateralis, gastrocnemius and hamstring muscle group was recorded. The results showed that none of the exercises influenced the amount of translation in healthy individuals. Beutler et al. (2002) concluded from the electromyographic levels of quadriceps activation in their study that one-legged squats and step-ups would be effective in muscle rehabilitation and may also be protective of anterior cruciate ligament grafts.

The force developed from a quadriceps contraction is not able to generate enough tension to disrupt the anterior cruciate ligament and is the primary protector of the ACL from injury during anterior tibial translation (Aune et al. 1997). According to Bodor (2001) the quadriceps is the primary restraint of anterior tibial translation during closed kinetic chain activities such as running, jumping, walking and standing. It creates an inferior/posteriorly directed force vector during closed chain knee extension and an opposite superior/anteriorly directed force vector during open chain knee extension. The inferiorly directed vector has an anterior femoral-tibial or posterior tibial-femoral component, which protects the anterior cruciate ligament (ACL) from anterior tibial-femoral shear during weight bearing activities. The quadriceps complex protects the ACL regardless of the activity of the hamstrings and findings by Bodor (2001) suggest that: (1) weak quadriceps are a risk factor for non-contact ACL injuries, (2) strong quadriceps are important for ACL injury prevention and rehabilitation and (3) preservation of quadriceps strength is an important surgical goal.

Emphasis in the past has been placed on the quadriceps/hamstring strength ratio for stabilization training of ACL deficient and reconstructed knees. Studies have shown that although these ratios are important factors, lower limb alignment and dynamic stability also rely on contributions from the soleus, gastrocnemius and popliteus muscles, as well as the hip external rotators and extensors.

The posterior hip muscles must also be considered in CKC knee function. The gluteus maximus contributes to hip extension and the gluteus medius, as a primary abductor of the hip, stabilizes the leg during the unilateral stance phase of gait. The deep hip external rotators help to decelerate pronation of the hip into flexion, internal rotation and adduction. Weakness in these muscles can lead to excessive valgus stress during weight bearing eccentric deceleration. Concentric propulsion into the lower quarter extension pattern may then occur with improper alignment and an incorrect instantaneous axis of motion for any of the joints in the kinetic chain.

The soleus primarily decelerates subtalar pronation while contributing to propulsion into supination. It also acts to directly affect the knee by contributing to eccentric deceleration of the tibia on the step-through phase of gait, although it does not cross the joint. The gastrocnemius has similar affects on the ankle, but also assists the hip external rotators by contributing to eccentric deceleration of the femur.
into internal rotation. Tightness and/or weakness of the gastrocnemius may also contribute to genu recurvatum of the knee.

The soleus and gastrocnemius also play key roles in reducing ACL strain by eccentrically controlling the anterior motion of the tibia during closed chain knee flexion. The soleus is the primary muscle controlling tibial motion for low-level activity and gait. During higher-level functional activities both muscles are emphasized for control of joint translation. Coactivation of the quadriceps and gastrocnemius muscles is important for knee stability during squatting motions, whereas hamstring muscle co-activation is relatively insignificant (Kvist and Gillquist 2001). More emphasis should thus be placed on training the gastrocnemius muscle due to its contribution in providing functional stability to the ACL-deficient knee (Lass et al. 1991).

Nyland et al. (2005) described the popliteus as a dynamic guidance system for monitoring and controlling subtle transverse and frontal plane knee joint movements. This included guiding anterior, posterior and lateral meniscal translations, unlocking and internally rotating the knee joint during flexion initiation, assisting with 3-dimensional dynamic lower extremity postural stability during single-leg stance, preventing forward femoral dislocation on the tibia during flexed-knee stance, and providing for postural equilibrium adjustments during standing.

The majority, if not all of these functions, are most important during mid-range knee flexion when the supportive structures are the least able to tolerate stress. The popliteus has attachments close to the borders of both collateral ligaments providing the potential for instantaneous kinesthetic feedback of tibial movement. It also acts in synergy with the hip musculature for dynamic control of femoral internal rotation and adduction, as well as subtalar control of tibial abduction-external rotation or adduction-internal rotation (Nyland et al. 2005). Afferent feedback from this muscle may help to prevent athletic knee joint injuries and assist the quadriceps femoris, hamstrings and gastrocnemius in providing stability to the knee within the sagittal plane. Muscle spasm, altered timing or inhibition of the popliteus may contribute to an alteration in normal lower quarter mechanics.

Abnormal Myokinematics

Abnormal motor patterns result from a myriad of causes and may be either a primary or secondary phenomenon. If motor dysfunction stems from local joint or nerve pathology, then the latter impairments are addressed prior to muscle performance training. Restoration of proper joint mechanics can assist in the normalization of afferent mechanoreceptor feedback improving motor performance. These motor patterns should be retested after resolving more acute impairments, associated with the primary pathology, to assess their level of contribution to the existing abnormal motor dysfunction.

Both down training of abnormally facilitated muscle and uptraining of inhibited muscle may be necessary to normalize dynamic function. Excessive strain on compensatory muscles may lead to pathologies such as tendinopathy. The tendinopathy may be the initial painful experience, but it is actually a secondary impairment to the primary motor weakness. For example, an Achilles tendinopathy may develop with excessive activity of the gastrocnemius-soleus complex when attempting to compensate for weakness in the extensors of the knee and/or hip to eccentrically stabilize knee flexion during weight bearing activity.

Specific motor dysfunction leads to compensatory muscle recruitment patterns that also place excessive stress and strain on passive joint structures. Improper lower limb alignment during functional activities may alter the axis of motion creating abnormal cartilage compression and collagen tension in the ligaments and joint capsules of the lower quarter. Inhibition of the VMO may lead to lateral tracking of the patella and secondary patellofemoral pain syndrome (PFPS). An altered
Potential for injury to capsules, ligaments and menisci are also increased. Jonsson and Karrholm (1994) measured joint motion on ACL-deficient knees during step training, finding little change in tibial adduction and abduction. But they did note a shift of the femur anteriorly as well as a distal and anterior shift of the rotary axis in sagittal plane motions. The abnormal adduction component of the femur during weight bearing training, as seen with a valgus moment at the knee, may not be as significant as deficient external rotation support at the hip. Hamstring weakness is also associated with poor outcome in ACL-deficient knees (Tsepis et al. 2004). The clinical emphasis is not to identify one specific muscle that is weak, but to assess the entire lower limb for motor pattern dysfunction. Individual muscles may be emphasized in a specific exercise design, but are facilitated in synergy with the supporting muscles.

Muscle weakness or inhibition associated with joint damage can be highly selective. Knee disorders commonly produce quadriceps atrophy with limited affect on the hamstrings predisposing the joint to a position of flexion (Young et al. 1987). This phenomenon can be attributed to altered mechanoreceptor activity selectively inhibiting the quadriceps muscles. By initially focusing on reducing pain and effusion to normalize mechanoreceptor function, the recruitment patterns of the quadriceps can be restored. This approach may prove to be more effective than simply stretching tissue and potentially facilitating a flexion pattern of recruitment.

Tightness of the iliotibial band (ITB) is often associated with knee pathology, including lateral tracking of the patella. Classically this dysfunction is described as inhibition of the gluteus medius with compensatory over activity of the tensor fascia lata and iliacus muscles leading to ITB tightness. Secondary symptoms may include hip bursitis or lateral knee pain. Iliotibial band syndrome (ITBS) may not really exist as a freestanding pathology, but rather as a symptom within a cascade of mechanical breakdowns throughout the lower limb in closed
chain activities that frequently correlates with gluteus medius weakness. EMG studies have shown that both athletic and arthritic hips with symptoms of ITBS usually have poor gluteus medius facilitation and an inability to isolate gluteus medius recruitment from the tensor facia lata (TFL) in standing (Fredericson 2000, Kasman 2002). In long distance runners with ITBS, symptom improvement and return to preinjury training correlates with increased hip abductor strength (Fredericson 2000). Rather than a stretching program for the ITB, emphasis is placed on uptraining of the gluteus medius and down training of the TFL/ITB.

The Manual Therapy Lesion concept attempts to provide a pathological model that incorporates joint biomechanics, myokinematics and neurophysiology with tissue pathology (Grimsby 1988). The basic concept is that damage to mechanoreceptors from primary tissue pathology leads to tonic muscle inhibition, altered joint motion and further abnormal tissue strain. The tissue and receptor trauma is not exclusive to the primary joint of dysfunction as Bullock-Saxton et al. (1994) demonstrated that subjects sustaining ankle sprains, with associated collagen and receptor damage, had reduced hip extension strength. Lower lumbar spine pathology can lead to inhibition of hip muscles, contributing to abnormal stress on the entire lower quarter. Hart et al. (2006) identified quadriceps weakness after fatiguing exercises to the lumbar spine paraspinals that was even more significant in subjects with a history of back pain.

In more chronic states of pathology, motor dysfunction is not so much associated with reduced feedback from peripheral receptors, as it is related to altered cortical feedforward control of specific motor patterns. Feedforward mechanisms have been identified in tests where motor performance requires such a fast response that there is not sufficient time for an afferent feedback loop to influence motor performance. The drop jump test suggests a centrally pre-programmed activity and the associated elastic behavior of the series elastic component in the knee extensor muscle, in conjunction with the muscle contractile properties, playing a major role in regulating motor performance (Horita et al. 2002). The implications of the manual therapy lesion concept requiring assessment and treatment from the lumbar spine to the foot for all lower limb patients goes beyond the scope of this text.

Alterations in afferent input affecting motor patterns may occur prior to tissue trauma, as a result of muscle fatigue or edema. Tissue injury may then be a secondary consequence of the altered movement patterns, as described in the manual therapy lesion concept. Joint position sense is believed by some authors to be primarily signaled by the muscle spindle (McCloskey 1978, Gandevia et al. 1995, Proske et al. 2000, Forestier et al. 2002, Proske 2005). Local muscular fatigue modifies the peripheral proprioceptive system by increasing the threshold for muscle spindle discharge and affecting alpha–gamma motor neuron co-activation (Pedersen et al. 1999). When local muscles are fatigued metabolic products of muscular contraction, including bradykinin, arachidonic acid, prostaglandin E2, potassium and lactic acid activate nociceptors. These inflammatory substances and metabolites have a direct impact on the discharge pattern of muscle spindles (Pedersen et al. 1999).

Simple muscle fatigue can thus play a significant role in the breakdown of normal myokinematics. Tonic muscles, responsible for arthokinematic control, can be more significantly affected in cases of pathology due to inhibition or excessive fatigue from pain and muscle guarding. Previous studies in the lower extremity of healthy young adults have shown that exercise-induced local muscle fatigue adversely alters joint position sense, impairing neuromuscular control (Skinner et al. 1986, Marks 1994, Lattanzio et al. 1997). Other studies of the knee (Marks and Quinn 1993), elbow (Sharpe and Miles 1993) and shoulder joint (Pedersen et al. 1999) have revealed no such effects.
Exercise-induced local muscle fatigue has been shown to alter knee joint position sense in older adults (Riberior et al. 2007). Early training focuses on coordination and endurance training of the tonic system attempting to normalize movement patterns and reduce the effects of fatigue. Contributions of the Golgi tendon organ (GTO) to modulations in motor performance are not fully understood. Proske and Gregory (2002) found that the GTO signals a rise in tension only when the motor unit is contracting with direct action on the GTO. It did not fire with passive tension placed on the tendon. Thorough understanding of the GTO mechanism of function may not be completely clear, but enhanced
motor performances following exercise is due to both improved mechanical properties of the muscles and better kinesthetic sensibility (Bouet and Gahery 2000). Closed kinetic chain training as well as knee extension exercises in supine have both been shown to improve knee proprioception (Lin et al. 2007).

The basic approach for treatment within the manual therapy lesion concept is to initially focus on the primary tissue in lesion with the optimal stimulus for repair. Repetitive motion for repair results in improved tissue tolerance, as well as reductions in pain and abnormal muscle guarding patterns. Motor recruitment patterns are improved through joint capsule mobilizations to increase collagen mobility and allow for normal receptor feedback. Intracapsular edema and muscle guarding are resolved by increasing local vascularity with repetitive motion that also helps to normalize neuromuscular spindle feedback. Clinically it is impossible to directly assess the level of receptor damage or recovery.

These receptors may take months to repair, or may never fully recover, depending upon the level of damage. Other receptors in the system must be sensitized through training to replace the afferent information to the joint system. The muscle spindle then becomes the primary focus through direct training of tonic muscles to coordinate joint motion around a physiological axis. As noted above, these receptors provide joint position sense and contribute to alpha motor neuron firing for motor recruitment. Other receptors that can contribute to motor facilitation during early coordination training include cutaneous receptors (taping/bracing), adjacent mechanoreceptors in other joints of the kinetic chain (repetitive motion), receptors in the vestibular system (weight bearing balance training), receptors of the ocular system (watching motion or EMG computer screen) and auditory receptors (EMG signals turned to auditory feedback).

Emphasis on the muscle spindle is first addressed by concentrically training the tonic muscles associated with arthrokinematic control of joint motion.

Resistance below 50% of 1RM allows for high repetitions to train coordination, avoid fatigue and compensatory movement patterns, as well as improve circulation to resolve muscle guarding. Increasing resistance to 60% of 1RM will serve to improve endurance qualities by stimulating tissue capillarization. Isometric work is then used to help stabilize joint motion in the newly gained range for hypomobilities or toward the range of pathology or instability for hypermobilities. Isometric work allows for training at greater resistances than with concentric work, which helps to efficiently increase muscle spindle sensitivity. Eccentric motion is then performed toward, but not into the pathological range to further increase muscle spindle sensitivity with dynamic training.

The use of cutaneous receptors to augment afferent feedback from functioning receptors, and to replace lost signals from damaged receptors, can be achieved through the use of taping and bracing. A study testing the ability of the knee to replicate joint angles after application of a neoprene sleeve (sleeve effect) was found to be significantly less during the supine closed kinetic chain test (0.3 degrees, +/- 1.4 degrees) than during the sitting open kinetic chain test (Birmingham et al. 1998). Sleeve effects were small in this study, particularly during the supine closed kinetic chain test, but 72 percent of subjects felt that the sleeve improved their test performance. Taping techniques to the skin have also been used to improve knee proprioception. Callaghan et al. (2007) studied the effect of taping in joint position sense, active angle reproduction and passive angle reproduction on patients with PFPS. As a whole, taping did not improve these three variables, but a subgroup of those with significant deficits in proprioception did show significant improvements. Similar results were found in ankle taping, as only those subjects with deficits in proprioception demonstrated improvement (Callaghan et al. 2002). Taping and bracing can be used early to improve proprioception, but the patient should be gradually weaned from dependency on cutaneous input for normal motor function. Clark et al. (2000) did demonstrate that exercise, not taping, is responsible
for earlier discharge from therapy in patients with anterior knee pain.

Many techniques can be used to increase the firing pattern of the quadriceps. One of the most common is to use the afferent receptors of the skin to facilitate quadriceps activity. There are many uncontrolled studies stating that the McConnell taping regimen has given 92–96 percent pain reduction after five to eight sessions (McConnell 1986). This technique calls for an immediate pain reduction of 50 percent with the corrective taping in order for its use to be deemed appropriate. Eboure and Bannister (1996) compared McConnell taping with isometric quadriceps training, and found them to be equally effective at controlling patellofemoral pain. The Cochrane Review (2002) for patellofemoral pain found moderate evidence for McConnell taping and strong evidence for therapeutic exercise in managing patients with patellofemoral pain syndrome.

**Vascularity / Circulation**

Dosage for improving vascularity and circulation requires low resistance, high repetition dynamic motion. Isometric training is avoided in this stage, as it creates intramuscular pressures that lead to circulatory stasis within the particular muscle(s) involved. Pain is also avoided with training to prevent onset of muscle guarding that can lead to abnormal movement patterns. In the presence of significant tonic fiber atrophy, resistance set at <40% of 1RM is enough to facilitate strength gains, prevent quick fatigue and compensatory motor recruitment patterns, as well as minimize intramuscular pressures that reduce local circulation at higher RM percentages. Emphasis on local muscle circulation and endurance is most efficiently achieved at around 60% of 1RM. Specificity of repetitions, resistance and rest breaks ensures enough energy is left in the system for protein synthesis of repairing tissues. Performing a high number of repetitions also provides both a mechanical as well as a neurological influence for tissue repair and pain inhibition.

**Coordination / Motor Learning**

Coordination is the contraction and relaxation of muscles in a specific sequence and magnitude that produces movement around a physiological axis of motion for proper joint function. It is a function of neuromuscular control or neurological adaptation that improves with repetitive training. Coordination relates to the execution of a particular skill, while motor learning refers to the process of acquisition of the skill. Coordination training with motor learning techniques should emphasize natural patterned movements when possible, rather than attempting to isolate a specific muscle. For example, the vastus medialis obliquus is often exercised in isolation to help normalize patellar mechanics and knee function. Attempting to train in this manner is both nonfunctional, and inconsistent with the neurological drive that governs patterned movements. Cerny (1995) showed that the VMO could not be isolated or preferentially recruited with various open kinetic chain or closed kinetic chain exercises, which was also confirmed by Laprade et al. (1998) and Vaatainen et al. (1995). Exercises attempting to isolate the VMO are actually training the knee extensor pattern which includes all the muscles of the quadriceps complex. Although it cannot be selectively isolated, the VMO can be emphasized with specific exercises. Muscle isolation programs may have some benefit in improving kinesthetic function, however they lack functional relevance according to Cowan et al. (2002). As previously described, normal myokinematics for the knee are not achieved by a single muscle, but involves muscles of the entire lower limb, including the lumbar spine, pelvis, hip, knee and ankle. Initial exercise programs should progress to more functional designs as soon as tolerated by the injured tissue. Weight bearing exercises have been shown to be more effective in rehabilitation of injured limbs, and is partly attributed to the greater recruitment of the afferent neural receptors in the inert and contractile tissues of the knee. Exercise design should include groupings of muscles working in synergy to complete a movement pattern, as this is more consistent with normal motor patterns.
The literature contains studies outlining various approaches of motor recruitment for coordination training. Many of these studies emphasize afferent mechanoreceptor function in the joint structures and their influence on normal motor recruitment. Freeman and Wyke (1967) stated that the joint receptors likely contribute to the “coordination of muscle tone in posture and movement” via the gamma motor neuronloop. Sojka et al. (1989) concluded that the cruciate ligaments play a sensory role acting on the central nervous system via reflex actions of the gamma motor spindle system that regulates muscular stiffness of the knee joint, and improve dynamic stability. Elmqvist et al. (1988) suggests that the reason for decreased maximum and total knee extensor performance is due to a change in knee joint receptor afferent inflow. Passive manual techniques, as well as mobilization exercises, to improve capsular mobility will assist in normalizing afferent input for proper motor recruitment. Resolution of spinal segmental dysfunction or facilitation can assist in reducing pain levels at the knee and improving lower quarter motor recruitment. Similar improvements in afferent responses and lower quarter patterns will also be noted with restoration of normal mobility in the joints of the hip, ankle and foot. Mobilizing exercises for these regions are covered in their respective chapters.

Quadriceps training can and should be incorporated early in rehabilitation programs, including acute stage ACL reconstruction (Morrissey et al. 2004). Weight bearing exercises should be added as soon as indicated for early synchronization of the vasti and hamstring muscles to facilitate co-contraction and provide stability to the knee.

Open Kinetic Chain and Close Kinetic Chain Exercise

The lower quarter kinetic chain is comprised of the hip, knee and ankle joints (Palmitier et al. 1991). Closed kinetic chain (CKC) exercise refers to having the foot fixed on a surface with free movement of the proximal segments. They employ specificity of training principles through recruitment of all hip, knee and ankle extensors in synchrony. The spine is typically left out of the discussion in relation to CKC training, but is an important part of the kinetic chain. Lumbopelvic stability will affect the alignment of the pelvis on the fixed femur, and have direct implications on function of the lower limb joints. Hip weakness, commonly associated with knee pathology, may have a lumbar origin that requires direct intervention in conjunction with a knee rehabilitation program.

For testing performance, CKC movements are unable to effectively evaluate specific muscle function and instead are more geared toward assessing functional performance. Conversely, open kinetic chain (OKC) testing is better able to isolate and detect specific muscle impairment. Augustsson and Thomee (2000) found a significant correlation between tests of functional performance and closed and open kinetic chain tests of muscular strength. Petschnig et al. (1998) found moderately strong correlation between isokinetic quadriceps strength tests and four different functional performance tests in healthy subjects and post-ACL repair patients. Blackburn and Morrissey (1998) found weak correlation between open kinetic chain knee extensor strength and the low vertical and standing long jump tests.

Östenberg et al. (1998) recommended not using functional performance and isokinetic testing interchangeably. For clinical purposes, OKC testing may assist in identifying specific muscles to emphasize during training that may even translate to CKC training. Functional CKC testing may serve as an indicator for when to progress with functional exercises and return to athletic activities. The effectiveness of training or rehabilitation programs should be based on changes in performance rather than tests of muscular function (Murphy and Wilson 1997). Carter and Edinger (1999) found only half of the competitive athletes in their study had achieved at least 80 percent of their leg strength six months after ACL surgery. Despite these strength deficits, it is not uncommon to allow patients to return to full activities at six months,
2. Exercise for the Knee

Benefits early motor facilitation of inhibited muscles through cross-education training. Recruiting muscles of the uninvolved limb will have a neurological cross-education effect and improve facilitation of the same muscles on the involved limb. Seger and Thorstensson (2005) demonstrated a specific cross-education effect with both concentric and eccentric training. Work type and velocity specific increases in strength occur in the contralateral, untrained leg and are accompanied by a specific increase in eccentric to concentric EMG ratio after eccentric training.

Tissue Stress / Strain with OKC and CKC

Support in the literature exists for both OKC and CKC exercises for all knee pathology, including ACL deficient knees and those with patellofemoral pain syndrome (PFPS). Proper exercise design and dosage will determine the degree of safety and quality of the functional outcomes. Both OKC and CKC exercises can be modified and implemented for quadriceps training after ACL reconstruction without causing excessive ACL strain or patellofemoral joint stress (Fitzgerald 1997, Ross et al. 2001).

Co-contraction and synergistic muscle recruitment during closed chain activities may be safer in the presence of knee laxity, as less load is placed on the capsuloligamentous structures. OKC exercises are commonly restricted to seated knee extension for quadriceps training and prone hamstrings curls. But OKC training can also includes sling exercises that allow for essentially zero resistance flexion and extension to stimulate tissue repair, reduce pain and resolve edema. Some authors report an increase in co-contraction of the hamstrings and quadriceps with CKC exercises, believed to increase dynamic stability to ACL deficient knees (Beynnon and Fleming 1998, Fleming et al. 2001b). Other authors have noted little hamstring recruitment during squatting motions, but rather a synergistic action between the quadriceps and gastrocnemius muscles (Kvis and Gillquist 2001).
Anterior translation in normal, ACL-deficient and ACL-reconstructed knees. A notable finding was that the ACL reconstructed knee using a bone-tendon-bone autograft demonstrated a significantly smaller increase in translation. Reduced laxity in the reconstructed knee may be related to a stiffer central third of the patellar tendon graft versus a normal ACL, increased stiffness from early degenerative arthritis or a minimal generalized fibrosis that may occur following major reconstructive surgery.

Choosing and designing exercises that minimize the potential for anterior shear forces, and ensuring proper technique during the exercise, can minimize the cumulative effect on the ACL deficient or repaired knee during rehabilitation. Restoration in the integrity of the ligamentous structures is difficult to predict. Nawata et al. (1999) did measure about a one third increase in ACL laxity in normal knees after 20 minutes of running at seven km/hr., but integrity was restored within one hour after running. Sumen et al. (1999) assessed post-exercise translation in ACL reconstructed knees with a hamstring graft 15 months after surgery, finding increased laxity in the control group, but no increase in the reconstructed group.

Weight bearing motion in the pathological knee typically does not demonstrate abnormal adduction or abduction of the tibia on a fixed foot, but rather abnormal femoral motion. Jonsson and Karlholm (1994) measured joint motion on ACL deficient knees during step training and found little change in tibial adduction/adduction, but noted an anterior shift in the femur (PCL strain) and a distal and anterior shift of the joint axis for sagittal plane rotation. The abnormal adduction component of the femur during weight bearing training, as seen with valgus moments at the knee, may not be as significant as the deficient external rotation support at the hip.

It has been widely accepted that female athletes sustain disproportionately more ACL injuries than do male athletes who compete in similar sports (Arendt and Dick 1995, Ferretti et al. 1992, Gray

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**Benefits of CKC Exercises**

- Increase co-contraction of the quadriceps and hamstrings (Beynnon and Fleming 1998, Fleming et al. 2001b).
et al. 1985, Hutchinson and Ireland 1995, Nielsen AB, Yde 1991, Zelisko et al. 1982). It has also been widely thought that material properties of the ACL are affected by the normal fluctuations of the hormones associated with the menstrual cycle, possibly leading to increased risk of injury (Liu et al. 1996, Liu et al. 1997, Myklebust et al. 2003, Slauterbeck et al. 1999, Slauterbeck et al. 2003, Wojtys et al. 2002). Contrary to these previous authors, Pollard et al. (2006) did find an increase in ACL laxity in females, as opposed to males, after training, but the stage of menstruation or estrogen levels did not correlate with increased laxity. Belanger et al. (2004) also demonstrated that ACL laxity is not significantly different during the follicular, ovulatory and luteal phases of the menstrual cycle. The authors did list intrinsic factors that influence the anatomy and physiology of the knee directly for injury risk, including generalized ligamentous laxity, ACL size, femoral notch dimensions, limb alignment and ligamentous physiology. Extrinsic factors were considered more remote, but nevertheless influence the development of loads in the joint. These included the level of strength and conditioning, body mechanics, neuromuscular performance and footwear.

During weight bearing squats the tibial plateau tips forward, sloping anterior. Body weight causes an anterior translation of the femur on a fixed tibia, placing tension on the PCL and unloading the ACL. Lutz et al. (1993) demonstrated significantly greater compression forces and increased muscular co-contraction at the same angles at which the open-kinetic-chain exercises produced maximum shear forces and minimal muscular co-contraction.

<table>
<thead>
<tr>
<th>Rehabilitation Exercise/Test</th>
<th>Peak Strain Percent (mean standard error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isometric quadriceps contraction at 15 degrees (30 Nm extension torque) (OKC)</td>
<td>4.4 (0.6)</td>
</tr>
<tr>
<td>Squats with sport cord (CKC)</td>
<td>4.0 (0.6)</td>
</tr>
<tr>
<td>Active flexion–extension of the knee with 45 N weight boot (OKC)</td>
<td>3.8 (0.5)</td>
</tr>
<tr>
<td>Lachman test (150 N of anterior shear load; 30-degree flexion)</td>
<td>3.7 (0.8)</td>
</tr>
<tr>
<td>Squats (CKC)</td>
<td>3.6 (0.5)</td>
</tr>
<tr>
<td>Active flexion–extension (no weight boot) of the knee (OKC)</td>
<td>2.8 (0.8)</td>
</tr>
<tr>
<td>Simultaneous quadriceps and hamstring contraction at 15 degrees (OKC)</td>
<td>2.8 (0.9)</td>
</tr>
<tr>
<td>Isometric quadriceps contraction at 30 degrees (30 Nm extension torque) (OKC)</td>
<td>2.7 (0.5)</td>
</tr>
<tr>
<td>Stair climbing (CKC)</td>
<td>2.7 (1.2)</td>
</tr>
<tr>
<td>Leg press at 20-degree flexion (40% body weight) (CKC)</td>
<td>2.1 (0.5)</td>
</tr>
<tr>
<td>Anterior Lunge (CKC)</td>
<td>1.9 (0.5)</td>
</tr>
<tr>
<td>Stationary cycling (CKC)</td>
<td>1.7 (0.7)</td>
</tr>
<tr>
<td>Isometric hamstring contraction at 15 degrees (to 10 Nm flexion torque) (OKC)</td>
<td>0.6 (0.9)</td>
</tr>
<tr>
<td>Simultaneous quadriceps and hamstring contraction at 30 degrees (OKC)</td>
<td>0.4 (0.5)</td>
</tr>
<tr>
<td>Isometric quadriceps contraction at 60 degrees (30 Nm extension torque) (OKC)</td>
<td>0.0</td>
</tr>
<tr>
<td>Isometric quadriceps contraction at 90 degrees (30 Nm extension torque) (OKC)</td>
<td>0.0</td>
</tr>
<tr>
<td>Simultaneous quadriceps and hamstring contraction at 60 degrees, 90 degrees (OKC)</td>
<td>0.0</td>
</tr>
<tr>
<td>Isometric hamstring contraction at 30, 60 and 90 degrees (10 Nm flexion torque) (OKC)</td>
<td>0.0</td>
</tr>
</tbody>
</table>

** The failure strains of the normal ACL are approximately 15% (Butler et al. 1992).
Open chain extension also involves anterior movement of the tibia on a fixed femur, placing excessive strain on the ACL. Jenkins et al. (1997) found an increase in anterior tibial displacement in open chain, compared to closed chain isometric work at 30 degrees and 60 degrees. This issue is most relevant to the ACL deficient, ruptured or repaired knee, and is dependent upon the amount of distal resistance.

Studies of knee laxity after heavy resistance squat training are consistent with increased PCL rather than ACL tension due to anterior femoral translation during closed chain activities. Increased PCL tension throughout the range has been demonstrated for a closed chain squat (Escamilla 2001), while open chain knee extension increased ACL tension from 40 degrees to full extension (Wilk et al. 1996). Stuart et al. (1996) had similar findings of a net posterior tibial shear force (PCL strain) with power squats, front squats and lunges. Assessment of both normal subjects and post ACL reconstruction patients, support safer and more beneficial outcomes with a closed chain emphasis when compared to open chain activities. Chandler et al. (1989) found no increased laxity with power lifters and weight trainers after eight weeks of heavy resistance squat training. Panariello et al. (1994) found no increase in laxity with squat training in football players. Yack et al. (1993) demonstrated significantly less stress to the anterior cruciate ligament using closed chain parallel squats, compared to the relative anterior tibial displacement during knee extension. Heijne et al. (2004) showed that ACL strain produced during step-up, step-down, lunge and one-legged sit to stand exercises was similar to that produced during other rehabilitation exercises (i.e., squatting, active extension of the knee) previously tested.

Athletic activity has been attributed to increased laxity of the knee. Steiner et al. (1986) suggests that repetitive physiologic stresses at a high strain rate produce significant ligamentous laxity, where this is avoided with fewer repetitions at higher loads. Increased ligamentous laxity was found in college runners and basketball players up to 90 minutes after participation, but not in weight trainers performing squats. Kvist et al. (2006) measured increased laxity in both male and female volleyball players, comparing measurements before and after performance, while swimmers were found to have no increased laxity. Grana and Muse (1988) measured a significant increase in ACL laxity in controls and in ACL deficient knees after 20 minutes on a bicycle ergometer, though Belanger

A generalized ACL rehabilitation program has been previously described in detail (DeMaio et al. 1992a, DeMaio et al. 1992b, Mangine et al. 1992, Noyes and Barber-Westin 1997) and divided into four phases consistent with the four stages in this chapter (Barber-Westin and Noyes 1993, Barber-Westin et al. 1999). This program was assessed for long term ACL laxity, and was found that the rehabilitation program was not itself injurious and resulted in an acceptable failure rate of 5 percent (Barber-Westin et al. 1999).

- **Phase 1:** The assisted ambulatory phase (approximately lasting up to the fourth to eighth week after surgery). Patient using crutch or cane support with exercises for range of motion: straight leg raises (extension, flexion, abduction and adduction), quadriceps muscle isometrics, electrical muscle stimulation, and closed-chain exercises (minisquats, toe raises).

- **Phase 2:** The early strength training phase (from 4th to 8th postoperative week to the 12th to 16th). Exercises incorporate balance, proprioception and gait-training.

- **Phase 3:** The intensive strength training phase (varies for each patient lasting from between the 12th to16th postoperative week to between the 24th and 52nd). More strenuous training consists of progressive resistive exercises, swimming, bicycling, ski machines, stair climbing machines and running programs.

- **Phase 4:** The return to sports phase (begins after successful completion of phase 3). Formal rehabilitation is discontinued with return to sport.
et al. (2004) found no significant ACL laxity in a 10-week cycling program in healthy female college athletes, suggesting over time these temporary changes in laxity in training may not of concern.

**Muscle Performance with OKC/CKC**

Muscle fatigue is a relevant issue pertaining to excessive ACL strain and injury. Increased injury rates during the later portion of games in a variety of sports have been identified including rugby (Gabbett 2000 and 2002), in the arms of baseball pitchers (Lyman et al. 2001), soccer (Rahnama et al. 2002) and with rapid run and stop testing (Nyland et al. 1994). More specifically Chappell et al. (2005) compared anterior tibial shear with fatigue related to stop-jump tasks. Subjects performed vertical, anterior and posterior stop-jumps with assessment of jump height and anterior tibial motion. Fatigue significantly increased the peak anterior shear force on the proximal tibia for both male and female subjects. Fatigue also increased the valgus moment at the knee in both male and female subjects. Russell et al. (2006) also found that women land from a single leg drop jump in more knee valgus than men, both before and upon impact. The authors concluded that excessive valgus knee angles displayed in women might be one explanation for the sex disparity in anterior cruciate ligament injury. Adequate rest breaks during early training to avoid fatigue can assist in reducing the overall anterior shear forces during rehabilitation, and may be more important in females. Ensuring ample overall training time to reestablish endurance and strength will also reduce fatigue upon returning to sport, and thus reduce risk of re-injury.

The issue of recruitment ratios within the different portions of the quadriceps complex is irrelevant in closed chain training. Synergistic function between the different portions of the quadriceps musculature is necessary for all knees, but may be of particular importance in designing training programs for establishing control of the patellofemoral joint in subjects with patellofemoral pain syndrome (PFPS). The importance of the recruitment ratio between vastus medialis obliquus (VMO) and vastus lateralis (VL) for controlling patellar tracking is debatable. Mellor and Hodges (2005) demonstrated a neuromuscular motor unit synchronization of the VMO and the VL in closed chain exercises, not found with open chain extension. Stensdotter et al. (2003) also found more balanced initial quadriceps activation in closed chain versus open chain exercises. Tang et al. (2001) did find lower VMO/VL ratios of PFPS subjects compared to unimpaired subjects, though not statistically significant, during knee isokinetic CKC exercises. Slightly greater coupling between the VMO and VL has been shown with CKC versus OKC (Mellor et al. 2005). Stensdotter et al. (2003) assessed the onset of EMG activity of the four different muscle portions of the quadriceps with isometric knee extension, findings more simultaneous contractions in CKC than in OKC isometrics. In OKC isometrics the rectus femoris had the earliest EMG onset, and the vastus medialis obliquus was activated last with smaller amplitude. CKC training seems to promote more balanced initial quadriceps activation and may be more efficient for coordination training of quadriceps coupling in the PFPS patient. Knee and trunk positions as well as Q-angle and femoral/tibial torsion must be considered with PFPS patients as all these factors all affect the patellofemoral joint. For instance deeper squats and lunges increase patellofemoral contact forces especially with knee flexion between 60–90 degrees (Huberti et al. 1984, Ho et al. 1994, Grelsamer et al. 2001), but trunk flexion reduces quadriceps tension and joint compression at any given angle (Ohkoshi et al. 1991). Tibial and femoral torsions, as mentioned earlier, affect patellar contact locations and increased Q-angles can magnify loads placed on the lateral aspect of the patellofemoral joint. Also patella alta can reduce contact between the quadriceps tendon and femoral groove, which affects the mechanical ability to relieve pressure on the patellofemoral joint at high flexion angles (Huberti et al. 1984). Therefore it is important to monitor positioning of the entire leg from the hip to the foot, the range of the exercise and trunk position so that forces across the knee are properly managed during rehabilitation.
OKC extension training in normal knees is also associated with a relative shift in the instantaneous axis of motion. Distal resistance on the tibia shifts the axis from the femoral condyles toward the attachment of the quadriceps tendon at the tibial tubercle. This causes the tibia to translate posteriorly during extension, rather than anteriorly, increasing tension on the posterior cruciate ligament (PCL) while relaxing the ACL. Reduced recruitment of the quadriceps and increased facilitation of the hamstrings ensues, with some eccentric participation of the quadriceps (Grimsby 1980). Applying a pulley strap proximal to the tibial insertion of the quadriceps for extension training and starting in a range greater than roughly 30–40 degrees of flexion, will produce a normal anterior tibial translation.

Exercises that are more closely related to a required task will more efficiently improve muscle performance qualities for that task. Blackburn and Morrissey (1998) demonstrated that CKC muscle strengthening was more highly related to jump performance than knee extensor OKC strengthening. Isokinetic quadriceps training for patients with PFPS has shown positive effects on passive position sense, as well as increasing strength and work capacity (Hazneci et al. 2005). But isokinetic training has also shown poor correlation with function hopping tests (Alaca et al. 2002), suggesting the need for inclusion, or an eventual progression, to more functional exercises.

Clinical Comparisons of OKC/CKC

Previous research identified specific traits of OKC and CKC training as it relates to motor recruitment, forces across the joint, tissue stress and isolated training variables. Bynum et al. (1996) compared two rehabilitation protocols for ACL reconstruction, which included both an open chain and closed chain program. The CKC group was found to have lower mean KT-1000 arthrometer side-to-side differences for anterior shear, less patellofemoral pain and more often returned to normal daily activities and sports sooner than expected. Hooper et al. (2001) also compared OKC and CKC programs in patients with ACL reconstruction by measuring walking, stair ascent and stair descent. Seventeen knee variables were studied and only the angle of knee flexion during stair ascent, favoring earlier increases in ROM...
with the OKC group, was noted as a statistically significant difference between the groups.

Stiene et al. (1996) compared OKC and CKC exercises for patients with patellofemoral dysfunction to controls. Both groups improved in peak torque measures of the quadriceps at different speeds, but only the CKC group demonstrated significant improvement in CKC testing and perceived functional status. Witvrouw et al. (2000) compared an OKC to a CKC five-week program in subjects with patellofemoral pain. No significant difference was noted in muscle characteristics, subjective symptoms and functional performance at the end of the treatment period, and three months later. The CKC group tested better for the triple-jump test, the frequency of locking in the knee joint, clicking sensations in the knee, night pain and pain during isokinetic testing, suggesting that CKC training was little more effective than the OKC program. A five-year follow up again found little statistical significance between the two training groups (Witvrouw et al. 2004).

The Biomechanical Chain

Relative to a fixed foot on the ground, and a less mobile hip and pelvis, the knee is by nature unstable. Though it primarily acts as a hinge joint with one degree of freedom, accessory motions of the knee include spin and lateral gliding between the tibia and femur. The lateral gliding movements are a part of normal valgus and varus moments at the knee. Weight bearing internal rotation of the tibia occurs with ankle dorsiflexion and knee flexion, as plantarflexion and knee extension are accompanied by tibial external rotation. In open chain movements the screw home mechanism involves an external rotation of the tibia. Inert structures, such as ligaments and joint capsules, assist in guiding motion in the lower limb.

Basic descriptions of biomechanical breakdown include excessive supination creating an abnormal varus force moment at the knee, while excessive pronation would cause a valgus moment and collapse of the medial arch. Addressing the passive inert structures may require an alteration in footwear or an orthotic lift to support the arch. Limited dorsiflexion at the talocrural joint will reduce the amount of internal rotation of the tibia. A compensatory increase in external rotation of the femur can result creating the potential for tissue damage, such as meniscal and cruciate ligament injury. Conversely, reduced hip internal

Adjunct Treatment

Treating mobility issues in the knee, whether hypomobile or hypermobile, requires an assessment of both proximal and distal structures. A basic tenet of stabilizing hypermobile joints is to initially restore mobility to any adjacent joint or tissue restrictions. Mobilization exercises for the foot, hip and lumbopelvic region may be a necessary precursor to functional stabilization training for the knee. A hypomobile knee may be placing excessive stress on surrounding tissues and any accompanying restrictions in adjacent joints of the lower limb need to be identified and addressed in Stage 1. A comprehensive treatment plan consisting of both active and passive interventions must consider the joint and muscle function from the lumbar spine to the ankle, yet a complete description of the biomechanical relationships between these joints goes beyond the scope of this chapter.

Figure 2.27a,b: Partial squats using the pull down machine with the gravity assist cage. Body weight is reduced using the weight stack as a counter balance. This will allow the person to perform a coordinated movement pattern with more pain free repetitions.
rotation from a restricted capsule may lead to compensations at the knee or foot. Reduced extension of the first metatarsophalangeal joint can lead to excessive external rotation of the entire lower limb transmitting abnormal forces across the medial knee joint. Numerous restrictions from joint capsules, and myofascial structures can all contribute to mechanical changes in mobility and force transmission in the lower quarter.

Not only mobility, but also alignment of the joints in the biomechanical chain can affect motion and motor recruitment. Abnormal movement patterns, compensations and weak muscles may all normalize, or at least improve, when normal biomechanical relationships are restored. Joint restrictions should be addressed first followed by a reassessment of motor function to help direct specific exercises for improved motor performance. Treatment at the hip for reduction of knee pain has been shown to be effective by Cliborne et al. (2004). After just a single session of hip mobilizations, patients experienced increases in knee range of motion as well as decreases in pain complaints, and painful test findings. These improvements may be from inhibition of muscle guarding, improved lower quarter biomechanical function, increased muscle facilitation and/or resolution of referred pain originating from the hip. This study illustrates the need to assess the mechanics and function of all surrounding joints in order to determine their potential effects on the knee.

The Myokinematic Chain

The myokinematic chain refers to synergistic muscle function of the pelvis and lower limb. Functionally all muscles are synergistic working together around the joint axis to properly coordinate motion of the joint system. The brain acts to fire muscles within global functional patterns, rather than in isolation. Tepperman et al. (1986) found that the facilitation of either ankle plantarflexors or dorsiflexors during isometric knee extension significantly increased quadriceps peak torque. Alterations in function of any muscle or muscles in the chain of a movement pattern, can have deleterious effects on function.

Knee dysfunction, including patellofemoral dysfunction, is often blamed on weakness or poor timing of the vastus medialis obliquus (McConnell 1986, Boucher et al.1992), while weak hamstrings have been implicated in anterior tibial shearing with anterior cruciate ligament dysfunction (Tsepis et al. 2004). While these specific muscle tests constitute important findings, evaluating more complex muscle recruitment patterns can serve as better indicators of abnormal function.

The gluteus medius, gluteus maximus and deep external rotators are the main stabilizers at the hip during lower quarter weight bearing activity. Eccentric function of these muscles in weight bearing stabilizes the pelvis on the hip, as well as preventing adduction collapse of the femur relative to the knee. Leetun et al. (2004) found that basketball and track athletes who did not sustain lower extremity injuries had stronger hip abduction and external rotation strength. Impairments such as lateral patellar tracking problems, joint degeneration, patellar tendinopathy or ITBS (Iliotibial Band Syndrome) often present with motor weakness proximally at the hip and less often at the ankle. Predominant proximal weakness at the hip, pelvis and lumbar spine may contribute to unopposed hip adduction, flexion and internal rotation leading to abnormal knee valgus and compression of the patellofemoral joint. Weakness of the gluteus medius is compensated for by excessive tensor fascia lata (TFL) facilitation, placing increased tension through the iliotibial band (ITB). The ITB is then determined to be tight and treated as a primary cause of dysfunction, rather than as a secondary compensation for posterior hip weakness. Stretching the ITB will not improve proximal hip stability, reduce the knee valgus moment or the tissue irritation at the lateral knee.

Proximal dynamic stability includes not only the hip, but the lumbar spine as well. The hip abductors and external rotators along with the ipsilateral spinal muscles all act together to provide weight bearing stabilization to the pelvis on the femur. Lumbar dysfunction resulting in motor
inhibition will negatively affect stability of the lower kinetic chain. Hart et al. (2006) measured reduced quadriceps strength after performance of spinal extension exercises to fatigue, in both normal subjects and those with a history of low back pain.

Motor function at the knee may also be influenced by mobilization of adjacent joints in the kinetic chain. Normalizing hip capsular mobility will assist in normalizing motor function of the hip musculature and improving lower quarter dynamic support. Uptraining the gluteal muscles will reduce the abnormal alignment and forces transmitted to the knee joint. Acute low back pain or chronic segmental facilitation, can result in reduced motor recruitment of the hip and knee musculature. Treating the lower lumbar segments may serve to normalize tone, as well as improve facilitation and coordination of these muscles. For example, segmental dysfunctions at L4/5 or L5/S1 can increase the resting tone of the hamstring muscle group leading to increased patellar compression in flexion. Rather than stretching the tight hamstrings, treatment to the lumbar spine may be more effective in restoring hamstring length.

Distal function at the ankle also effects knee and hip motor function. Plantarflexor weakness reduces extension stability of the knee from mid stance to step off and may lead to overuse pathologies of the patellar tendon. Bulluck-Saxton et al. (1994) demonstrated how previous ankle ligamentous and receptor injury decreased the activation of the hip extensors. Passive viscoelastic ligaments and dynamic viscoelastic muscles provide stability to joint systems. The viscoelastic effects of the ligaments are activated and applied strictly upon the geometric and kinematic configuration of the joint moving through its range of motion. The musculature can apply both passive as well as variable dynamic viscoelastic effects and are the primary structures for absorbing and transmitting forces up the biomechanical chain. Ligaments act to primarily guide the joint around its axis of motion and provide afferent feedback for proprioception and recruitment via mechanoreceptor activation.

Just as ligamentous strain (hypermobility) or capsular stiffness (hypomobility) can alter normal mechanics and function of the lower limb, abnormal motor responses result in reduced performance and excessive tissue stress and strain from the lumbar spine to the foot. Preservation of joint stability must be considered as a synergistic function in which bones, joint capsules, ligaments, muscles, tendons and sensory receptors and their spinal and cortical neural projects and connections function in harmony. The role of the musculature in maintaining stability while controlling joint motion is considered to be one of the most important factors for proper joint stability Solomonow and Krogsgaard (2001).

The Neurological Chain

The neurological system plays an obvious role in function. Nerve pathology proximal in the lumbar spine, or associated with peripheral nerve entrapment, will impact motor function and pain levels. Adverse neural tension may even have an impact on gross mobility, and has been suggested as a component of hamstring strain injury (Turl and George 1998). Any dysfunction of the nervous system should take precedence, or be treated in conjunction with, the primary knee pathology. But even with normal nerve conduction and mobility, the impact of the central nervous system and peripheral afferent system on motor function should be addressed. Issues of central balance will be addressed later in this chapter.

The osteopathic lesion, or segmental facilitation, was first described by Korr (1947) as an abnormal afferent bombardment of a segment resulting in an altered efferent response with sensitization of the gamma motor system, as well as increased sympathetic and even glandular output. Facilitation in the L3 lumbar segment can increase pain sensitivity and alter normal motor patterns. Addressing segmental sensitization, when present, prior to direct training to the knee may reduce pain and improve motor performance allowing for a higher level of training. Mechanoreceptors embedded in collagen provide afferent feedback for
muscle activation, pain modulation and balance reflexes. Spinal treatment at the level that correlates with the symptomatic region may have a profound result in decreasing tone or improving motor recruitment to the involved joint.

Slow adapting mechanoreceptors act to monitor joint position and slow-adapting receptors offer feedback for speed and acceleration variables with joint motion (Schutte et al. 1987). Small changes in the tension of the ligaments can influence the fusimotor system of the muscles acting at the knee joint, participating in the regulation of stiffness, and ultimately to dynamic stability (Sjolander et al. 1989, Johansson et al. 1991). The receptors of the collateral ligaments in response to tension act to regulate muscle stiffness and increase stability at the knee as those found in the ACL (Sojka et al. 1991). The neurophysiological system that monitors motion, speed, chemical changes, pain and pressure within joint systems must be taken into consideration with any rehabilitative program. If the environment of the joint structure is not conducive to proper receptor function, the desired outcome of the exercise program cannot be achieved.

Summary

Numerous combinations of joint restriction, joint hypermobility, muscle stiffness, muscle weakness, poor motor timing and poor motor conditioning can lead to a multitude of pathological presentations. Thorough evaluation of the biomechanics, motor performance and neurological function will assist in a complete treatment plan and more specific exercise design and dosage.

Section 2: Stage 2 Exercise Progression for the Knee

Training Goals

Stage 1 exercises resolved the acute issues of muscle guarding, joint restriction, inflammation and pain. Emphasis may be placed on one or all of these depending on the patient’s pathology, stage of healing, type of surgical intervention, training level and general health. Each exercise is progressed as the specific functional quality being trained is realized. Progression to Stage 2 implies that proper joint mechanics have been restored, alignment of the lower limb is normalized, and a level of tissue healing has occurred to allow for more challenging exercises. The focus shifts more toward an emphasis on motor performance and stabilization within the newly gained range of motion.

Training Goals Stage 2

- Increase repetitions (endurance)
- Increase number of sets
- Increase number of exercises
- Increase speed (strength/endurance)
- Histologically—increase lubrication of tissue
- Increase range of motion (if hypomobile or pain free)
- Body/limb change from recumbent to dependent
- Add isometrics in the range that strength/stability is wanted
- Locking: change to coordinative locking or remove altogether
- Planar motions with exercise
- Add upper extremity closed chain exercise

Basic Stage 2 concepts include increasing the range and speed of training as well as increasing the overall number of repetitions in the program. The focus is on continuing to improve tissue tolerance and coordination while shifting from predominantly open chain to closed chain weight bearing activities and working toward achieving full 3-dimensional range of motion. A closed chain emphasis should address the lower limb as a functional unit, rather than focusing only on the knee. Specific hip or ankle exercises should be employed if deficits exist (refer to the hip and ankle chapters of this text).
Increase Speed not Weight

Increasing weight or resistance is often the first choice made by therapists when progressing exercises. Speed, rather than weight, should be the initial change as it acts to further challenge coordination and actually increases resistance due to the forces of inertia. Coordination is speed specific. Increasing speed to the level of functional requirement is necessary for a return to activity or sport. Recruitment strategies require slow controlled movements initially to establish neurological pathways for properly timed patterns of motor unit activity. This phenomenon of neurological adaptation leads to improvements in coordination with more efficient recruitment patterns that allow for increases in the speed of training. Clinically this often occurs naturally with the patient performing the exercise in less time, which may signal the need to progress the activity.

As mentioned above speed increases the inertial forces of acceleration and deceleration, which adds resistance to the performance. Weight is not increased as these forces provide an adequate increase in tissue stress and demands on muscle performance. Once the speed of the task has reached the functional requirement, then the weight can be increased with a slight reduction in speed to ensure proper coordination. Alternating increases in speed and resistance will continue through Stage 3 and Stage 4.

Speed may also be adjusted to assist or challenge motor performance. Speed changes have different impacts on concentric work (CW) compared to eccentric work (EW). Slow CW allows for a greater load to be overcome, as time allows for additional motor units to be recruited. For example, performing step-ups slowly allows for improved coordination and greater recruitment of the lower limb musculature to assist in overcoming body weight. For eccentric training, speed is increased to increase peak muscle force that acts to reduce the workload. A slow eccentric step-down may be painful and difficult to coordinate. Increasing the speed where the patient quickly “falls” off the step landing on the unininvolved lower limb allows the exercise to be performed early to reestablish coordination for descending stairs. As coordination improves, speed is gradually reduced with eccentric work to better match more normal functional patterns of movement.

Increase Repetitions

A basic progression of Stage 2 is to increase the number of repetitions in the overall training session, or in a daily program. This is accomplished by adding additional sets to the existing exercises, and/or adding exercises to the program. Initial exercises consisting of one or two sets may, if appropriate, increase to three or more sets. Additional exercises may not only address the knee but focus on the lumbar spine, pelvis, hip or ankle. These areas are typically not directly addressed in Stage 1, as the focus is on more acute issues within the knee. The additional repetitions act to continue the process of selective tissue training for repair, and further enhance coordination.

Endurance Training

Tonic muscle performance is emphasized early, as it relates to arthrokinematic and postural support for the lower limb. Tonic muscle fiber is designed for lower load, high endurance performance and is initially targeted with exercise dosage. Endurance training is a function of improved vascularization, cardiovascular conditioning, and tissue capacity. It can be improved through increased repetitions, sets, and time of training as well as reduced rest breaks. Initial coordination training in non-weight bearing from Stage 1 should progress to coordinating lower limb alignment with functional weight bearing activities and exercises.

Isometrics

Isometric work (IW) was avoided in Stage 1 due to the presence of muscle guarding, as circulation is reduced with significant increases in intramuscular pressure. It also fails to provide the repetitive
motion necessary for early tissue repair, pain modulation and coordination training. With resolution of muscle guarding and increasing joint mobility, isometrics are added to assist in fixing strength within the newly gained range of motion.

The main emphasis of IW early in rehabilitation is to more quickly establish joint stability. IW can generate greater peak torques than CW and allows for the use of greater resistances to improve strength qualities. The primary use of isometric work in Stage 2 is to sensitize the muscle spindle to stretch. As the manual therapy lesion described earlier, mechanoreceptor damage in the joint reduces the normal afferent reflex responses for motion. Sensitizing the spindle increases the afferent input to assist in normalizing movement patterns, replacing some of the afferent input lost with the mechanoreceptor damage. As the muscle lengthens toward the hypermobile range, the spindle responds to the tension from the changing length of the muscle. Afferent input from the spindle will assist in the recruitment of alpha motor neuron pools for normal motor recruitment. The primary muscles that would eccentrically stabilize the hypermobile range are trained isometrically in their shortened range. The shortened range is a joint position opposite of the hypermobility. In this range isometric work can be safely performed to begin the process of sensitizing the spindles. In later stages, as a progression, the isometric work can be performed in a range closer to the hypermobile range.

A basic clinical example of this concept is a knee with an ACL injury or surgical repair. The hamstrings would function eccentrically to decelerate the lower leg toward knee extension in open chain activity. Damage to the ligament and joint capsule would damage mechanoreceptors and reduce muscle recruitment for lower limb motor patterns. Stage 1 began concentric work from a mid to shortened range of the muscle, or mid to full flexion of the knee. End range extension is avoided. Stage 2 begins isometric training of the hamstrings with higher resistance, but with the knee in full flexion. As the spindle becomes more sensitive to stretch into the lengthened position, it will fire more easily when the moving toward full extension. The spindle will fire recruiting alpha motor neuron pools for improved recruitment of the hamstrings to decelerate the leg from end range extension.

**Isometric Training Goals**

- Sensitize the muscle spindles in the shortened range of the muscle
- To fix strength

The concept of fixing strength with IW should be performed in the ranges requiring stability and are started with the joint in the opposite range as the instability and the muscles in their shortened position. Stage 2 emphasizes the shortened position of the muscle to sensitize the muscle spindle. Later stages, a progression, may add IW in different joint positions closure to the pathological range of motion. In 1953 Hettinger and Muller published their pioneering work on isometric strength training demonstrating that a six-second isometric hold at 75% of 1RM was sufficient to increase strength. Isometric holds for six seconds at 2/3 of an isometric maximum (IM) were found to lead to the best increase in strength (Muller 1957). Lower levels of resistance can be used with longer hold durations. One isometric hold, at a heavier resistance, can replace one dynamic set in a three set exercise. Isometric peak torque is greater than that of concentric peak torque allowing for a greater resistance with isometric work than used during the dynamic set.

**Joint Locking Training Techniques**

Joint locking concepts are more related to the spine, but the concept is simply to protect tissues from a particular range of motion. For the knee, basic locking may relate to limiting the degree of knee flexion and/or extension. This can be accomplished by having the weight stack come to rest with open chain exercises. An artificial block of the pelvis may be used in weight bearing or partial weight bearing.
closed chain exercise to create a safe environment for initial squat training.

Figure 2.28: Decline sleds, such as the Vigor Gym® pictured, allow for a reduction in body weight for closed chain exercise, but a block for flexion can be set at any range. With the sled in resting position the pelvis is slid down toward the feet until the desired degree of flexion is attained. Repetitive unloaded squatting exercises can then be performed with a mechanical block of end range flexion.

Locking techniques may also be used to influence muscle performance. For example, placing a heel wedge under the medial calcaneous creates slight plantarflexion and inversion of the hindfoot. With squat training this acts to slightly inhibit the soleus and place a greater demand on the quadriceps.

Figure 2.29: Soleus inhibition, with quadriceps emphasis during squatting. A medial heel wedge creates slight inversion and plantarflexion leading to partial inhibition of the soleus function of decelerating the tibia anteriorly during the squat, placing more demand on the quadriceps.

Functional Testing

As Stage 2 shifts toward a more closed chain weight bearing emphasis, functional testing can provide an objective baseline for establishing deficits and guide exercise design. This testing may simply relate to daily weight bearing activities and at times they can be incorporated into the exercise program (de Vreede et al. 2004). For example, the patient recovering from a total joint replacement may have difficulty transferring out of a chair or climbing stairs. Duplicating the functional activity is necessary to establish coordination, and unloading may be necessary to reduce the body weight to allow for a coordinated and safe movement pattern.

Examples of Functional Tests / Measures

- Chair Raise: The coordination of rising from a high chair and the variability of rising from various chair heights indicate a functional recovery after TKA implantation (Boonstra et al. 2006).
- Single Leg Raise: The single leg rising performance demonstrates a positive relationship with knee extensor strength (Aasa et al. 2003).
- 6-Minute Walk: The six-minute walk (6mw) is a well-established measure of aerobic capacity in elders with cardiorespiratory and peripheral vascular disease and may be an accurate measure of functional performance in healthy elders (Bean et al. 2002).
- Self-Timed Walking: Self timed walking test for knee osteoarthritis. Measurements of self-paced walking time can provide both reliable and valid data for evaluating functional performance (OA) of the knee (Marks 1994).
- For more athletic patients there are: Single hop, triple hop, cross-over hop and timed 6-meter hop tests (Noyes et al. 1991).

Functional testing of the lower extremity is an effective and necessary predictor for successful return to pre-injury activity. Most reliable functional tests can be too strenuous for a patient in the acute stage of recovery, and are typically performed in Stage 2. Functional testing provides a baseline of objective measures to mark improvement, predict capacity for return to work/sport, identify movement dysfunction and motivate...
the patient. Exercise programs built around functional tasks are feasible and show promise of being more effective for improving functional performance than a resistance exercise program in elderly women (de Vreede et al. 2004).

Balance Testing / Training

Star Excursion Balance Test (SEBT)
The Star Excursion Balance Test (SEBT) may offer a simple, reliable, low-cost alternative to more sophisticated instrumented methods for testing dynamic balance. The test requires the patient to maintain balance on a single limb, while manipulating the other limb. The SEBT is more extensively outlined in the Ankle Chapter, but will briefly be covered as it relates to the knee.

The SEBT involve single leg stance while reaching in different directions with the opposite lower limb. The reach is performed as far as possible in each of eight prescribed directions (the star pattern), while maintaining balance on the contralateral leg (Olmsted et al. 2000). Directions of reach are listed relative to motion away from the stance leg. A star pattern can be placed on the floor with four lines of tape: vertical, horizontal and two diagonals at 45 degrees angle. Alternatively, one line of tape can be placed on the floor with the subject altering the body position relative to the line for each test, and replicate all eight test directions. The subject lightly touches the furthest point possible on the line with the most distal part of the reach foot, and returns to the center (Olmsted et al. 2000). Measurement of the distance along the tape is recorded in centimeters. For testing purposes, each direction is repeated three times, with a 15 second rest between each reach. A trial is deemed invalid and repeated if the subject 1) does not touch the line with the reach foot while maintaining weight bearing on the stance leg, 2) lifts the stance foot from the center grid, 3) loses balance at any point in the trial or 4) does not maintain start and return positions for one full second (Olmsted et al. 2000). Directions of reach identified with balance deficits can easily be used as clinical and home exercises. Chaiwanichsiri et al. (2005) demonstrated effective outcomes with STAR pattern exercise for ankle instability. This approach can be used for any functional balance deficit. Testing should not only include measurement of the reach distance, but also identification of abnormal compensatory movement patterns that need to be corrected for training. The distance of the balance reach exercise is limited to the coordinated range with proper alignment of the trunk and lower limb. Common compensations include:

- Trunk lean in the opposite direction of the lower limb reach, as a counter balance. The patient should be instructed to maintain the head and trunk directly above the stance foot.
- With a vertical trunk, the pelvis may compensate by shifting in the opposite direction of the reach as a counter balance. The patient should be instructed to maintain alignment of the hip, knee and ankle in a vertical line.
- Knee valgus is common with hip external rotation and/or extensor weakness. This valgus moment can lead to numerous pathologies at the knee and ankle.
- Hip extensor weakness may present as the knee flexing forward beyond the toe with the hip and pelvis remaining vertical without posterior motion. Instruction should be to initiate the motion by bringing the pelvis posterior, as if sitting back in a chair, and then flexing at the knee.
- Weakness at the hip and/or knee may lead to excessive ankle pronation, as forces are focused in the lower leg. Passive arch supports may be necessary for training, but the patient can also be instructed to actively externally rotate through the lower limb to dynamically stabilize the medial arch of the foot.

Hertel et al. (2006) looked at whether all directions of the SEBT needed to be performed to identify functional deficits in individuals with chronic ankle instability (CAI). The complete test was found to be somewhat redundant with reaching in the antero-medial direction, where the medial and
postero-medial directions were found to be the most sensitive to testing functional deficits. Future studies or clinical experience may identify specific directions of reaches being more important to test and train in specific diagnoses, but training should focus on the deficient directions.

Loss of any proprioceptive input due to joint mobility restrictions or adaptively shortened muscles can slow the rehabilitation process and increase the prevalence of injury. Ankle motion can be limited from a tight gastrocnemius muscle, and play a significant role in the stability of the knee (Lass et al. 1991). Lower limb exercises must address hip, knee and ankle function as a unit, and not solely focus on the knee. Elias et al. (2003) described the agonistic behavior of the soleus muscle to the anterior cruciate ligament, as it decelerates the anterior motion of the tibia beyond mid stance. Soleus strength and function should be included in rehabilitation strategies to reduce the incidence of ACL injury, and to improve function in ACL deficient knees or postsurgical repairs.

Pain free weight bearing status for lower quarter and lumbar patients is necessary for a safe and effective balance training program. Pain reduction alone is not enough to restore weight bearing balance function (Bennell and Hinman 2005). Decreased proprioception and balance is noted in knee osteoarthritis (Hinman et al. 2002, Wegener 1997). Proprioceptive loss at the knee and ankle from trauma to the somatosensory system has been shown to significantly delay ankle muscle responses while upper leg and trunk responses are not delayed (Bloem 2002). Without retraining of the lower leg somatosensory system, the majority of lower leg balance correcting responses will be initiated by hip and trunk proprioceptive inputs (Bloem 2002). Isakov and Mizrahi (1997) found foot-ground reaction forces were the same between normal and sprained ankles while standing with either eyes open or closed. But standing with eyes closed, irrespective of the ankle status, produced significantly higher reaction forces than standing with eyes open.

Primary endings of ankle muscle spindles play a significant role in the control of posture and balance during the swing phase of locomotion by providing information describing the movement of the body’s center of mass with respect to the support foot (Sorensen et al. 2002).
noted for any functional activities. Strength training had a more significant impact on functional tests. Balance training should be included as soon as weight bearing tolerance allows, as early proprioceptive training is needed to effectively progress to a functional strengthening program.

Adding balance and proprioceptive training to rehabilitation does improve outcomes in individuals with ACL deficient knees. Cooper et al. (2005) studied improvements in joint position sense, muscle strength, perceived knee joint function, and hop testing after proprioceptive and balance exercises. The study showed some benefits in the proprioceptive group for measures of strength and proprioception, however no improvements were

Figure 2.31a,b: Balance testing/training with bilateral stance and cervical motions. With the eyes open, the head and neck move in all three planes of motion. If performance is at an accepted level, the same testing can be performed with the eyes closed to remove compensation with ocular input. Directions of poorest performance can be modified for safe daily exercises. Labile surfaces can be added as a progression as balance improves.

Figure 2.32a,b: Balance testing/training with eyes closed, bilateral close stance position and cervical motion. Feet are positioned next to each other to reduce the base of support. With the eyes open, the head and neck move in all three planes of motion. If performance is at an accepted level, the same testing can be performed with the eyes closed to remove compensation with ocular reflexes. Directions of poorest performance are given as daily exercises. Labile surfaces can be added as a progression as balance improves.

<table>
<thead>
<tr>
<th>Direction of Training</th>
<th>Dosage and Frequency</th>
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</table>
| **Balance Training for Unilateral Lower Limb Stance** | • 15 seconds at each progression  
• 45 second rest between  
• Daily 5–15 minutes. |
| • Stable surface, eyes open  
• Stable surface, eyes closed  
• Stable surface, eyes open, cervical motion  
• Stable surface, eyes closed, cervical motion  
• Stable surface, eyes closed, trunk external challenge  
• Stable surface, eyes open, lower limb reach  
• Stable surface, eyes closed, lower limb reach  
• Stable surface, eyes open, upper limb reach  
• Stable surface, eyes closed, upper limb reach | |
| **Options** | • As above with labile surface:  
Tilt board—single plane challenge  
Tilt board with foot at 45 degrees diagonal  
Wobble board—3-dimensional challenge  
Foam—(vestibular challenge) | • Progress:  
• 30 seconds per exercise  
• 15 second rest |

Table 2.2: General guidelines for balance training.
of compensation can provide insight into which joints or muscle groups are impaired. Trunk lean in the opposite direction of the reaching limb reduces the load on hip muscles but is an abnormal pattern. The patient should be instructed to maintain a vertical trunk or perform the activity next to a wall to prevent the lean. Hip extensor weakness can create an abnormal pattern of reduced hip flexion and increased anterior translation of the knee over the distal end of the foot with single leg squatting.

**Figure 2.35a,b:** Star Excursion Balance Test. Star pattern for lower limb balance reach involves standing one foot with the opposite lower limb reaches in different directions. The eight lines positioned on the grid are labeled according to the direction of excursion relative to the stance leg: anterolateral (AL), anterior (A), anteromedial (AM), medial (M), posteromedial (PM), posterior (P), posterolateral (PL), and lateral (L).

**Figure 2.36:** Single leg stance-lower quarter reach. Patient performs single leg balance while reaching the opposite foot away from the center of gravity. External feedback is provided by placing a bolster on the medial knee to avoid excessive valgus from occurring at the knee. This exercise is an example where decreasing the speed can increase the required coordination.

A block in front of the knees will limit the anterior
moment, requiring posterior motion of the pelvis and increased hip flexion. Upper limb reaching may also be used as a counter weight to balance body weight on either side of the axis of motion of the hip. The patient can be instructed to maintain the arms at the side for an increased challenge. Weakness at the hip may also result in a valgus moment at the knee. A bolster placed on the medial side of the knee can provide external feedback to engage hip muscles and prevent occurrence of the valgus moment.

Upper Limb Reaches

Upper limb reaching can also be used with SEBT testing and exercise to either assist the motion or increase the challenge with balance activities. The subject stands on the involved limb while reaching either extremity away from the center of gravity and then returns while maintaining single leg balance. Reaching can take place in any direction deemed functionally necessary. A hand can reach toward a specific target as a measurement of function or as an external cue for training. Simple distance away from the center point can be measured by having the subject drop a sand bag at the end point, with measurement being from the tip of the first toe to the sand bag (Gray 2000).

As discussed in the exercise prescription section, Chong et al. (2001) assessed balance improvements with training on the BAPS® board (biomechanical ankle platform system) to determine if they could be attributed to retraining deficits in the ankle and foot. Improvements observed during training were attributed from diffuse enhancement of proprioception in other body segments such as the knees, hips, spine and upper extremities rather than targeting proprioception specific to the ankle. Improvements in the proprioception of the entire body, as well as local gains in coordination and strength may be of clinical benefit, but may not be optimal for balance training. Utilization of balance board training as a preventative measure for ankle sprains in healthy individuals is controversial as some studies support injury prevention in the ankle (Verhagen et al. 2004) and others refute a positive impact for lower quarter injuries (Soderman et al. 2000). Rehabilitation programs should include multifaceted concepts to specifically address the individual needs of patients with specific reference to the goal of the exercise.

Figure 2.37a,b,c,d: Lower quarter reach balance training. The exercises start with standing on a firm surface with eyes open. The foot reaches forward staying roughly one inch off the floor and then returns to neutral. The patient reaches only as far as can be coordinated to return without touching the floor to regain balance, or without abnormal mechanics of the stance limb. Progressions include closing the eyes, using a labile surface to challenge lower quarter somatosensory input, use of foam to challenge the vestibular system, and to perform all of these options with lower quarter reaches in multiple directions.

Figure 2.38a,b: Example of right anterior upper limb horizontal reach. The subject stands on one leg while
reaching forward as far as possible, and then dropping an object for measurement. The distance from the 1st toe to the bag is measured to score the test. The drop counts only if the subject can return to neutral without losing control of single leg balance.

Performing upper limb reaching is a simple way to train more functional applications of single leg balance. Targets can be set for the hand to repetitively and/or sequentially hit while maintaining balance. Combinations of using either extremity in different directions can replicate any necessary functional requirements. Speed should be slow and consistent through the performance initially to establish coordination. It can then be increased to meet the functional needs of the task being trained. The opposing lower limb may be used as a counter balance for the upper limb reach to establish coordination with the motion. The non-weight bearing limb can then be held in neutral, rather than used as a counter balance, to place more significant challenge to the stance limb.

Multidirectional exercise concepts can be added to balance reach training. The main force line is gravity, which can be increased by the use of a free weight in the reaching hand. Increasing gravity will emphasize the extensor muscles of the hamstrings, gluteus maximus and long trunk extensors. Often the trunk instability accompanied with lower quarter weakness includes rotary patterns as well.

Providing a horizontal line of resistance from a pulley or elastic band will recruit a rotational vector of muscle for core facilitation. The lumbar multifidi, transverse abdominus and deep hip rotators are facilitated improving the proximal stabilization for balance and reach training.

Figure 2.40a,b,c,d: Upper quarter reach balance training. Reaches can be performed in any degree within the star pattern. Alternatives including the addition of an inferior or superior vector to the reach. A dumbbell weight can be added in the hand to increase the extension vector against gravity. A lateral pulley line can be added to the non reaching hand to increase the rotational vector to the trunk. Closing the eyes or standing on a labile surface will further challenge central balance.

Figure 2.39a,b: Example of right lower limb balance with left upper limb anterolateral and inferior reach. A bolster is used as a target to touch with the finger. Lower limb alignment is maintained, avoiding abnormal compensation. The speed is fixed through the performance to improve coordination.

Multidirectional training of upper quarter reaches forward as far as possible, and then dropping an object for measurement. The distance from the 1st toe to the bag is measured to score the test. The drop counts only if the subject can return to neutral without losing control of single leg balance.

Figure 2.41a,b: Multidirectional training of upper quarter
reaches in a diagonal pattern with a right lateral force from a pulley, held in the right hand. The pulley creates a right rotational trunk moment. The right lumbar multifidi, deep hip external rotators and the transverse abdominis are recruited through the upper extremity to resist the force. Increasing central recruitment for stabilization will improve the control of the weight bearing leg for balance reach training, whether for upper quarter or lower quarter reach training.

Figure 2.42a,b: Balance foam will reduce afferent receptor input from the cutaneous receptors on the plantar surface of the foot as well as joint mechanoreceptors of the foot and ankle. This may emphasize the vestibular system more and be less functional than a regular wobble board or balance reach training on a level surface.

Balance Training with Upper Limb and Trunk Motion
Ball toss and catch requires a combination of coordination, balance and stabilization or strength. An unplanned pattern of motion reacting to a ball provides a greater challenge on coordination, with focus on the upper limb performance rather than the stance leg. For an unstable joint, the catch is first performed on the side that will move the body away from the primary direction of instability. As coordination is achieved, the next progression is to catch the ball on the side that will move the body toward the instability but with an isometric stabilizing catch that does not allow the body to move toward the range of instability or tissue trauma. Finally the catch is made with an eccentric deceleration toward the direction of instability, but not into the pathological range, followed by a quick concentric return and throw. A plyoball rebounder can be used, or the therapist can manually toss and catch a ball with the patient.

Figure 2.43a,b,c: Example of a ball toss progression for right ACL internal rotary instability of the tibia. The first stage is to catch the ball on the left side, rotating the body to the left and the femur into internal rotation, with relative external rotation of the tibia. The next progression is to catch the ball isometrically on the right side, not allowing any rotation of the trunk or lower limb. The final progression is to catch the ball on the right decelerating with eccentric work into right rotation of the body, external rotation of the femur with relative internal rotation of the tibia. Muscles of the hip must control the eccentric deceleration to prevent rotary forces from translating down to the ACL.

Motions and Directions
Improved coordination is coupled with more efficient neurophysiological synchronization in firing of the motor unit, which increases stability.
Stage 1 exercises moved away from pain or instability, but motion is now directed toward the pathological range. Additional planes of motion are added to increase the challenge to the tissue in lesion and to coordination.

**Closed Kinetic Chain Training**

Closed kinetic chain (CKC) functional training may provide a method for more effectively rehabilitating an injured or reconstructed knee. Once the muscular system has proper neurological recruitment, the rehabilitation program can progress toward endurance and strength training (Nyland and Brosky 1994). Weight bearing can be progressed through the addition of weights or by utilizing the effects of gravity to increase the work. As the functional patterns being trained become better coordinated, the need for external support or cueing decreases.

The high correlation between quadriceps strength and functional performance suggests that improved postoperative quadriceps strengthening could be more important to enhance the potential benefits of TKA. Postoperatively, quadriceps strength as measured by functional activities declined early after TKA but recovered more rapidly when quadriceps strength improved (Mizner et al. 2005).

**Unloading**

Progression of closed chain exercise is important to increase the stimulus to the repairing tissue, further challenge coordination of the lower limb, and provide a more functional type of training. The decline board option—such as a Total Gym®, Vigor Gym or horizontal Nautilus squat machine—provides an easy way to adjust the angle of the body and amount of weight borne through the extremity. Weight bearing is progressed as tolerated with both bilateral and unilateral exercises.

**Adjunct Popliteus Training**

Nyland et al. (2005) described the popliteus as a dynamic guidance system for monitoring and controlling subtle transverse and frontal plane knee joint movements. The affect of the popliteus included controlling anterior, posterior and lateral meniscus movement, unlocking and internally rotating the knee joint (tibia) during flexion initiation, assisting with 3-dimensional dynamic lower extremity postural stability during single-leg stance, preventing forward femoral dislocation on the tibia during flexed-knee stance and providing for postural equilibrium adjustments during standing. Early training may involve direct training of the popliteus with resisted internal rotation training of the tibia in non-weight bearing.

**Gait Training**

Early gait training may emphasize balance, coordination and range of knee flexion to clear the toe with step through. Initial emphasis may simply be on walking with the eyes looking forward, rather than down at the ground. Central balance deficits may be more provoked when attempting to walk forward but looking right to left or up and down. Lateral walking, cross over stepping and turning are all basic applications to early gait training. Stepping over objects creates an external cue to increase hip and knee flexion during walking and also places a greater challenge on coordination and balance strategies. Further progression to uneven surfaces may provide functional training for challenges with outdoor walking.
Basic Squatting

Closed chain squatting can place excessive stress on healing or repaired tissues. The angle of the lower limb joints plays an important role in distributing forces safely for replication of functional movement patterns. Tibial translation increases with squatting except when the center of gravity is behind the feet. Proper activation of the soleus and gastrocnemius is necessary to control the anterior tibial moment and co-activation of the quadriceps and gastrocnemius muscles is important for knee stability. Kvist and Gillquist (2001) found hamstring muscle co-activation relatively insignificant for control of anterior shearing in ACL deficient knees, as it was more related to gastrocnemius eccentric function and displacement of the center of body mass posterior to the feet during the squat motion.

Posterior displacement of the body mass behind the feet is not only important for ACL deficient knees, but should be emphasized with all knee dysfunction. It acts to increase recruitment of the hip muscles reducing the forces transmitted to the knee, which can cause abnormal tissue strain.
External cues are more effective than internal cues for motor learning when teaching the proper squat technique. Rather than cueing patients to move their pelvis posterior, a chair placed behind them to sit back on can serve as an external cue for more efficient motor learning. Another common compensation is to shift weight toward the uninvolved limb. Neitzel et al. (2002) described a significant load shift toward the uninvolved lower extremity for up to 12–15 months post-anterior cruciate ligament reconstruction. Even loading with bilateral training should be emphasized, as load shifting can place unwanted stress on the uninvolved limb and create compensatory pathologies and repetitive strain injuries.

Tibial rotation during squat training may also be of benefit. Miller et al. (1997) demonstrated that leg rotation does not affect the VMO/VL EMG activity ratio in subjects with PFPS, though a general decrease in VMO/VL EMG activity ratio was found when the leg was externally rotated in the asymptomatic control group. Leg rotation may not have a an effect within the quadriceps for motor recruitment, but can effect the firing pattern of the entire lower limb and change the tissue strain moment of the patella. Internal rotation of the tibia moves the insertion of the quadriceps medially, reducing the lateral moment on the patella. This subtle change in foot position may be enough to reduce pain and allow for training. As tissue tolerance and motor performance improves the foot position is gradually returned to normal alignment.

Figure 2.49: Incorrect squatting technique with excessive anterior tibial translation. This is a classic compensatory squatting technique in the presence of weakened hip and trunk muscles. The body remains vertical without any hip flexion moment, placing excessive stress on the quadriceps, increasing patellofemoral compression and creating a less functional movement pattern.

Figure 2.50a,b: Squats: unloaded with a pull down machine and gantry. The patient supports the body weight in a gantry or with a pull down bar. Weight is placed on the pull down machine to assist the lower quarter with the squat motion.

Figure 2.51: Unloaded squats may be performed in the home setting with support through the arms on two chairs.

Figure 2.52: Door jam squats. The patient stands with the hands holding on to a door jam, feet close to the door jam. A squat motion is performed, keeping the knees above the toes and dropping the hip backward. The arms provide as much resistance as necessary to avoid pain, allow for the desired repetitions and/or achieve the desired range.
The use of external cues as targets can more quickly enhance motor learning than internal cues where the patient focuses on a particular muscle or movement such as preventing the knees from moving beyond the toes when squatting. Placing a block in front of the knees provides an external cue that instantly creates a posterior pelvic movement. Having a posterior target, such as a chair, to sit back on is also an effective external cue to help with motor learning.

Abnormal valgus moments at the knee result from weakness of the hip external rotators and abductors leading to femoral adduction and internal rotation. Hip, pelvis and lumbar dysfunction can be potential contributors to weakness of these muscles and must be screened during the initial evaluation. Closed chain training of knee flexion may require improved facilitation of these muscles to ensure proper alignment and reduce transmission of forces to distal muscles and joint structures of the lower quarter. Gravity provides the primary force for closed chain knee flexion training. Providing a secondary medially directed line of force at the knee creates a stimulus for recruitment of the hip abductors and external rotators. This can be achieved using a wall pulley or elastic resistance for bilateral squats, unilateral squats, lunging, step-up and step-down training. In more acute cases with higher levels of dysfunction a varus force can be used to assist weak muscles at the hip to allow for earlier pain free weight bearing training. These approaches have been used since the 1970’s in the Medical Exercise Therapy approach from Norway (Holten/Faugli 1996).

Figure 2.54: Squatting with a varus force moment to assist muscles of hip abduction and external rotation. This technique may be used to support/protect tissues at the knee or ankle that would be further traumatized with valgus at the knee (i.e., MCL strain or repair). A light varus force is placed at the knee joint line from an elastic band or wall pulley to help maintain the knee in neutral alignment. Resistance is increased until knee flexion can be performed without pain and with proper alignment of the hip, knee and ankle.

Figure 2.55: Squatting with a valgus force moment to facilitate muscles of hip abduction and external rotation. Resistance from a wall pulley or elastic band is placed at the knee joint line creating a valgus moment. This multidirectional training technique allows for earlier pain free training of the quadriceps for sagittal plane flexion by increasing the motor facilitation in the frontal and transverse planes at the
hip joint. Improved facilitation at the hip will again improve dynamic control of the entire lower extremity, reducing tissue strain at the knee. A heavy resistance for the valgus moment is not necessary to improve muscle facilitation and may be less safe in early training.

Figure 2.56: Bilateral knee valgus moment for multidirectional squat training. An elastic band may be looped around both knees creating a valgus moment at both knees improving bilateral facilitation of hip muscles. An elastic band provides an easy home application, as well as creates bilateral facilitation at the hip, which may improve the crossover effect of recruitment.

Figure 2.57a,b: Multidirectional squat training for combined lumbar and hip stabilization training. Proximal weakness in the knee patient may extend beyond the hip, requiring improved stability of the pelvis and lumbar spine. In these cases, a lateral force moment from a wall pulley is held anterior away from the body. Here both hands are shown holding the line for bilateral trunk recruitment. The force moment from the pulley naturally recruits the fiber direction of the transverse abdominus, the oblique abdominal muscles, the rotational vector for the lumbar multifidi of the lumbar spine and the deep rotators of the hips. The pulley is stabilized anteriorly while the squat motion is being performed. Further progression may involve rotational motions of the trunk during a normal squatting motion. As a motor assessment tool, if the patient is able to squat further with less pain when holding a horizontal resistance, the exercise may help in diagnosing or identifying proximal weakness as a component of the overall motor impairment.

The stance phase of gait is associated with knee flexion and ankle dorsiflexion with facilitation of both the hamstrings and quadriceps influenced by mechanoreceptors in the cruciate ligaments. Body weight is transferred to the femur, which glides anteriorly on the tibial platform applying tension to the PCL, not on the ACL (Grimsby 1980). Mechanoreceptors in the ACL assist in facilitation of concentric quadriceps and eccentric hamstrings, whereas the PCL receptors assist in facilitation of concentric hamstring work and eccentric quadriceps. A preloading of the anteromedial and posterolateral fascicles in the ACL and the anterior and posterior fascicles in the PCL has an effect on facilitation of the hamstrings and quadriceps (Raunest et al. 1996). Static and dynamic loading of the anteromedial fibers of the ACL, create increased EMG activity in the hamstrings and a simultaneous decrease of the quadriceps. Loading

Figure 2.58: Unweighted squat with unilateral valgus force moment (multiple resistance exercise). Regardless of the planes of weakness, and what type of proximal facilitation that is required, the body weight may still be too high to allow for weight bearing training without some type of unloading device. The use of a varus or valgus force moment can be added to any unloading device, whether a pull down machine with an unloading gantry, horizontal Nautilus® type machine or Total Gym®. If a portable pulley is not available, or there is no proper attachment sites for an elastic band, the therapist may be required to manually hold a strap around the knee to create the required force moment.
of the posterolateral fibers of the ACL create a significant excitation of the quadriceps. When mechanical shear is applied both to the anterior and posterior fascicles of the PCL an activation of the ipsilateral quadriceps muscles is induced with a simultaneous inhibition of the hamstrings. The quality of mechanical loading (the static or dynamic shear) determines the amount of muscular activity, which demonstrates a proprioceptive mechanism of the cruciate ligaments (Raunest et al. 1996).

During the deceleration of knee flexion during the stance phase of gait, the quadriceps work eccentrically. As the knee approaches extension during “toe off” the quadriceps work concentrically, increasing the compressive tension on the patella and preventing further anterior glide of the femur. Knee extension involves anterior roll of the femoral condyles increasing tension on the PCL, which is reduced with concurrent posterior glide of the femur on the tibial plateau. The ACL, in turn, is less exposed to tension during normal gait than the PCL, which explains the fact that the PCL collagen fibers are thicker and stronger.

Basic Step / Pull Through Training

Step through training begins with mid stance gait training on the involved limb. An ankle strap around the swing leg is attached to a sport cord or wall pulley. The front-pull begins with the swing leg positioned posteriorly in a toe-off position and swings through to heel contact with body weight remaining on the stance leg. The back-pull exercise is reversed with the uninvolved limb swinging posteriorly from heel contact to a toe-off position. Hopkins et al. (1999) compared these exercises with sport cord on healthy subjects, comparing EMG activity between a lateral step-up and a unilateral squat. The front-pull and back-pull exercises with elastic resistance produced higher levels of biceps femoris activity than the lateral step-up during the knee extension phase. During knee flexion both the
front-pull and back-pull exercises produced higher levels of biceps femoris activity than unilateral one-quarter squats and the lateral step-ups. The front pull was also associated with higher levels of recruitment for vastus medialis activity than the unilateral one-quarter squat, lateral step-up and back pull during knee extension.

Schulthies et al. (1998) analyzed the front-pull, back-pull, crossover-pull and reverse crossover-pull using elastic tubing. The front-pull had significantly greater VMO and vastus lateralis (VL) contributions, the back-pull was greatest for the VL, the front cross-over pull was greatest for semitendinosus and semimembranosus, and the back crossover pull was greatest for the VL and biceps femoris. During these tests, the hamstring to quadriceps ratio was greatest for the front-pull and crossover pull exercises.

**Basic Lunging**

Lunges can be performed in many ways with emphasis placed on the needs of the patient including range of motion, tissue repair, balance and/or stability. The basic anterior lunge recruits the vastus lateralis, vastus medialis and biceps femoris muscles as a unit during both the concentric and eccentric phases (Pincivero and Aldworth 1999). The lunge has been shown to increase quadriceps muscle activity and decrease hamstring muscle activity, compared with the power and front squats (Stuart et al. 1996).
is maintained on the posteriorly placed uninvolved limb, while the involved limb is placed a short distance anteriorly on the ground. Weight is then slowly shifted onto the involved limb. As coordination and weight bearing tolerance improve, the amount of weight shifted anteriorly is increased prior to increasing the distance of the lunge.

Lunging can be performed in many ways to emphasize different aspects of joint motion and muscles recruitment. Early in knee rehabilitation the emphasis is often on restoring hip coordination and reducing the excessive forces transmitted to the knee. The fall-out lunge technique increases recruitment of the lumbar and hip muscles while reducing the load on the quadriceps and compression forces at the patella. The trunk remains in line with the posterior leg, the knee remains extended and the heel is fixed to the ground. Weight is transferred over the anterior leg with the nose over the front toes. Load should be felt in the front foot, without excessive force through the quadriceps and knee. The patient is instructed to avoid an abnormal valgus force moments at the knee. When the uninvolved leg steps forward, the involved limb is also trained for eccentric deceleration of the tibia from the soleus. More traditional lunges involve the trunk remaining vertical, the back knee flexing with the majority of the load placed on the quadriceps with excessive patellar compression. This may be a progression for later stages, but early on the emphasis is on activating the back and hip for more efficient force distribution and unloading injured tissues distal to the hip.

Initial coordination training can involve the arms as an assist. Reaching lateral during the anterior lunge will create a relative external rotation moment in the trunk and lower limb, preventing a valgus moment at the knee. The rotary moment can also improve facilitation of the deep hip rotator muscles during the exercise for improved dynamic stability. Progressions include lunging and reaching with different combinations and in different directions and/or with the addition of hand weights. Reaching lateral also shift more weight lateral to the hip axis, unloading the gluteus medius for hip and pelvis stabilization. With significant lateral hip weakness the lateral reach may serve as an assist. Later progression may include reaching forward and then medial to gradually increase the relative body weight medial to the axis of hip motion for abduction. Creative thinking during exercise design can unload or load specific joint tissues and/or muscles.
A similar rotary moment at the hip can be created with a medially directed force at the lower thigh. A pulley line or elastic resistance is placed just proximal to the knee joint, which acts to facilitate the hip abductors and external rotators.

The same concept can be applied to improve recruitment of the gastrocnemius and soleus complex for eccentric deceleration the tibia on the talus during gait. The line of resistance is placed to create an anterior tibial force moment that must be countered by the gastrocnemius-soleus complex while the uninvolved limb performs an anterior lunge, as previously shown.
Concentric peak torque is increased at slower speeds, which may provide time for additional motor units to be recruited when performing a slower step-up. Conversely, eccentric peak torque is greater with increased speed that may allow for pain-free completion of the step-down at faster speeds. The involved limb acts to eccentrically lower the body with the uninvolved limb accepting the body weight on landing. Speed can be gradually decreased with the step-down to increase the challenge and train a more functional movement.

- Decrease speed to assist concentric step-up
- Increase speed to assist eccentric step-down

The involved limb acts to eccentrically lower the body with the uninvolved limb accepting the body weight on landing. Speed can be gradually decreased with the step-down to increase the challenge and train a more functional movement.

The step-up can be performed as a pure concentric activity, with the uninvolved limb performing the step-down eccentric phase. On the other hand, the step-down can be performed as a pure eccentric activity, with the uninvolved limb performing the step-up concentric phase. Progression includes performing both the concentric and eccentric phases in the step-up and step-down exercises.

The step height should initially be set at a functional level that can be managed by the available range of motion of the involved knee. It is more functional to train at a normal step height and provide assistance to allow for pain-free coordinated motion, than to lower the step height below a typical level of six to eight inches. Many types of unloading devices can be used to reduce the body weight to allow for a pain-free performance. Utilizing work physiology concepts associated with speed of training precludes the need for unloading equipment. Concentric peak torque is increased at slower speeds, which may provide time for additional motor units to be recruited when performing a slower step-up. Conversely, eccentric peak torque is greater with increased speed that may allow for pain-free completion of the step-down at faster speeds. The involved limb acts to eccentrically lower the body with the uninvolved limb accepting the body weight on landing. Speed can be gradually decreased with the step-down to increase the challenge and train a more functional movement.

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- Increase speed to assist eccentric step-down

The involved limb acts to eccentrically lower the body with the uninvolved limb accepting the body weight on landing. Speed can be gradually decreased with the step-down to increase the challenge and train a more functional movement.

The step-up can be performed as a pure concentric activity, with the uninvolved limb performing the step-down eccentric phase. On the other hand, the step-down can be performed as a pure eccentric activity, with the uninvolved limb performing the step-up concentric phase. Progression includes performing both the concentric and eccentric phases in the step-up and step-down exercises.

The step height should initially be set at a functional level that can be managed by the available range of motion of the involved knee. It is more functional to train at a normal step height and provide assistance to allow for pain-free coordinated motion, than to lower the step height below a typical level of six to eight inches. Many types of unloading devices can be used to reduce the body weight to allow for a pain-free performance. Utilizing work physiology concepts associated with speed of training precludes the need for unloading equipment. Concentric peak torque is increased at slower speeds, which may provide time for additional motor units to be recruited when performing a slower step-up. Conversely, eccentric peak torque is greater with increased speed that may allow for pain-free completion of the step-down at faster speeds. The involved limb acts to eccentrically lower the body with the uninvolved limb accepting the body weight on landing. Speed can be gradually decreased with the step-down to increase the challenge and train a more functional movement.

- Decrease speed to assist concentric step-up
- Increase speed to assist eccentric step-down

The involved limb acts to eccentrically lower the body with the uninvolved limb accepting the body weight on landing. Speed can be gradually decreased with the step-down to increase the challenge and train a more functional movement.
foot can be prevented from plantar flexing for assistance with dorsiflexion of the toes prior to the opposite leg stepping up.

Figure 2.77: Step-down (Eccentric emphasis). From the edge of the platform, the patient steps forward and down onto the uninvolved foot. The uninvolved foot then step back and up onto the step. In this way the involved side limb performs the eccentric phase only. As peak torque for eccentric work increases with speed, the patient can be instructed to allow the body weight to fall down more quickly on the eccentric phase to allow for a pain free and coordinated movement for the desired number of repetitions. Lowering the step height can also reduce the challenge, removing pain, but training at a higher speed eccentrically at a functional step height is more desirable for early functional training.

Anderson and Herrington (2003) established a relationship between patellofemoral pain syndrome and poor eccentric control of weight bearing knee flexion by the quadriceps. A break in eccentric performance was noted in a higher percentage of patellofemoral pain patients than controls, assessed with eccentric isokinetic testing and functionally descending stairs. The break, or giving-way reflex, was theorized as a response, not just to the degree of pain but as a way to prevent further stress on joint and soft tissue structures. These findings stress the neurological retraining aspects of dysfunction.

Figure 2.78a,b: Lateral step-ups (concentric emphasis). The patient stands next to the lateral side of a step. Lateral steps increase emphasize lateral hip and medial thigh musculature. The foot of the involved limb is placed up onto the step. To avoid plantarflexion from the uninvolved limb assisting the motion the patient can be instructed to dorsiflex the digits of the uninvolved foot. Swinging the arms up and forward will assist the motion. To minimize the eccentric phase, the patient can be instructed to fall off the step, catching the body weight with the uninvolved limb, rather than eccentrically lowering with the involved limb.
cause compensation by the anterior fibers of the iliacus to aide hip abduction leading to overuse and displacement of abnormal forces on the iliotibial band (ITB). Iliotibial band syndrome (ITBS) should not be considered a freestanding pathology, but rather a symptom of mechanical breakdown of forces throughout the lower limb with closed chain activities. Symptoms of ITBS frequently correlate with gluteus medius weakness. EMG studies have shown that both athletic and arthritic hips with symptoms of ITBS usually have poor gluteus medius facilitation and an inability to isolate gluteus medius from the tensor fascia lata (TFL) in standing (Fredericson 2000, Kasman 2002). In long distance runners with ITBS, symptom improvement and return to preinjury training correlates with increased hip abductor strength (Fredericson 2000).

Retraining coordinated function of the gluteal muscles requires establishing a normal neurophysiological movement pattern. Starting in a partial or non-weight bearing position and, in some cases, adding an external line of force may be necessary to facilitate the gluteus medius. Progressing to full weight bearing training in functional triplanar patterns, as well as incorporating jump training for eccentric and plyometric capacity, are required to achieve a higher level of dynamic stability.

Adjunct Hip Training

Anterior fibers of the iliacus contribute to hip flexion, with the posterior fibers contributing to hip abduction and internal rotation (Pare et al. 1981). Weakness or inhibition of the gluteus medius can
states. A cuff weight at the knee may allow for more specific exercise dosage, but this exercise typically emphasizes the functional quality of coordination with only the weight of the leg. As coordination of the exercise is achieved, a functional progression into weight bearing may be more appropriate than the addition of weight.

Figure 2.82. Horizontal hip abduction in supine with pulley resistance. Gluteus medius training is emphasized with down training of the tensor fascia lata. As a non-weight bearing exercise for the hip, there may be limited carry over to weight bearing function. Progression to a weight bearing option is more appropriate than progressive weight training.

Non-weight bearing training of the hip abductors may be a necessary step for limitations in tissue tolerance and overall strength. Muscle strength needed for non-weight bearing does not meet the torque levels needed for weight bearing training. Functional training in weight bearing is a necessary progression for normalizing hip strength.

Squatting can also be modified to emphasize function at the hip. Combining upper limb reaches with squats, lunges and step training can either assist or increase the challenge of balance, lower limb alignment and loading on specific muscles. Reaching with the upper extremity shifts the relative amount of body weight in the direction of the reach. Weight shifted lateral to the hip joint moves more weight lateral to the hip axis of hip abduction, thus reducing the amount of weight the hip abductors need to stabilize. The direction of arm reach can also increase the recruitment of specific muscles, as in an anterior reaching increasing hamstrings and gluteus maximus recruitment.

Figure 2.83: Hip Fire Hydrant: quadruped horizontal hip abduction to attempt to facilitate the gluteus medius and reduce recruitment of the tensor fascia lata. The knee is lifted laterally in isolation, followed by rotation of the pelvis and finally abduction of the weight bearing hip. The gluteus medius is facilitated bilaterally with increased activity associated with increased afferent input with partial weight bearing and the cross over effect.

Non-weight bearing training of the hip abductors may be a necessary step for limitations in tissue tolerance and overall strength. Muscle strength needed for non-weight bearing does not meet the torque levels needed for weight bearing training. Functional training in weight bearing is a necessary progression for normalizing hip strength.

Figure 2.84a,b: Weight bearing hip horizontal abduction. Horizontal left hip abduction, with the hip in a flexed position, will increase the demand on the gluteus medius while reducing recruitment of the tensor fascia lata by placing it in a relatively shortened position with hip flexion.

Figure 2.85a,b: Squat with medial reach (relative to involved limb)—away from involved knee (right). Reaching across the body shifts the center of gravity away from the involved knee, reducing the level of torque required at the hip and knee. This may allow for squatting without a valgus compensation at the knee and/or pain. As coordination improves the arms can be held at the side, progressing to a lateral reach.
loading for continued improvement in stress/strain
tolerance. Coordination of basic movement patterns
has been established, but dynamic stabilization
is still necessary with an eccentric emphasis
shifting toward more functional activities and
sport requirements. Isometric stabilization can still
be utilized to improve dynamic stabilization via
sensitization of muscle spindle receptors at higher
loads in specific ranges of instability.

Tissue and Functional States—Stage 3
• Full arthrokinematic and osteokinematic
motion with cardinal planes.
• Full weight bearing with limitation in loaded
weight bearing.
• Joint may be painful with excessive
repetitions.
• Edema has resolved pre and post activity.
• Muscle guarding has resolved.
• Palpation of primary tissues negative,
provocation tests negative, trigger points may
be positive to deep palpation.
• Fair to Good coordination in planar
motions—limitations in tri-planar motion.
• Fair to Good balance/functional status—
limitation in functional challenges.
• May have reduced fast coordination,
endurance, strength and power.

Summary
Stage 2 focuses on normalizing knee range of
motion and establishing coordination in partial to
full weight bearing functional exercises including
squats, lunges and steps. Pain is no longer an issue,
other than with excessive loading or training.
Progression to more complex movement patterns, as
well as strength and power training are addressed in
Stages 3 and 4.

Section 3: Stage 3
Exercise Progression for the Knee

Training Goals
Progression to Stage 3 concepts comes with
resolution of impairments from Stage 2. Pain is
resolved with general activity, although the healing
tissues may be still be reactive with higher loads
or longer duration of activity. Range of motion is
normalized due to restoration of capsular mobility
and/or elimination of muscle guarding patterns.
Tissue tolerance has improved for normal joint
loading and mobility, but requires increased

Figure 2.86a,b: Squat with lateral arm reach (relative to
involved right). The lateral reach will shift the center of
gavity toward the involved lower limb increasing the torque
moment at the hip and knee. This may present a greater
challenge for avoiding a valgus compensation at the knee.
During the eccentric phase of the squat the arms reach lateral
to the involved knee that acts to also increase the rotational
components of the gluteus medius in the sagittal plane.

A level of endurance has also been achieved
with previous training, though strength is not
fully returned. Quadriceps strengthening is an
effective approach regardless of the patient’s age,
sex, body composition, athletic level, duration
of symptoms, or biomechanical malalignment in
the lower extremities (Kannus and Niittymäki
1994). Most protocols speak of strength training
much earlier, but joint motion and coordination
must be established along with a level of muscle
endurance prior to beginning true strength training.
For athletes, exercise design should attempt
to incorporate more sport-specific exercises to
improve neuromuscular coordination and timing.
to protect against future injury. Educating the patient on how to reduce the risk of re-injury is necessary for any patient. Some conditions, such as osteoarthritis, may result in some level of permanent tissue damage and impairment. A progressive rehabilitation program that includes active therapeutic exercise may help delay the progression of disorders such as osteoarthritis and give patients more years of pain-free activity and improved quality of life (Vad et al. 2002).

**Basic Training Goals Stage 3: Dynamic Stability**
- Increase resistance
- Resistance increased to 70–80% of 1RM
- Strength and endurance
- Add isometrics toward pathological range
- Weight bearing functional exercises
- Avoid compensations/malalignment
- Concentric and eccentric exercises
- Functional patterns

### Increase Resistance / Speed

Weight bearing exercises have many variables that can be modified to increase the tissue challenge. In Stage 3 resistance is progressively increased along the coordination-endurance-strength spectrum ranging between 70–80% of 1RM. The increased resistance will provide greater tissue stress/strain and hypertrophy of the targeted muscles for long-term strength gains.

Speed can also be used as a variable to increase resistance to a muscle group instead of increasing the load (weight). In some cases, increasing speed may be of more importance than resistance, as in examples of sports that require a greater speed element than a slow strength performance. Speed not only affects local muscle performance but can also have an impact on the cardiovascular system. For example, running provides a more significant increase in cardiovascular challenge than walking.

### Eccentric Stabilization

Basic stabilization concepts involve progressive training of tonic muscles that contribute to dynamic control of arthrokinematic motion. Concentric work emphasis was employed first to emphasize coordination, reduce muscle guarding and/or facilitate inhibited muscle. Isometric work in Stage 2 was then incorporated to improve neurological adaptation for motor facilitation. Stage 3 concepts now emphasize eccentric work for greater muscle spindle sensitivity and dynamic control of the joint system. Eccentric emphasis or “lengthening contractions” were used in the 1960’s for meniscectomy rehabilitation (Kressley 1963).

The progression to eccentric stabilization is more deliberate for upper limb and axial skeletal training. To emphasize EW, the work order is changed to EW first with CW return. The force moment from the resistance is adjusted for eccentric length tension in the shortened range of the muscle. Eccentric emphasis for the lower limb is already built into the functional demand of closed chain training, and requires less of a deliberate adaptation of training unlike the upper limb and axial skeleton. Open chain training requires more specific set up of the length tension curve and work order, whereas closed chain training naturally adjusts these variables for the lower limb.

The squat motion begins with the knee in full extension. The entire lower quarter is involved in eccentric deceleration of the body weight against gravity with a concentric return to the start position. Emphasis is placed on a quick transition between the eccentric and concentric phases. A slow transition results in a loss of energy during the stretch-shortening cycle, and is dissipated as heat. A progression to jump training emphasizes a quicker, more ballistic, transition between the work phases.

### Endurance to Strength Training

Dynamic stabilization, through coordination training and sensitization of afferent receptors, requires a progression into strength training. Resistance is elevated 10–20 RM percentage points.
Direction of training also needs to reflect gross functional requirements that can be assessed with gait, balance, squatting, lunging, step and jumping tests. Stage 3 should reflect a more specific match between the impairments and functional needs of the patient. Generalized protocols may not be appropriate for all situations. Neeter et al. (2006) found that testing power for knee extension, knee flexion and leg-press had a high ability to determine deficits in leg power six months after ACL injury and reconstruction. They were able to discriminate between the leg power performance on the injured and uninjured side, both in patients with an ACL injury and those who have undergone an ACL reconstruction surgery.

These types of tests may help in deciding when and whether patients can safely return to strenuous physical activities after an ACL injury or reconstruction, but they should be used in conjunction with functional performance testing. Functional tests that measure increases in strength alone may not be the most sensitive in determining the success of a rehabilitation program. Augustsson and Thomee (2000) showed that a moderately strong correlation exists between the test of functional performance and muscular strength tests for both closed and open chain positions. They suggested that the effect of training or rehabilitation interventions should not be based exclusively on tests of muscular strength but rather on various forms of dynamometry including functional performance tests.

Weight Bearing Closed Chain Progression

Bracing or assistive devices are discarded during training exercises in Stage 3 as full weight bearing tolerance has been achieved. Bracing may still be used as an adjunct to athletic performance or competition outside the rehabilitation setting. Stairs are ascended and descended in alternating steps and step-ups can be progressed by increasing the height of the step and/or emphasizing the eccentric component at different speeds. Resistance can be increased with aerobic equipment, by inclining...
a treadmill or using a stair stepper. Basic weight bearing exercises are progressed in range, direction, resistance and speed as well as with balance and surface challenges.

**Squat Progressions**

The basic progression for squats is to increase the resistance. A weight bar can be used posteriorly across the shoulders or held anteriorly with crossed arms to unload body weight. Dumbbells or weighted boxes can also be used for more functional squat-lift training to increase resistance. Single-limb squats can be incorporated to increase the overall torque on the lower limb, challenge balance and replicate any necessary functional requirements. Single-limb squats at increased levels of resistance have been shown to increase the co-activation of the hamstring muscles along with the quadriceps, which is essential to optimize neuromuscular control of the knee (Sheilds et al. 2005). Single-limb squats can initially be assisted by unweighting the body, or providing upper limb assist and progressed to full body weight and an eventual addition of resistance.
anteriorly to the left hip. Anterior musculature of the hip and trunk are emphasized, including the transverse abdominus, the obliquus' and left hip flexors.

### Step Training Progression

Basic step training in Stage 2 focused on improving coordination and endurance with ascending and descending stairs. Progression of step training can focus on different variables, depending upon the functional demand. Increasing weight will impart strength qualities and increasing the step height will help to improve dynamic control through a greater range of motion. Balance, coordination and agility may be addressed by adding lower limb rotations to the task. Any one of these options or a combination may be emphasized to vary the challenge based on functional needs of the patient.
and trunk is created with gravity during the step-up motion. The right lateral force increases the extension moment from the inferior vector, but also a right trunk rotational moment. The arms swing through to the left, creating an left rotational trunk pattern, increasing activity of the right lumbar multifidi, right hip deep external rotators, the oblique abdominals and the transverse abdominus.

**Step Progression / Challenges**

- Step-up with increase speed (CW) for motor challenge
- Step down with decrease speed (EW) for motor challenge
- Increase step height
- Step with hand weights/weight bar
- Step-up/down in different directions (i.e., anterior, anterolateral, lateral or posterior etc.)
- Step-up/down with external rotation of foot
- Step-up with external rotation of pelvis
- Step-up/down with arm reaches
- Step-up and hop
- Step-down and jump—unilateral and bilateral jump

**Lunge Progressions**

Lunges in Stage 2 emphasized coordination of the lower kinetic chain for maintaining alignment during the loading phase. In the frontal plane, the hip, knee and ankle remain in alignment with each other and in relation to the trunk. For the fallout lunge technique the back knee is kept straight with the trunk leaning forward in line with the back leg to emphasize hip and lumbar musculature recruitment. For a quadriceps emphasis the trunk is kept vertical, the back knee flexed and the majority of load is placed on the knee. The latter option is not typically recommended for patellofemoral or tendinopathy issues, as excessive stress and strain is placed on tissue of the anterior aspect of the knee. Many option on lunging exist, there is not “one way” to do them. The style of squat used should match the tissue injury and the functional need.
gravity. The anterior pulley line further increases the extensor moment from the trunk, but the line is also attached to the right shoulder and wrapped around the body. Attachment to the right shoulder causes a relative left rotational trunk moment. The lumbar multifidi on the left are recruited, along with the deep external rotators of the left hip, to resist this force moment.

Figure 2.98a,b: Multidirectional right lateral lunge training with left arm resistance from a right lateral force moment. The pulley recruits a diagonal line of muscle from the left arm, crossing the lumbodorsal fascia, into the right hip. Posterior musculature is emphasized, including the lumbar multifidi and the deep hip rotators. The primary resistance for the right hip is the landing of the lunge, but further stabilization is required to control the rotary vector caused by the pulley. This approach is used primarily for the knee patient that has associated lumbar instability due to poor motor control of posterior muscles, such as the multifidi.

Figure 2.99a,b: Multidirectional lateral lunge training with right arm resistance from a right lateral force moment. The pulley recruits a diagonal line of muscle from the right arm, crossing anteriorly to the left hip. Anterior musculature is emphasized, including the transverse abdominus and hip flexors. Greater recruitment is achieved through the left side internal obliques, right external obliques, transverse abdominus and hip flexors to control the rotary vector from the pulley. This approach is used primarily for the knee patient that has associated lumbar instability due to poor motor control of anterior muscles, such as the transverse abdominus muscle.

Figure 2.100a,b: Multidirectional right anterior lunge training with a secondary right lateral force moment. A lateral force moment from a wall pulley is held anterior away from the body during a anterior fallout lunge. The force moment from the pulley is stabilized with both hands, requiring motor recruitment of both anterior and posterior muscles of the trunk and pelvis. The trunk is pulled into right rotation, which is resisted by the deep rotators of the right hip and the right lumbar multifidi. More indirect challenges can be added to central muscles of stability by closing the eyes, requiring improved processing of somatosensory input. Lunging onto a labile surface, such as a wobble board or foam, will also increase the balance challenge through the entire lower extremity. Head motions, as shown previously, can further challenge cervical contributions to posture and balance. Head motions may provide a more functional athletic challenge than a labile surface.

Figure 2.101a,b: Multidirectional anterior lunge training with right arm resistance from a right lateral force moment. A lateral force moment from a wall pulley is held anterior away from the body during an anterior fallout lunge. The force moment from the pulley is stabilized with both hands, requiring motor recruitment of both anterior and posterior muscles of the trunk and pelvis. The trunk is pulled into right rotation, which is resisted by the deep rotators of the right hip and the right lumbar multifidi. More indirect challenges can be added to central muscles of stability by closing the eyes, requiring improved processing of somatosensory input. Lunging onto a labile surface, such as a wobble board or foam, will also increase the balance challenge through the entire lower extremity. Head motions, as shown previously, can further challenge cervical contributions to posture and balance. Head motions may provide a more functional athletic challenge than a labile surface.

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Lunge Progressions / Challenges

- Traditional vertical trunk lunge
- Fall-out lunge
- Lunging in different directions
- Lunging with external rotation of the leg
- Lunging with resistance to the trunk
- Lunging with weight in the hands
- Lunge with upper limb reaches in any vector
- Lunge up onto a step—anterior to lateral
- Lunge down off of a step—different directions
- Walk-lunge
- Lunge onto labile surface
- Lunge off labile surface to a solid surface
- Lunge with upper limb arm swings—with arm weights
- Resisted trunk lunge—trunk attached to sport cord or pulley
- Ballistic lunge—high speed with a fast transition from the eccentric to concentric work
- Lunge with reactive activities, such as catch and throw activities
One Leg Hop Test / Exercise

Hopping is the next progression from lunging. The hop-and-stop is a task that requires concentric forward propulsion by the back stance leg followed by eccentric stabilization for the landing on the opposite leg. Both the quadriceps and hamstring muscles contribute to the forward propulsion phase, but the hamstring seems to play a more important role during the single leg hop enabling subjects to jump further (Pincivero et al. 1997). Landing, or “stopping,” on the forward leg requires eccentric deceleration and stabilization from the lumbar spine through the entire lower limb. Distance and speed of hopping are reduced to allow for proper coordination of landing avoiding a valgus collapse of the lower limb. An indicator for a safe return to running involves first establishing a solid hop and stop performance. Training then can be progressed to bounding, or successive hopping, with a solid landing followed by an immediate propulsion phase forward. Once these exercises can be performed with proper coordination and an absence of secondary tissue irritation, a gradual return to running can be safely attempted.

Hopping for distance and stability is a necessary functional requirement on the progression from walking to running. Landing from a hop with a stable limb involves maintaining proper alignment.
of the lower kinetic chain as well as avoiding excessive ankle, arm and/or trunk compensations to maintain balance. The knee should land solidly, maintaining position without significant movement. Testing for hopping stability is a good indicator of functional improvement to determine when an athlete is ready to progress to jumping, jogging and running activities. Louw et al. (2006) assessed the front foot landing phase of adolescent pitchers finding that the uninjured players had significantly greater hip and knee flexion angles, as well as eccentric activity, on landing than that of the injured players.

Mattacola et al. (2002) assessed 20 subjects from 10 to 18 months post anterior cruciate ligament reconstruction (ACLR) with a patellar tendon autograft. Significantly shorter distances were identified with the single-leg hop for distance on the involved side versus the uninvolved side. This group of young athletes had already returned to athletic activity, but their performance levels with functional testing did not meet the requirements for a safe return to athletic performance. Weakness and/or instability with hopping and landing can lead to abnormal tissue strain and degeneration over time.

The single leg hop for distance test is a commonly employed functional test in the evaluation of patients with ACL deficient or reconstructed knees. It is scored by hop distance as well as the hop index, which is the ratio or percentage of hop distance of the involved leg relative to the opposite leg. Norms for the hop index were empirically established by Barber et al. (1990), who found that greater than 90 percent of subjects without a history of ACL injury had a hop index equal to or greater than 85 percent, while Daniel et al. (1982 and 1988) found the number to be equal to or greater than 90 percent. Reliability of the hop test score has been well established (Bolgla and Keskula 1997, Kramer et al. 1992, Bandy et al. 1994, Greenberger and Paterno 1994). Validity studies have revealed low sensitivity rates in detecting abnormal limb symmetry in ACL deficient subjects (Barber et al. 1990, Noyes et al. 1991).
Agility Training and Early Stage Plyometrics

Return to athletic activities may require a higher degree of functional coordination training, rather than just simple strength training with basic cardinal plane movements. Performing agility walking, lunging, hopping and jumping tasks in different directions can provide significant neuromuscular challenges that better mimic sport performance. The specific exercises and directions chosen for training should reflect the functional demands of the sport or activity to be performed. Houck et al. (2006) demonstrated that unanticipated straight walking and side-stepping were associated with increased levels of hip abduction, with abnormal foot placement causing excessive trunk motion to compensate.

The slideboard can be incorporated to add challenges to the proprioceptive system and improve balance with weight shifting. EMG analysis by Heller and Pincivero (2003) found that the VMO, vastus lateralis and anterior tibialis act as the prime movers during the push off phase in normal and ACL deficient knees. Blanpied et al. (2000) also found the slideboard to be an effective strengthening exercise for post ACL reconstruction. Concentric firing of the gluteus medius to push off the board with speed requires coordination, strength and power. Greater degrees of knee flexion during the slide impart an increased challenge to the quadriceps and gluteus medius muscles, increasing their capacity to tolerate more stress. Throwing and catching a weighted ball while sliding will add more complexity to the exercise, as it shifts the center of gravity and challenges the base of support requiring a higher level of recruitment and coordination. This exercise can be further progressed by throwing the ball to different spots, challenging reactive reach and balance responses.

Jump Training

Jump training is added once coordination has been established with performance of lower level activities such as lunges. Lunging requires a solid single leg landing while maintaining proper alignment of the lower kinetic chain. Ballistic lunging incorporates a fast transition between eccentric deceleration and concentric propulsion, which then progresses to low level jumping. Landing from the jump requires a fast and synchronous recruitment of the lower limb muscles to stabilize the hip, knee and ankle. Even a low degree of valgus collapse at the knee can lead to abnormal tissue strain, particularly with high repetition rehabilitation activities. In a cadaveric study Withrow et al. (2006) demonstrated a 30 percent increase in ACL ligament strain with improper muscle support allowing a valgus moment in knee flexion with simulated landing. Chappell et al. (2005) found fatigue with stop-jump tasks led to increased peak anterior tibial shear, as well as an increased valgus moment at the knee. Caution should be taken to avoid fatigue, with observation of proper knee alignment during the exercise.

The eccentric phase of jump training has been associated with delayed onset muscle soreness (DOMS) (Byrne and Eston 2002). But these types of studies commonly reflect healthy subjects training at excessively high levels. Jump training is added later in a rehabilitation program once progressive training has improved tissue tolerance, coordination, endurance and strength to levels that are appropriate and safe for performance of higher level activities such as jumping. Properly performed and dosed, early low-level jump training should not represent a level of eccentric performance that is at risk of creating any significant DOMS.

The beginning of light plyometrics can be introduced on a rebounder, to reduce impact forces on healing joint systems. Mats on the floor can also be used to reduce these forces and eventually removed with improved tissue tolerance. Light jumping in place can also be employed for an initial plyometric training program as it limits the range of training and loading of the lower quarter.

More aggressive jump training for agility can be achieved by incorporating greater speeds, changes of directions and higher jumps. Initially a taped line
or cross on the floor can be used as a marker for cardinal planes of training. Multiple combinations of jumping with both legs in different directions can be trained and progressed to single leg training. Boxes of varied heights can then replace the tape to offer greater ballistic challenges by jumping on and/or over them with both legs, or a single leg.

Examples of Early Jumping Training Options and Progressions

- Jumps-in-place
- Standing Jumps—for distance or height
- Bilateral jumps forward and back
- Bilateral jumps side to side
- Hop and stop
- Unilateral hops forward and back
- Unilateral hops side to side
- 4x4 grid
- Diagonals on grid
- Jumping over a barrier—anterior or lateral

Circuit Training

Circuit training involves performing a group of different exercises in a series without a rest break. Exercises are chosen to train the entire body but can also include specific exercises related to the primary pathology. Measurements for improvement include reduced heart rate at the end of the circuit, reduced time to complete the circuit, as well as decreased time to recover to resting respiration rate and resting heart rate. Endurance can also be improved through the performance of circuit training. Performance is measured on the amount of sets/reps completed in a given time period. As the time improves, the challenge is increased so they are performing increased sets/reps in the same period of time. This type of training can be performed in the clinic and with aerobic cross training as well. Adding more repetitions or sets via increasing the amount of exercises will affect the endurance capacity of the involved muscle groups. For the knee, a circuit training program might include squats, step-ups, step-downs, lunges, lateral steps with resistance, hopping/jumping drills and more.

Section 4: Stage 4
Exercise Progression for the Knee

Training Goals

Stage 3 training marks the end of all primary impairments and symptoms focusing on improving the overall training state of healing tissues as well as incorporating more specific training for functional demands. Exercises are modified to train deficiencies with functional tasks as they relate to endurance, coordination, speed, strength and directions of dysfunction. Balance and proprioceptive retraining is also continued and further challenged during activity simulation. All exercises are performed through the full physiological range with a focus on strengthening around 80% of 1RM. Resistances, however, may be reduced to lower percentage RMs when initially performing more complex activities at higher speeds, as they require a greater degree of coordination. With improved motor control, the resistance can then be elevated to train for strength and power. The latter functional quality is addressed with explosive training at near maximal resistance and may include such activities as pushing blocking sleds, bungee running and resisted block starts.

Tissue and Functional States—Stage 4

- Full active and passive range of motion
- Pain free joint motion at a significant level of exercise
- Good coordination for functional motions
- Limited endurance and/or strength with functional performance
- Limitations in athletic performance
soreness suggested inflammation from muscle fiber damage. As the tissue matures and tensile strength increases, activities and exercises should be progressed accordingly to maximize its hypertrophy and functional capacity. Aggressive agility tasks including plyometrics and other triplanar exercises can be employed. For rehabilitation of ACL repairs, typically the tissue has healed sufficiently by six months to allow for the initiation of aggressive agility exercises including figure-8’s, lateral cuts, ball toss on the slide board, scissor running and quick start/stops.

Prevention programs have long been thought to help in reduce the incidence of ACL ruptures and other ankle, knee and hip injuries. Recently more evidence has been compiling in favor of the development and application of these prevention programs. Olsen et al. (2005) concluded that a structured program of warm-up exercises prevent knee and ankle injuries in young people playing sports. Preventative training should be introduced as an integral part of sports programs and include running, cutting, balance, proprioceptive and

### Motions and Directions

Tissue that is unaccustomed to eccentric exercise can sustain muscle fiber damage and delayed-onset muscle soreness (DOMS) within a few days after the exercise. A second bout of eccentric exercise, less than a week after the first bout, can typically be tolerated with much less damage and soreness (Brockett et al. 2001). Increases in leg girth in some subjects that reported muscle

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<tr>
<td>Lower Body Multiple Joint Exercise</td>
<td>35–45% of 1RM</td>
<td>1–3 sets, 10–15 repetitions</td>
<td>2–3 minutes</td>
<td>Moderate</td>
<td>2–3x/week</td>
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<tr>
<td><strong>End Stage Rehab/Healthy/Trained</strong></td>
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<tr>
<td>Lower Body</td>
<td>45–70% of 1RM</td>
<td>2–3 sets, 6–12 repetitions</td>
<td>2–3 minutes</td>
<td>Moderate to fast</td>
<td>1–2x/week</td>
</tr>
<tr>
<td>Jump Training</td>
<td>35–45% of 1RM</td>
<td>2–3 sets, 6–10 repetitions</td>
<td>3–5 minutes</td>
<td>Fast to ballistic</td>
<td>1–2x/week</td>
</tr>
<tr>
<td>Olympic Lifts</td>
<td>80–90% of 1RM</td>
<td>6–8 sets, 1–5 repetitions</td>
<td>5 minutes</td>
<td>Fast to ballistic</td>
<td>2x/week</td>
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Table 2.7: Dosage guidelines for lower body power training/jump training.
strength training as well as instruction in various landing techniques (eccentric and plyometric), which require an extremely high level of stability.

Weight Bearing Progression
Exercises to challenge weight bearing capacity can be further progressed at this time to include tri-planar motion through the full ROM. Step-ups and eccentric step-downs can be challenged by adding a rotation component. Increasing the depth of squats or lunges as well as changing the direction of motion are other examples of increasing weight bearing challenges.

Figure 2.111: Step-up with external rotation. The patient stands to the side of the platform, depending on how much rotation is desired. One foot is placed on the platform as the patient remains facing straight ahead. As the body weight is shifted to the stance leg, the trunk is rotated toward the platform with the knee kept centered over the foot.

Figure 2.112: Resisted squats with weight bar. The weight bar is rested posteriorly on the shoulders, off the cervical spine. The gaze is forward or up to assist in maintaining a neutral thoracic and lumbar spine. The patient is instructed to initiate the motion by shifting the hips posteriorly, rather than the knees forward. The depth of the squat should be no lower than is pain free, with the thigh going no lower than a horizontal position relative to the floor.

Figure 2.113: Front squat is a variation of the standard squat with the barbell resting on the front shoulders rather than on the back. The more upright position of the front squat creates less hip involvement with less gluteal contribution, places more emphasis on quadriceps, reduces spinal flexion as the patient cannot lean forward and increases abdominal contribution to stability.

Advanced Lunge and Step Training

Figure 2.114: Right anterior fallout lunge with posterior weight bar. The fallout lunge technique places more emphasis on the hip musculature compared to the knee. A weight bar on the shoulders will increase the demand on the spinal extensors, as well as increase torque at the hip.

Figure 2.115: Right anterior fallout lunge with right rotation:
weight bar. The fallout lunge is performed with a weight bar on the shoulders. At the end position of the forward lunge the trunk is rotated toward the front foot (right rotation shown). The addition of rotation will significantly increase the contribution of the deep hip external rotators, working eccentrically to decelerate the motion, as well as the rotational vectors of the lumbar multifidi and abdominals.

Figure 2.118: Lateral lunge with shoulder flexion. The patient steps laterally maintaining alignment of the hip, knee and foot of the lunging foot. The knee of the anchor foot remains in extension. Shoulder flexion is performed at the end of the lunge position. The lateral lunge emphasizes lateral hip musculature, with shoulder flexion increasing torque on the lumbar and hip extensors. For push off back to the start position, emphasis is placed on slight pronation of the foot and slight valgus at the knee to recruit the entire lower quarter extension pattern. Allowing the foot to supinate at push off reduces recruitment of extensor muscles of the hip and knee. A common compensation with lower quarter weakness is to shift the pelvis more lateral, outside the functional axis of the lower limb, maintaining the trunk more medial rather than outside of the foot. The patient should be instructed to keep the shoulders and trunk over the foot with the hip, knee and ankle in alignment.

Figure 2.119a,b: Anterior lunge onto a labile surface. To emphasize balance, stability and proprioception, rather than strength training, having the patient lunge onto a labile surface will increase the demand on the somatosensory system to coordinate the movement. Different types of surfaces can be used to vary the challenge. The patient can be allowed to look at the surface to assist with coordinating the motion, but may later be progressed by being asked to look forward during the movement. A progression may also be to have the patient move the cervical spine, looking lateral, up or down, increasing the challenge to postural and balance reflexes. These types of training challenges may be more indicated when proximal weakness at the hip and knee is identified, or significant central balance deficits are present.
earlier in the rehabilitation progression for the uninvolved joints. For instance, strength training for the hip may begin prior to the knee in order to help protect it from further physical trauma during weight bearing activity. Dosage for strength training is typically set between 80–90% of 1RM with a range of roughly eleven to four repetitions respectively. There are a variety of weight training concepts available to challenge the neuromuscular system including super sets, tri-sets, giant sets, pyramid training and negative training.

Power is a function of adding speed to an exercise dosed for strengthening and is typically associated with athletic performance. Initial strength training levels are usually dosed at 70–75% of 1RM with pure strengthening emphasized at approximately 80–90% of 1RM with eight to 12 repetitions per set. Rest periods between sets are increased with high end strength training due to increased energy consumption. The amount of time is dependent on cardio-vascular conditioning ranging from two to five minutes for a return to steady state. General weight training and body building concepts do have some application in the clinical setting. Options for alternating different types of exercise, loads and/or directions of training can be applied to vary the motor challenge and prevent boredom.

**Super Set**

Super sets refer to training two separate, often opposing muscle groups, for two to three sets with a two to three-minute rest between each set. Dosage for super set training is typically in the strength training range for healthy weight trainers, but dosage can reflect training for coordination and endurance as well. Body builders and power lifters may employ this method to improve strength gains. The knee may include opposing quadriceps and hamstring exercises. For rehabilitation purposes a modification in the super set concept may include the addition of rest breaks between the sets of each exercise. Super sets may also involve exercise groupings that include one trunk and one lower limb exercise, or one upper and one lower limb exercise, rather than antagonistic muscle groups.
performed consecutively per set on the same group of muscles without a rest break. This is basically the same as the tri-set example, but without a rest break until all bouts are completed.

Drop Sets/ Stripping/Pyramid Training
Drop sets involve multiple sets beginning with a high weight that allows for only one to three repetitions. Resistance is gradually decreased for the subsequent two to five sets, but repetitions may vary based on fatigue. These types of techniques are typically reserved for strength or power training for healthy athletes. Lower RM percentages can be used as a modification for patients at lower tissue training states. Stripping involves a specific number of repetitions for each set with gradually decreasing weight. Pyramid training begins with light weights and high repetitions then progressively increases weight and decreases repetitions over two to three sets followed by a reversal of the training pattern. Rest breaks are taken between each set based on the dosage. These types of techniques are effective in adding variety to the exercise regime, preventing stagnation in training and providing a different neurological challenge.

Negatives
Negatives are eccentric repetitions that are usually set at a resistance higher than the one lift concentric maximum (1RM) and performed for strength training. A spotter is required to assist with the concentric phase of the lift. This type of heavy lifting is not a common approach to clinical rehabilitation, but similar concepts are applied to pure eccentric training for tendinopathy.

Oscillation Repetitions
Oscillation repetitions involve performing a lift with back and forth concentric-eccentric contractions through the entire range of the exercise (Garfield 2003). Alternating acceleration and deceleration is performed five to ten times through one full repetition of the motion. Overcoming inertia during the transition between the deceleration and acceleration phases of the oscillation adds to the overall workload. This is a result of the
greater demand placed on the neurological system to coordinate motor performance throughout the range of the exercise. The total number of repetitions may need to be reduced, as fatigue will occur with fewer repetitions. As an example, squatting activities can be performed where the motion is stopped at several ranges for both eccentric and concentric phases.

**Functional Training for Jumping, Running and Agility**

Agility training and plyometrics might also be added to allow return to pre injury activity levels. If fast ballistic training is required, it should be performed when the patient has attained an adequate level of functional coordination, eccentric stability and tissue tolerance that allows for safe, pain free performance of these activities. This can be achieved through progressive resistance and anaerobic training in the earlier stages of rehabilitation. It must be remembered that specificity of training is important for all rehabilitation stages, including plyometrics, to ensure that the exercises chosen are applicable to the sport or skill being trained. This is achieved by determining specific needs during the initial evaluation and periodic reassessments, as the patient progresses through the physical therapy regimen.

![Figure 2.123a,b: Agility ladder hopping with 45° lower extremity internal and external rotation. Unilateral hopping is performed with targets (ladder squares). The patient performs alternating rotational motions of the lower quarter while maintaining the shoulders and trunk facing forward. Small rotational motions are progressed as coordination is established. This would represent a torsional challenge for rotary dysfunction retraining in the knee, as in ACL pathology.]

![Figure 2.124a,b: Agility stepping/running with ladder. The patient is asked to perform quick stepping within the agility ladder. Many variations are possible with alternating the direction (forward, backward and laterally) or by changing the target sequence of the squares in the ladder.]

![Figure 2.125a,b: Bounding is a progression of the hop-and-stop. Rather than the emphasis being on a stable landing, emphasis is on a quick, plyometric explosion forward to the alternate foot. The stride distance may start short to establish coordination but is progressed to exceed that of a normal running stride length. This is an exaggeration of a normal running stride with emphasis on improving stride length and stability on landing.]

![Figure 2.126: Resisted running or lunging. A sport cord or speed pulley is attached to the waist. The patient performs resisted motions of walking, jogging, lunging and/or running. Resisted motions can also include lateral, backward or in combined vectors.]

Figure 2.124a,b: Agility stepping/running with ladder. The patient is asked to perform quick stepping within the agility ladder. Many variations are possible with alternating the direction (forward, backward and laterally) or by changing the target sequence of the squares in the ladder.
Plyometrics / Jump Training

Jump training has its roots in Europe, with interest increasing in the 1970’s after Eastern European athletes began excelling in the world of sport competition (Chu 1988). Jump training was not referred to as plyometrics until the term was coined by an American track and field coach, Fred Wilt (1975). The terms jump training and plyometrics can be used synonymously, but for the purposes of this chapter, jump training is used in Stage 3 to represent the less aggressive initial stage of training for healing tissue states. Plyometric training, on the other hand, is more associated with end stage training emphasizing improvement of athletic performance. Plyometric exercises help a muscle reach its maximum strength in as short a time as possible (Chu 1988). They combine speed with strength, otherwise known as power training, where the muscles are trained to overcome heavy resistance through a short burst of activity.

Motor activation involved in fast ballistic movements tends to favor multi-joint phasic muscles, with reduced activation of single joint tonic muscles (Mackenzie et al. 1995, Thorstensson et al. 1985). Plyometrics rely on anaerobic capacity that requires rest periods for adequate recovery between repetitions and sets to maintain optimal training conditions (Chu 1988). It must be noted that bouts lasting four to 15 seconds deplete the creatine phosphate energy stores requiring a significant amount of rest for recovery, whereas bouts that last 30–90 seconds help to train lactic acid tolerance which may be preferable for some patients (Chu 1988). Recovery periods between sessions typically range from 48–72 hours depending upon the intensity of training to allow for tissue repair (Chu 1988).

In the example of jumping, emphasis is placed on spending as little time on the ground as possible. A quick transition is performed between the eccentric deceleration and concentric propulsion. Early jump training may involve a slower performance, focusing on coordination with landing to maintain proper lower quarter alignment and avoid pain. Plyometrics emphasize a ballistic, or explosive transition, to maximize energy transfer for propelling the joint system. The process has also been referred to as the stretch-shortening cycle, where collagen elongation during the eccentric phase is followed by an elastic recoil in the concentric propulsion phase. It also is governed by preset muscle tension via feedback from muscle spindles and mechanoreceptors to the spinal cord that can act to increase motor output. A delay in this process or transition, also known as the amortization phase, leads to a loss of energy via friction-generated heat and can be shortened by applying learning and skill training (Chu 1988). Assessment of motor responses in the ankle during jump performance suggests that the muscle response for an immediate jump after landing occurs too quickly for afferent signals to reach the spinal
Exercise for the Knee

Depth jumps involve jumping off a box, landing and immediately jumping again for height. Depth jump training has been shown to be more effective than weight training, jump and reach, and horizontal hops for improving speed and strength capabilities (Verhoshanski and Tatyan 1983). Determining the height for depth jumps has been studied, but is too individualized for a predetermined protocol, but Chu (1988) recommends a testing procedure for each athlete. First vertical jump is measured with the jump and reach and then the depth jump is tested using an 18-inch box. If the jump after landing is equal to the initial vertical jump test, than the box height is raised in six-inch increments until the athlete can no longer reach the original test height. If the first test on the 18-inch box is lower then the vertical jump test, than the box height is lowered.
Plyometric Jump Options

- Jumps-in-Place—Jump and land from same spot. Repeated in succession with a progressive increase in the rate of jumping to improve transition between eccentric landing and concentric propulsion phases. They can also be progressed by jumping higher.

- Standing Jumps—a single maximal effort in a horizontal or vertical direction that may be repeated following a complete recovery from the previous effort.

- Multiple Hops and Jumps—Maximal effort jumps performed one after another over a distance of less than 30 meters that can be performed with or without barriers (boxes, cones, hurdles, etc.). They act as a precursor to box drills described earlier.

- Ninety Degree Jumps—Jump and turn 90 degrees in the air. Land and jump and turn 90 degrees opposite back to the starting position. Jump and turn 180 degrees then 270 degrees and finally 360 degrees.

- Anterior barrier hops—unilateral, bilateral, or alternating feet

- Lateral barrier hops—unilateral, bilateral, or alternating feet

- Stair (stadium) hops—bilateral step jumping

- Step-up and jump

- Lateral step-up and jump

- Agility running

- Scramble-Up—Start from a prone position and scramble up to a balance standing position as quickly as possible. To increase the difficulty, perform the exercise with the eyes closed.

- Standing long jump with sprint: sprint in any direction (i.e., anterior, lateral and posterior).

Running Options

- Bounding.

- Jogging/running different directions: anterior, posterior, lateral.

- Cutting—jogging/running with direction change (i.e., anterior and cut lateral).

Figure 2.131: Resisted walk/run. A chest harness is placed around the trunk or a strap is used around the pelvis. Appropriate weight is added to challenge balance and recruitment. The patient starts from a standing or crouched position (start position in sprinting), then pushes through the stance limb to propel the body forward. If starting from crouched position, the patient "explodes" to a standing position. In both cases, the patient takes a few steps to challenge balance and weights can be placed in the hands to further increase the challenge.

Figure 2.131a,b: 3-Point resisted track start with speed pulley.

Summary

It has long been thought that therapeutic exercise plays an important role in the rehabilitation of joint pathology. A review of the literature found that numerous clinical trials used either exercise or a patellofemoral physical therapy treatment plan that
included therapeutic exercise as a control (Antich 1986, Thomme 1997). These trials all showed significant improvement related to one or more of the following:

- **pain reduction**
- **strength gains**
- **improved EMG activity**
- **improved patellofemoral congruence**

The Philadelphia Panel (2001) found good evidence to include strengthening, stretching and functional exercises together as an intervention for osteoarthritic knees. Numerous studies have also shown correlations between obesity and prevalence of knee OA (Coggon et al. 2001, Felson et al. 1997, Cicuttini et al. 1997). Bynum (1995) performed a randomized clinical trial (RCT) comparing open-chain and closed chain kinetic exercise following ACL reconstruction, demonstrating that subjects that performed closed kinetic exercises experienced a significant reduction of preoperative patellar pain and significantly less patellar femoral pain following surgery and subsequent rehabilitation.

Nyland et al. (1994) stated that an understanding of the afferent neural system of the knee is imperative to properly plan a rehabilitation program since there is an intricate relationship that exists between the afferent receptors and the contractile tissues of the knee. They believe that closed kinetic chain functional training (CKCFT) may provide a method for more effectively rehabilitating an injured or reconstructed knee by incorporating sensorimotor integration through motor learning.

This section has outlined an integration of the sensory motor afferent system beginning with initial coordination exercises aimed at developing proper recruitment patterns. Once these neuromuscular recruitment patterns are established, the rehabilitation program is progressed along the endurance-strength continuum by gradually increasing load and lowering repetitions to meet the functional demand. Generally, the average patient population requires strength capacity of approximately 85% of 1RM, which should be sufficient for performance of a majority of activities of daily living. A home program is also necessary to direct self-care. Findings by Chamberlain et al. (1982) suggest that if patients are not held accountable for their home exercise program however, the majority will not remain compliant. The effects of home-based exercise, even for more chronic issues such as osteoarthritis, have been shown to be beneficial (Thomas et al. 2002), and act to serve the greatest benefit to those who adhere to the program (Hart et al. 2003). Post rehab exercise need not involve continued progressive resistive training, but may include a simple return to normal activity levels and/or sport.
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Exercise Rehabilitation of the Hip Joint

Introduction

Review of published physical therapy literature presents little information on treatment progressions of the hip using manual therapy techniques for joint mobilization and exercise. Manual therapy involves passive stretching and manipulation techniques aimed at restoring joint function (Cyriax 1996). The current definition of manual therapy practice includes exercise as a component and is not limited to passive joint treatments. Orthopaedic Manual Therapy is a specialized area of physiotherapy/physical therapy for the management of neuromusculoskeletal conditions, based on clinical reasoning, using highly specific treatment approaches including manual techniques and therapeutic exercises (IFOMT). Long axis distraction is one of the most commonly used manual therapy techniques for hip pain (Kisner et al. 1985, Woerman et al. 1989), and has shown to be beneficial for both pain inhibition and increasing hip range of motion (Kaltenborn 1980).

Exercise therapy administered by a physical therapist, described as active and passive exercises aimed at improvement of pain, range of motion, muscle function and ambulation (Minor 1994, Hofmann 1993) is also reported to be effective in the treatment of patients with osteoarthritis of the hip (Van Baar 1998, Smidt et al. 2005). While both exercise and manual therapy have been shown to be effective on painful hips, Hoeksma et al. (2004) compared the effectiveness of manual therapy, consisting of stretching and manipulation techniques, versus exercise alone on hip osteoarthritis. They found manual therapy to be more effective than exercise alone in the treatment of hip osteoarthritis. Exercise is a part of manual therapy and a combined approach of both passive and active treatment is recommended, as neither can be fully replaced by the other.

Passive joint mobilization and soft tissue work may be necessary prior to initiating exercise. Passive manual therapy techniques are aimed at restoring arthokinematic mobility, improving range of motion, reducing pain, resolving muscle guarding and assisting mechanoreceptors to facilitate normal motor patterns (Grimsby...
Exercise for the sacroiliac joints and pelvic girdle are typically not performed in isolation. It is clinically difficult to separate influences of the lumbar spine and hip joints from the structural and dynamic stability of this region. This chapter will attempt to focus on exercise concepts and progressions for the pelvis. The reader is also encouraged to review the Hip and Lumbar chapters for integration into a more complete exercise program, should these areas require treatment as well.

Initial exercise will address rehabilitating the primary diagnosis of connective tissue abnormalities and/or weakness and lack of coordination of musculature related to the pelvis. Much conflict and controversy exists pertaining to the existence of sacroiliac related pathologies, but core science consistently reports motion occurring at the articulations between the iliac bones and the sacrum (Jacob et al. 1995, Smidt et al. 1995/1997, Lund et al. 1996, Wang et al. 1996). Though most of the available motions at these articulations occur in the frontal plane around a more sagittal axis, motion also occurs around vertical, anterior/posterior and oblique axes, making these joints functionally multiaxial. A detailed evaluation of the related anatomical systems must be performed to identify load sensitivity of key ligamentous and fascial structures, as well as abnormal function at the articulations between the ilia and sacrum, and the pubis. Evaluation must also include assessment of the motor system, including volume, coordination and strength. Muscles of the hip, pelvis and lumbar spine must function in proper synergy to be transducers of force between the lower limb and the upper and lower torso. It is assumed the reader has an extensive knowledge of sacroiliac joints and pelvic girdle anatomy, with a basic understanding of biomechanics. This chapter will provide limited reviews of these sciences, with emphasis on exercise application.

The sacroiliac joints (SIJ) are subjected to great shear forces. The ligamentous and capsular structures close to the instantaneous axis of motion, as well as collagen structures more distal to axis, need to be able to resist up to 4,800 N of force (Gunterberg et al. 1976).
Exercise Rehabilitation of the Lumbar Spine

Introduction

Treatment of the lumbar spine has been described as “the medical catastrophe of the 20th century” (Waddell 2000). Exercise has been applied for therapeutic purposes for thousands of years, and the treatment of the lumbar spine is no exception. Unlike many of the other topics evaluated by the Cochrane Study (Hayden et al. 2006), the report showed some evidence of benefit for exercise when used with patients experiencing chronic low back pain. Unfortunately, in reviewing the randomized trials, it is clear that the methodology used did not place subjects into subgroups. This resulted in very heterogeneous populations of subjects with low back pain being treated with specific exercise approaches. It is not reasonable to expect good outcomes if the same exercise protocol is applied to a group of patients with low back pain that have a variety of diagnoses and degree of acuity. Looking at the studies, it was generally found that exercise for low back pain has minimal to no effect for acute pain, with good evidence for benefiting patients with chronic pain (Hart et al. 2006, Hayden et al. 2006, Hayden et al. 2005a/b/c).

It is easy to predict only marginal outcomes with exercises for back pain if they are not specific to a patient’s diagnosis, and this needs to be the focus of future scientific inquiry. After detailed tissue differentiation, exercise can be applied to not only improve symptoms and function, but to assist in facilitating tissue repair. Tissue differential diagnosis is challenging, yet it should remain a goal with each patient to better establish a treatment program. Even if an evaluation fails to identify a specific tissue, many tissues can be ruled out and any contraindications can be identified. Also, a pattern of symptoms with compression or tension can be established to assist in designing a safe program to improve tissue tolerance. Much of the literature addressing the application of exercise in the treatment of lumbar pain has identified two main properties: muscle strength or motor control. The application of scientific therapeutic exercise progressions (STEP) addresses these two issues, as well as tissue regeneration, resolving muscle guarding, reducing fear and avoidance.
behaviors, acute pain control, initiating functional training, increasing endurance and edema reduction.

Exercise is not applied alone to the spine, but is a part of a more complete treatment program involving modalities, soft tissue work, joint mobilization, exercise and prophylaxis. Exercise and manual therapy have been shown to be more effective at reducing pain levels than exercise alone (Geisser et al. 2005). The individual patient may require more emphasis on one of these interventions over another to control symptoms, but exercise is the primary intervention in improving overall performance. Benefit is noted from combining manual therapy with exercise for low back pain patients (Bronfort et al. 1996, Niemisto et al. 2003). Rasmussen-Barr et al. (2003) found no difference in treating low back pain patients with manual therapy versus stabilization exercises. Stabilization training, however, seemed to be more effective in terms of reducing the need for recurrent treatment periods. Conversely, Aure et al. (2003) found manual therapy to be more advantageous than exercise therapy. Improving joint mechanics with passive mobilization techniques prior to exercise can assist in normalizing afferent feedback to influence motor patterns. Segmental mobilization techniques in the lumbar spine have been shown to improve recruitment of the superficial abdominal muscles in subjects with chronic low back pain, though no improvements were found in the transverse abdominis muscle (Ferreira et al. 2007). Improved recruitment of the transverse abdominis following spinal manipulation has been reported in a case study (Gill et al. 2007). In a follow up controlled trial, Ferreira et al. (2007b) assessed outcomes for general exercise, specific motor control exercise or spinal manipulation for chronic non-specific back pain. A six and 12 month follow up found motor control exercise and spinal manipulative therapy slightly better than general exercise for short-term function and perception of effect, but not better medium or long-term effects. As all three approaches have evidence for positive outcomes, the emphasis on passive manual techniques, specific motor training and general exercise should be determined on an individual basis, rather than assuming one is superior for every patient. An overall treatment incorporates passive manual treatments, exercise and education. Manual therapy, as defined in this text, includes exercise therapy. For every degree of mobility improvement through passive treatment, comes the need for active treatment to stabilize this new range.

Wand et al. (2004) demonstrated the benefit of an assess/advise/treat model of care, offering better outcomes, than an assess/advise/wait model of care. Early intervention consisted of biopsychosocial education, manual therapy, and exercise. In the short-term, intervention is more effective than just advising the patient to stay active. Early intervention leads to a more rapid improvement in function, mood, quality of life, and general health. The timing of intervention also has an affect on the development of psychosocial features. When treatment was provided later, the same psychosocial benefits were not achieved. Though physician advice to stay active and return to work does have psychosocial benefits, a complete treatment program involving education, manual care and exercise can be more effective and more long lasting. Early intervention is also more cost effective due to an earlier return to work (Wright et al. 2005).

The lumbar spine is inherently unstable (Lucas and Bresler 1961), with the upright spine devoid of musculature only being able to support two kilograms of vertical load. Normal weight of the head and torso would cause buckling unless adequate muscular support is available. Looking at exercise to address low back pain, it is important to be able to see the body both globally and at a cellular, or tissue, level. From a mechanical standpoint, the human body is built so that the lumbar spine is a transition point between weight bearing through the feet and the active head, neck and trunk. As the lumbar spine endows the pelvic girdle with movement at L5/S1, it is also a natural point of stress. The requirements of coordination, strength, and flexibility are apparent in observation of the union of the stable pelvis with the relatively
large moment forces from the head, shoulder, upper limbs, and torso. The lumbar spine has a higher number of Type II mechanoreceptors, compared to Type I, which are associated with recruitment of phasic muscle systems. Strength is crucial, but without the appropriate timing of contraction and coordination, recurrence has a significantly higher chance of occurring, as much as a six times greater chance of recurrence was measured two and three years after implementation of an exercise program (Hides et al. 2001).

This chapter will attempt to outline a thought process for exercise dosage and progression to address a continuum of clinical requirements from pain and mobility up through stability and function. It is assumed the reader is familiar with spinal anatomy and biomechanics, as well as earlier theoretical chapters in this book series. A more clinical approach is taken on how to apply work physiology concepts in a rehabilitative setting with conceptual outlines as well as specific examples.

**Bed Rest or Stay Active**

Bed rest and immobilization as the treatment for acute non-specific low back pain has come under question from a diverse accumulation of evidence based scientific research. Immobilization and bed rest for acute low back pain was based on the early understanding of the medical disease model. The thought was that early physical activity might increase pain, aggravate inflammation, prevent healing and eventually lead to chronic pain. John Hunter (1794) is credited as being one of the first to propose therapeutic rest as a treatment for wounds and inflammation based on the understanding of healing at that time (Waddell 1998). Later, Hugh Owens Thomas (1874), considered the father of English Orthopedics, applied the concept of therapeutic rest to the newly emerging field of orthopedics. This became the orthopedic rationale for acute injuries and is still described today as a basic principle of orthopedic treatment (Waddell 1998). Therapeutic rest has also been widely applied to acute cases of low back pain. According to the National Institutes of Health (NIH), low back pain ranks as the second most common symptom-related reason for seeing a physician, and is the most common and most expensive cause of work-related disability in the United States.

With the discovery of the herniated (or ruptured) disc in 1932, many physicians began to assume that most pain in the back was the result of this new problem. In addition, Nachemson (1966) discovered that the lumbar intradiscal pressures significantly change from supine (25–35 percent body weight) to over 300 percent in weight bearing positions. This information further emphasized the need to rest lying down. The thought was that laying and rest would allow the disc relief so that it may “go back in,” resolving the back pain (Waddell 1998). An increase in intradiscal pressure was mistakenly taken as a negative thing, rather than a natural stimulus for tissue maintenance. Cartilage pressure also increases with weight bearing, but progressive weight bearing training is a mainstay of rehabilitation of cartilage pathologies, not bed rest.

By the mid 1980’s, more and more research was published on bed rest and immobilization for acute back pain. Two key randomized control studies came out that challenged the idea of therapeutic rest for acute low back pain. Deyo et al. (1996) showed that patients who were advised to take two days bed rest returned to work sooner than those advised to take seven days. Gilbert et al. (1985) showed those who had no bed rest returned to normal activities faster than those who had four days’ bed rest. Waddell et al. (1988) did an extensive literature search for all randomized clinical trials of acute back pain comparing the effects of bed rest to advice by the medical practitioner to maintain activity levels. Ten trials of bed rest and eight trials of advice to stay active were identified. Consistent findings showed that bed rest is not an effective treatment for acute low back pain but may delay recovery. Advice to stay active and to continue ordinary activities results in a faster return to work, less chronic disability, and fewer recurrent problems (Waddell 1997). This review also found that early mobilization leads to fewer recurrent problems and less sick leave over the
demonstrated a significant decrease in the number of recurrences of back pain in subjects randomized to exercises, compared to controls (Donchin et al. 1990, Soukup et al. 1999, Hides et al. 2001).

The only time bed rest is prescribed is in the presence of nerve root compression. For the lumbar spine, this involves a loss of sensation, reduced deep tendon reflexes and reduced myotome findings. Bed rest is prescribed with compression to allow GAG to be broken down by enzymes, taking pressure off of the nerve. The half life of GAG is 1.7 to 7 days, in which time the clinical tests should move from a compressed state, to a mixed state, signaling the time to begin exercise. The mixed state involves at least one of the three tests moving from a state of compression to normal or hyperreactive state. As pain increases from a state of nerve compression to an irritated state, it cannot be used as a gauge for improvement. The patient should actually be warned that their pain might increase as nerve function improves. Continued clinical testing of the nerve function will allow the clinician to determine whether the treatment is having an overall positive effect. Too aggressive treatment can result in further tissue injury, leaking of more GAG from the disc and the nerve moving from an irritated state to a compressed state. Pain levels would decrease, but the state of tissue injury has actually regressed.

<table>
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<th>Nerve Root Pathology</th>
<th>Sensory</th>
<th>Motor</th>
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<tbody>
<tr>
<td>Nerve Root Irritation</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Mixed Stage</td>
<td>+/-</td>
<td>+/-</td>
<td>+/-</td>
<td>+/+</td>
</tr>
<tr>
<td>Nerve Root Compression</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5.1: Nerve conduction assessment. True nerve compression results in reduced clinical tests for sensation, reflexes and myotomes. This is accompanied with a relative reduction in pain signals, compared to the mixed and irritated states. The irritated state is defined by hyperesthesia.
Koumantakis et al. (2005a/b) compared general endurance exercise with supplemental stabilization training, concluding that physical exercise alone, and not the exercise type, was the key determinant for improvement in this patient group. Contrary to this, O’Sullivan et al. (1997) found specific exercises statistically significant in reducing pain intensity and improving functional disability levels for patients with chronically symptomatic spondylolysis or spondylolisthesis.

**Aggressive Generalized Back Exercise**

More aggressive, yet still generalized protocols and exercise programs have also been assessed. These programs have been deemed appropriate for more significant back pain, stemming from conditions such as lumbar disc degeneration, herniated nucleus pulposus, spinal stenosis, facet syndrome, Grade I–II spondylolisthesis, spondylolysis, myofascial pain and postoperative fusion patients or laminectomy patients (Cohen and Rainville 2002). Contraindication for aggressive back exercise is noted for more significant pathologies including: medical instability; lesions best treated with surgery; severe osteoporosis; fracture; tumor, Cauda Equina and Conus Medullaris Syndromes, progressive neurological deficit; spinal instability; Grade III–IV spondylolisthesis; visceral/systemic pathology and spondyloarthropathy (Cohen and Rainville 2002). Exercises in this program included Cybex back extension, Roman chair hyperextension, lumbar crate lifting, pull-down machine, Cybex rotary torso machine and the Multihip weight machine. Training sessions lasted from one to two and half hours, with two to three sessions per week.

Prospective and retrospective analysis of studies utilizing aggressive exercise as treatment for patients with chronic low back pain reveal significant improvements within a six to eight week period. Trunk flexibility has been shown to improve by 20 percent, trunk strength and lifting capacities by 50 percent and endurance by 20 to 60 percent (Hazard et al. 1989, Mayer et al. 1985, Risch et al. 1993, Brady et al. 1994, Curtis et al. 1994, Mayer et al. 1994, Pollock et al. 1989). Pain-related hyperreflexia and muscle spasm. The mixed state involves any combination of normal, irritated or compressed signs.
disability was reduced by 50 percent (Fairbank et al. 1980), on average, and pain severity by 30 percent (Hartigan et al. 1994). Successful completion of exercise in the presence of chronic pain, from a cognitive standpoint lessens fear and concern, improves self-efficacy and confidence for performing daily activities, resulting in reduced disability (Rainville et al. 1993, Dolce et al. 1986).

Exercise is a primary intervention for physical therapists in the treatment of back pain. Research utilizing generalized fitness or generalized stabilization approaches for back pain should have limited results. This chapter will attempt to incorporate more general and traditional exercise approaches for back pain, but more importantly will attempt to illustrate the potential for specifically dosed exercise programs addressing identified impairments and tissue pathology.

Section 1: Stage 1 Exercise Progression for the Lumbar Spine

Despite limited evidence for exercise for acute low back pain, much can be accomplished early in rehabilitation to control symptoms and improve impairments, while protecting injured tissue. A lack of evidence in the literature may reflect a lack of research on more specific training for acute issues, rather than a lack of effectiveness. Faster resolution of acute symptoms more quickly transitions the patient to a subacute stage, in which evidence does exist supporting the positive effects of exercise. The concepts and techniques outlined in the STEP curriculum provide safe options, for early training. The exercises, dosage and progression concepts outlined in this chapter are an extension of Medical Exercise Therapy (MET) principles originating from the 1960’s (Faugli and Holten 1996). Emphasis may be more on passive manual therapy techniques in the early stage, but this section will also provide many active options as well.

Stage 1 Progression Concepts

The basic components of an initial exercise program are to 1) normalize joint motion, 2) provide tissue repair stimulus, 3) resolve muscle guarding, 4) normalize motor patterns (coordination), 5) improve function and finally 6) to elevate the overall training level. Pain is indirectly improved by addressing these basic building blocks to function. Joint motion is facilitated first with both passive and active treatment. Arthrokinematic motion must be available to allow for normal range of motion, provide afferent input via mechanoreceptor firing in the surrounding joint capsule and to assist in normalizing muscle recruitment. Hypomobile joints require mobilizing exercises, while hypermobile joints limited by muscle guarding require exercise to normalize tone. For tissue training and improving motor function, additional exercises are dosed around the general parameters of high repetition with minimal resistance and slow speed.

Potential Tissue States and Functional Status: Stage 1

- Reduced arthrokinematic motion
- Decrease in active and passive range of motion
- Painful joint at rest and/or with motion
- Abnormal respiration patterns
- Pain with weight bearing
- Edema with palpable temperature (if in the superficial joint)
- Muscle guarding at rest locally and with distal referral (Active trigger points with satellites and referred patterns)
- Poor coordination
- Poor balance/functional status
- Positive palpation to involved tissues
- All higher level functions of endurance, strength and power are reduced
- Sympathetic hyperactivity
Exercises in Stage 1 are commonly associated with the functional qualities of pain reduction, edema reduction, resolution of muscle guarding, stimulation of metabolic activity of the injured tissue(s) for repair/regeneration, neurological adaptation to improve coordination and range of motion. Several or all of these functional qualities may be achieved in combination with simple pain free movements. Deciding which of these qualities to emphasize first will be influenced by a patient’s pathology, stage of healing, surgical intervention, training level and general health, as well as any other specific limitation of the diagnosis. The state of the tissues and the functional level of each patient are assessed to determine necessary starting points, required training goals and to establish the appropriate dosage of training. All impairments are addressed specifically through a properly dosed exercise program for the functional quality that will reverse the abnormal condition. A shot gun approach for every low level functional quality is avoided and a more focused program is designed.

For rehabilitative exercise there is no difference between the athlete and the non-athlete, the young or old, the male or female, other than the dosage of the exercise. Even overweight elderly subjects have demonstrated positive training results for the lumbar spine and extremities (Vincent et al. 2006). Exercises are dosed in a patient specific manner, based on the stage of healing in the tissue and the training state. Each exercise is tested for resistance, repetitions, coordination and speed, then adjusted to the specific functional quality desired.

**Many Repetitions / Dosage**

Initial training emphasizes high numbers of repetitions with minimal resistance. Safe, pain free repetitive motion will improve all Stage 1 functional qualities. Specific parameters for dosage are outlined below, with the patient’s performance and tolerance being the true gauge of how much should be initially achieved. Each of these functional qualities will be more specifically addressed in this section. Pain assessment and delayed onset tissue soreness (DOTS) will guide the clinician in modifying the program. Any pain during the exercise is avoided to prevent further tissue damage, increased muscle guarding or altered motor patterns due to motor reflexes from the pain. The introduction of additional pain during training would suggest abnormal tissue deformity or significant tissue ischemia, neither of which is a desired goal. Pain within several hours of a training session suggests excessive levels of stress to tissue, resulting in an inflammatory response. Development of pain or excessive stiffness the next morning would suggest unnecessary tissue stress or muscle soreness. This should also be avoided in the early stages. In later stages, when tissue tolerance has improved, post exercise soreness may relate more to muscle strain, that may be a tolerable level associated with higher levels of training.

**Tissue Repair / Edema Resolution / Pain Inhibition**

An acute ankle sprain is initially actively dosed with high repetitions of low resistance exercise to address pain, edema and muscle guarding. If dosed safely and performed within the available tissue tolerance level, improved healing should result. Depending on any contraindication present, this concept is no different for the spine. A patient with an acute strain of superficial fibers of the annulus fibrosus has a similar list of health issues, which can be tackled with both passive and active measures. High repetition, pain free movement recruits joint mechanoreceptors that will inhibit pain and muscle guarding. Movement will facilitate edema reduction and provide modified tension in the line of stress, promoting fibroblast activity related to tissue repair. Repetitive motion will also begin to address issues of motor recruitment, timing and coordination. Psychological benefits are also achieved by providing the patient with a safe environment to move, a positive exercise experience, and some personal sense of control over their situation. Rather than prescribing bed rest and limited activity, feeding into fear and anxiety, an active approach is prescribed that is safe and effective. Signs of over training need to be strictly monitored. Indicators of exercise exceeding tissue tolerance include increased...
II collagen is stimulated in the chondrocytes in the nucleus pulposus and facet cartilage. Annular fibers are more specifically targeted with modified tension in the line of stress with rotation, but this would also include flexion, extension and side bending. Compression and decompression for chondrocytes stimulation in the nucleus is also achieved with intradiscal pressure changes through rotation, but would also progress to all planes of motion and combined planes. Moving from lying postures to more erect postures will also increase the level of compression, improving the repair process (Nachemson 1966).

Restricted and/or Painful Lumbar Movement in 500 Patients

<table>
<thead>
<tr>
<th>Direction of Motion</th>
<th>Percent of Patients with Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension</td>
<td>73.2%</td>
</tr>
<tr>
<td>Flexion</td>
<td>43.4%</td>
</tr>
<tr>
<td>Sidebending</td>
<td>47%</td>
</tr>
<tr>
<td>Rotation</td>
<td>32%</td>
</tr>
</tbody>
</table>

Table 5.2: Holten tested 500 patients with no exclusion criteria to document which directions were most and least tolerated. Rotation was found to be the most tolerated with extension producing pain in the greatest number of patients (Faugli and Holten 1996). The initial direction chosen for tissue training is based on the direction of tolerance by the patient, not by statistical descriptions from research.

In a more basic sense, injured tissues need modified motion to stimulate repair without causing further tissue injury. Motion can be performed in one plane, or all three planes, depending upon the type of tissue injury and the severity. Matching the individual’s directional preference for pain free motion can significantly and rapidly decrease pain, the use of medication and overall improvement in all other outcomes (Long et al. 2004). The body should be placed in the most demanding position a patient can tolerate, though often initial training is in lying postures to reduce the tissue load. As tissue tolerance improves, similar exercises should be performed in more challenging postures, rather than

The dosage for tissue repair, edema resolution and pain inhibition is similar. Repetitive pain free motions are performed with minimal to zero resistance, stimulating tissue and cell repair. Just as an acute ankle sprain is moved repetitively for hours, so is the acute lumbar injury. The key is to begin with a comfortable posture, first moving in the least painful plane, and progressing to the most painful plane but remaining in the pain free range. Tissue training targets fibroblasts for type I collagen in the annular fibers of the disc, facet capsules and ligaments, while production of type II collagen is stimulated in the chondrocytes in the nucleus pulposus and facet cartilage. Annular fibers are more specifically targeted with modified tension in the line of stress with rotation, but this would also include flexion, extension and side bending. Compression and decompression for chondrocytes stimulation in the nucleus is also achieved with intradiscal pressure changes through rotation, but would also progress to all planes of motion and combined planes. Moving from lying postures to more erect postures will also increase the level of compression, improving the repair process (Nachemson 1966).
adding increased resistance to recumbent exercises. Repetitive movements are recommended on almost an hourly basis with shorter time periods to avoid tissue irritation.

Dosage for these basic functional qualities is typically less than 25% of 1RM, so fatigue is typically not a limiting factor. The patient performs these exercises throughout the day at a level of tissue strain that does not create pain, swelling or stiffness. The program is organized so the patient can perform several hours of pain free exercise daily. Inflammation secondary to overstraining tissue may take several hours to become symptomatic. Should delayed onset tissue soreness (DOTS) occur, then the level of training is decreased.

Exercise Examples for Lumbar Tissue Repair, Pain and Edema:
- Side lying caudal rotation
- Side lying cranial rotation
- Hip rolls supine
- Cat and camel
- Pelvic tilts
- Decline single and double knee to chest

Tissue repair models of exercise are most important for acute injury and post surgical patients. Chronic pain patients may no longer have acute, specific tissue damage requiring tissue training, but

<table>
<thead>
<tr>
<th>Body Position</th>
<th>Plane of Motion</th>
<th>Time and Frequency</th>
<th>Speed</th>
<th>Exercise Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tissue Repair</strong></td>
<td>1) Non weight</td>
<td>1) Alternate plane</td>
<td>1) x 15 minutes with 5–10</td>
<td>Specific and controlled motion progressing</td>
</tr>
<tr>
<td></td>
<td>bearing (WB),</td>
<td>from pain,</td>
<td>sessions daily, 2) &lt;30–60</td>
<td>to functional motions.</td>
</tr>
<tr>
<td></td>
<td>2) partial WB,</td>
<td>2) in plane of</td>
<td>minutes 1–3 sessions daily</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3) full WB,</td>
<td>pain but in the</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4) loaded WB,</td>
<td>opposite direction,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>may vary on</td>
<td>3) in plane of</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>body region</td>
<td>pain toward but</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>or tissue</td>
<td>not into pain</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Edema Reduction</strong></td>
<td>1) Recumbent</td>
<td>1) Motions at joints</td>
<td>1) At least 15</td>
<td>Specific and controlled cardinal plane</td>
</tr>
<tr>
<td></td>
<td>postures</td>
<td>proximal and</td>
<td>minutes with 5–10</td>
<td>motion progressing to functional</td>
</tr>
<tr>
<td></td>
<td>2) Dependant</td>
<td>distal, 2)</td>
<td>sessions daily, 2) At least</td>
<td>triplanar motions</td>
</tr>
<tr>
<td></td>
<td>postures</td>
<td>Controlled motions</td>
<td>30–60 minutes 1–3 sessions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>at joints</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>in least painful</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>planes</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pain Inhibition</strong></td>
<td>1) Non Weight</td>
<td>1) Distraction at</td>
<td>Perform daily when pain is</td>
<td>Specific and controlled motion</td>
</tr>
<tr>
<td></td>
<td>Bearing (WB),</td>
<td>joint, 2) motions</td>
<td>present of &lt;10 minutes – as</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2) to partial</td>
<td>at joints distal</td>
<td>frequently as is effective</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WB, 3) to full</td>
<td>and proximal, 3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WB, 4) to loaded</td>
<td>at joint but away</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WB</td>
<td>from pain, 4)</td>
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<td></td>
<td></td>
<td>toward pain but</td>
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<tr>
<td></td>
<td></td>
<td>not into pain</td>
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</table>

Table 5.3: General guidelines for acute training.
general exercise will still address improvement in tissue stress and strain tolerance. Improved joint mechanics and motor performance from exercise will also reduce excessive or abnormal loads to tissue. Patients should be encouraged to move as much as possible with daily activity and with specific exercises. Bed rest may address the fear and anxiety of the patient or clinician, but will only delay tissue healing and functional restoration.

**Literature Review on Recommendations to Surgeons for Lumbar Post-Operative Care (McGregor et al. 2007):**

- There is a lack of evidence for restricting post-operative activity
- Most restrictions are probably from anxiety or uncertainty of the clinician or patient
- Most restrictions are unnecessary
- Restrictions may delay recovery and return to work

Patients are uncertain of what they can and cannot do:

- Knowing what to expect can facilitate recovery
- “Let pain be your guide” is an unhelpful approach

Better outcome is achieved with early activation:

- Most recovery occurs in the first 2-3 months
- Function and activities of daily living may improve with early rehabilitation programs

Early return to work produces better outcomes and faster recovery:

- Early return to work is not harmful and may be helpful
- Most pain and disability is noted in those that do not go back to work

**Mobilization**

Not every patient has joint restriction, but when limited joint movement is present it must be corrected prior to attempting to gain any improvement in motor performance. Muscle performance cannot significantly improve if the hinge is not moving properly around a normal physiological axis. Assessment of joint mobility must also go beyond the lumbar spine, assessing the thoracic spine, pelvis and lower limb joints. Any restriction in the biomechanical chain will affect force transmission and motor performance. Treating only the area of pain often results in missing significant pain free impairments that are part of the primary symptom complaint. In some cases, simply restoring joint motion normalizes motor recruitment and patterns due to improved afferent input from joint mechanoreceptors.

Specific mobilization exercises involve the use of a segmentally specific wedge or block, but cannot be as specific as passive manual techniques. Dosage for mobilizing exercise is more classically initiated at one set of greater than 40 repetitions at <50% of 1RM to improve elasticity of collagen and lubrication of cartilage. Progressions with additional sets and number of repetitions are based on the patient’s response. Multiple sets may be performed during the day, or during training sessions; rest breaks between sets to restore oxygen are not necessary when training collagen, as with training muscle. Plastic deformity of restricted collagen in joint capsules is trained with similar resistance but with only two to five slow repetitions holding 10–20 seconds. Time, not force, is more effective in creating plastic changes. The clinical setting can provide segmentally specific mobilization exercises. Home exercise may not be as specific but is still important to maintain and augment improvements made in the clinic.

The dosage of the exercise, not the exercise itself, determines the outcome. For example, the simple supine hip roll exercise can be dosed differently to achieve pain inhibition, tissue repair, joint mobilization or motor performance. An exercise should not be considered to have a specific purpose, it is the dosage associated with it that determines the outcome.
The patient is instructed to relax the back muscles and perform the press up emphasizing muscles of the shoulder girdle. A pillow can be placed under the pelvis to reduce the extension range if pain or neurological compromise occurs. The mobilization can be performed with repetitive motion or as a sustained stretch. The press up is intended to be passive maneuver, not active extension, to load the tissues at end range for improved mobility and symptoms (McKenzie 2001). The press-up mobilization is contraindicated with nerve root pathologies due to foraminal closure with the maneuver.

**Dosage for Mobilization Exercises**

- **Elasticity**: one set 30–50 repetitions, one to three times daily.
- **Plasticity**: 10–15 second holds into mobilization, three to five repetitions, one time daily.
Figure 5.10: Caudal left rotation mobilization with legs crossed. The patient is instructed to cross the right hip over the left, then rotate the knees to the right (relative left rotation). The crossed legs will increase the stretch emphasis to the hip joint and tensor fascia lata.

Figure 5.11: Right rotation/extension mobilization prone. The patient lies in prone with the knees flexed to 90°. The lumbar spine is in neutral, without a pillow under the stomach. The feet drop off to the right, creating a relative right rotation of the lower lumbar segments.

Figure 5.12a,b: Slump flossing of lumbar dural and neurovascular structures. This approach is designed to floss the dura and neurovascular structures, not stretch the dura. The patient is in sitting with the lumbar spine flexed.
(slumped). The neck is in flexion to place tension on the cranial portion of the dura, while the knee is flexed to place slack on the caudal portion. The neck is extending, reducing cranial tension, while the knee is extended to increase caudal tension. The dura and neurovascular structures are, in this way, flossed through their surrounding tissues.

Figure 5.13: Dural flossing in supine. The lower extremity is placed up against a wall, with the knee extended. The neck is alternately flexed and returned to neutral to creating a flossing force.

Figure 5.14: Sciatic neural flossing with tibial nerve (L4,5; S1 to S3) emphasis. The tibial nerve descends inferiorly through the popliteal space, passing between the heads of the gastrocnemius muscle to the dorsum of the leg, as the posterior tibial nerve, and into the ankle and foot. As the posterior tibial nerve traverses under the flexor retinaculum at the tarsal tunnel, it may be subject to possible compression (i.e., tarsal tunnel syndrome). The patient is instructed to flex the neck and lumbar spine. As the medial and lateral plantar nerves course along the plantar surface of the foot, the tibial nerve is stretched by dorsiflexing and everting the ankle. The flossing may be performed by first dorsiflexing the ankle and extending the knee. Alternatively, the leg can be extended with the flossing from alternately dorsiflexing and plantar flexing the ankle.

Figure 5.15: Sciatic neural flossing with common peroneal emphasis. The common peroneal nerve (L4,5; S1,2) lies posterior to the proximal fibular head. The patient is instructed to flex the neck and lumbar spine. To place tension to the common peroneal nerve, the hip is flexed and medially rotated, the knee is extended, and the ankle is plantar flexed and inverted. The goal is to achieve functional gliding of the common peroneal nerve, not a stretch.

Figure 5.16a,b: Sciatic nerve flossing with heel slides on the wall. The patient is supine with pelvis against the wall and the involved heel on the wall, knee flexed. The heel is slide up and down the wall to provide a flossing force to the sciatic nerve. The ankle can first be positioned in dorsiflexion and eversion to emphasize the tibial portion, or plantar flexion and inversion to emphasize the common peroneal portion.

Figure 5.17: Femoral nerve flossing. The femoral nerve is a branch of the lumbar plexus, formed by the ventral primary rami of L1, L2, L3, part of L4, and possibly T12, continuing medial to the knee as the saphenous nerve. The knee is
progressively flexed to increase femoral nerve tension, along with stretching of the quadriceps femoris muscle. Hip extension can be added by first placing a pillow under the thigh. The lateral femoral cutaneous nerve can be stretched by adding hip adduction. The saphenous nerve is emphasized with hip in extension, abduction, and lateral rotation while extending the knee and dorsiflexing/everting the ankle.

Locking Techniques

Locking techniques with exercise provide better positioning, preventing motion from occurring in areas of contraindication and assisting in mobilizing specific joints or tissues. A hypomobile joint often causes a compensatory hypermobility elsewhere. The hypermobile joint is typically the area of pain complaints, while the hypomobile joint can be asymptomatic. Protecting the hypermobility of the joint while improving motion at the hypomobility, requires more specific exercise design than the general mobilizing exercises previously listed.

The utilization of locking techniques often allows early, more aggressive training models, than would otherwise be tolerated or safe. Locking techniques protect injured tissues, allowing muscles over the area to be trained safely and for higher level movement patterns or body position. For the purpose of mobilization, locking techniques may be utilized to focus all forces into restricted tissues, preventing more normal areas from participating in the exercise. Options for locking techniques include artificial, ligamentous (counter curves), joint locking (coupled force locking) and coordinative locking. For Stage 1, the most common forms of locking used are artificial and joint locking.

Artificial Locking

Artificial locking utilizes external belts, bolsters, wedges, benches, etc., to block movement from occurring into a range that is contraindicated. One of the most basic techniques is to have the weight stack on a pulley system come to rest to block any further range of resistance. Often with spinal treatment a specific block is necessary to allow for a more segmentally specific approach to training, either preventing motion from occurring at a specific segment or focusing for into an area.

Figure 5.18: Artificial Locking—caudal right rotation mobilization with locking of cranial segments. A mobilization wedge is placed at the level of the belt under the cranial segment that is to be blocked. Relative right rotation is performed from below with the cranial segments locked from the motion. The right lower limb horizontally abducts eccentrically into right rotation as a repetitive motion followed by a sustained hold of 20–30 seconds. This exercise is indicated for restriction from L3 to L5/S1 without any adjacent hypermobile segments. This exercise is best utilized to mobilize a stiff lower lumbar spine by focusing forces to the restricted area.

Figure 5.19a,b: Cranial left rotation mobilization. A mobilization wedge is placed under the right side at the level of the caudal segment. A belt around the trunk and angle bench will fixate the caudal segment and artificially lock the rest of the trunk. The left arm reaches down and across the body eccentrically into left rotation as a repetitive motion followed by a sustained hold of 20–30 seconds. This exercise is indicated more for thoracolumbar restriction without any adjacent hypermobile segments.

Figure 5.19a,b: Cranial left rotation mobilization. A mobilization wedge is placed under the right side at the level of the caudal segment. A belt around the trunk and angle bench will fixate the caudal segment and artificially lock the rest of the trunk. The left arm reaches down and across the body eccentrically into left rotation as a repetitive motion followed by a sustained hold of 20–30 seconds. This exercise is indicated more for thoracolumbar restriction without any adjacent hypermobile segments.

Ligamentous Locking (Counter Curve Locking)

Ligamentous locking techniques focus motion by taking up all the slack in the connective tissue around the area to be locked, while the specific joint or region is allowed to move. Because all of the slack in the collagen is taken up, this type of locking is contraindicated in the presence of a
hypermobile joint. Taking up all of the collagen slack in a hypermobile joint while exercising muscle or another joint region, will further deform collagen. Ligamentous locking is indicated to decompress painful joint structures during an exercise, such as cartilage or a nerve root and is most effective when performing exercises to mobilize joint restrictions in the absence of any compensatory hypermobilities.

Figure 5.20: Thoracic extension mobilization with lumbar ligamentous locking in flexion. The hips are flexed creating lower lumbar flexion, taking up collagen slack in facet capsules and interspinous ligaments, preventing extension into a painful or contraindicated range. An artificial lock in the thoracic spine allows an active extension motion to create a general mobilization to the mid thoracic region. A more vertical position reduces the mobilizing force, while a more decline position will increase the relative weight of the body to increase the mobilizing force.

Figure 5.21a,b: Seated active rotation mobilization of L2/3 to the right, ligamentous locking from below. The patient is sitting with lumbar flexion up to L3. A posterior resistance from a pulley is held in the hand or wrapped around the trunk. Left rotation is performed with emphasis on a slow eccentric phase to the end or right rotation range. For higher segments flexion counter-curve can be increased by placing the feet up on a stool, further flexing the hips. For lower segments abduct the hips and forward tilting the pelvis.

Figure 5.22a,b: Left cranial side bending with counter-curve locking (ligamentous locking) from below. The segment to be mobilized is at the level of the bolster. The lumbar spine is positioned in side bending to the right from below. The caudal locking will prevent the lumbar spine from participating in the right side bending, protecting a potential right lumbar hypermobility.

Figure 5.23a,b: Right cranial side bending with counter-curve locking—home version. If a drop seat is not available, placing folded towels under the contralateral ischial tuberosity can create caudal side bending for locking exercises.

Figure 5.24: Caudal right side bending from performing hip abduction with a left side bending counter curve from above with a bolster.
attain facet opposition. With a hypermobility, compression of the facets prevents motion of the vertebra with collagen on slack. Coupled forces dictate which direction rotation and side bending occur in the spine while in flexed or extended positions. Coupled force locking with exercise was introduced to the Medical Exercise Therapy (MET) curriculum by Ola Grimsby. Traditional lumbar coupled force descriptions involved rotation and side bending occurring in the same direction in flexion and the opposite in neutral or extension. Variations do occur in different individuals, which can be tested prior to designing a specific exercise utilizing coupled force locking techniques. Volume 1, chapter 16, of this text series provides a more thorough discussion of coupled forces and how to test them for the lumbar and lower cervical regions.

Joint Locking (Coupled Force Locking)
Ligamentous locking requires normal collagen structures to tolerate end range tension during locking procedures. Joint locking, or coupled force locking, locks joints in the opposite direction and utilizes the natural spine coupled forces to

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Figure 5.25: As previous, caudal right side bending with hip abduction, left side bending counter curve. Without a slant board, resistance can be decreased by flexing the knee.

Figure 5.26a,b: Hip extension mobilization with lumbar counter curve locking. A hypomobile hip joint in extension may result in a compensatory hypermobility at L5/S1 to extension. The lumbar spine is ligamentously locked in flexion, with hip extension performed. Emphasis can be on training the hip flexors with eccentric return into hip extension. The exercise shown is an assist to the hip flexors, lightening the weight of the lower limb to allow for 30–40 mobilizing repetitions. Depending on the training level of the patient, the weight of the leg may be tolerable for high repetitions, or even the use of cuff weights to the ankle may be appropriate if the patient is still be able to complete 30–40 repetitions.

Figure 5.27: Cranial left rotation with locking in the mid lumbar spine—stabilizing exercise for muscles of right rotation. The bolster placed at L2/3 creates a right side bending with a flexed lumbar spine. Normal coupled forces would induce a right rotation at L2/3, locked and not participating in left rotation occurring in the upper lumbar spine. This technique would be used to protect the L2/3 segment from moving into a left rotation hypermobility.

Figure 5.28: Cranial left rotation with locking in the mid lumbar spine—mobilizing exercise for left rotation. The bolster placed at L2/3 creates a right side bending with a flexed lumbar spine, creating right rotation at L2/3. Left rotation mobilization is performed eccentrically in the upper lumbar spine, with locking of the mid and lower lumbar spine.
Exercise for the Lumbar Spine

Figure 5.29: The hypermobile segment that needs to be protected in this case is located at L4/5, the level of the bend in the table. It needs to be protected from left rotation so it is kept in neutral and left side bent. Coupled forces will lock the spine from rotating to the left even though there is left rotation cranially. The same exercise can emphasize joint mobilization into left rotation by placing the resistance on the posterior side, allowing eccentric training into left rotation.

Figure 5.30: Left side lying caudal left rotation. The spinal locking occurs at the apex of the bolster, in this case L3/4. The exercise involves left rotation (always described using the cranial vertebral segment as a reference) from below but since the L3/4 segment is left side bent in neutral, coupled forces will rotate it to the right. The left rotation will not occur at the locked level due to facet opposition.

Figure 5.31: Caudal lumbar extension over a bolster. Extension can be trained from a position of full flexion. In the presence of a contraindication for end range extension, the patient is cued to use coordinative locking to prevent extension from occurring past neutral, working from full flexion to neutral only. This would be indicated in cases of lower lumbar hypermobility in extension, spondylolisthesis, nerve root pathology or for any reason requiring avoiding end range lumbar extension.

Figure 5.32: As a progression from the previous exercise, caudal lumbar extension performed with lifting the lower extremities off the bolster for added resistance.

Coordinative Locking

Coordinative locking involves controlled, coordinated motion, while actively preventing movement into a range of motion or joint region that is contraindicated. As a higher level of coordination is required, this type of locking is typically used as a progression in later stages from the above, more aggressive locking approaches. In a more general sense, all exercises in Stage 1 involve a certain amount of coordinative locking, as the patient is required to perform all exercises in a range that can be coordinated and pain free. In Stage 1, coordinative locking is more typically used when one point in the range negatively affects a specific structure. The final goal is always to be able to perform motion without the assistance of locking. The level of locking is gradually reduced until the patient can preform normal functional movements.

Coordination / Motor Learning

As joint mobility is improved by joint mobilization and resolving edema, exercise can begin to focus on functional qualities that more directly train the motor system. Basic qualities include coordination, motor learning and endurance. Resolving tonic muscle guarding should occur first as this is a cause of pain, reduced range of motion and altered movement patterns. The tonic muscle system is the arthrokinematic system responsible for controlling the axis of motion, which is fundamental to training coordination. Understanding which muscles serve this purpose and their functions, as well as
a complete knowledge of passive and dynamic constraints to motion makes exercise design specific and logical. Coordination can be disrupted for many reasons. The Manual Therapy Lesion outlined below describes a global and local influence of pathology on motor performance. An integration of deficits in biomechanics, neurophysiology, biochemical and psychology are integrated into a model of defining impairment. The broad view of dysfunction provides a logical approach to exercise design and progression.

Treatment addressing the manual therapy lesion first attempts to reduce pain and muscle guarding. Numerous passive treatments and modalities can be used to this end, but removing pain and guarding is not really treatment, only a necessary step to allow for more intervention to resolve specific impairment. Treatment must focus on the reduced tissue tolerance to stress and strain, abnormal joint mechanics, reduced mechanoreceptor function altering motor patterns and the resulting functional loss. Exercise provides the repetitive motion for tissue repair. Motor impairment is first addressed by attempting to improve afferent feedback in the presence of damaged mechanoreceptors. The use of cutaneous receptors, through taping techniques, will also increase afferent input to improve motor patterns for both central programming and distal motor performance. Emphasis, however, is on progressive training of the arthrokinematic tonic muscle system in attempting to sensitize local muscle spindles to provide adequate afferent feedback to normalize motor patterns. Nitz and Peck (1986) found the lumbar multifidus to have a significantly greater spindle density compared with the semispinalis, while no difference between the spindle densities of the cervical or thoracic multifidus and the semispinalis were noted. Muscle spindle density in arthrokinematic muscles such as the multifidus function as ‘kinesiological monitors’ generating important proprioceptive feedback to the central nervous system (Peck et al. 1984). Proprioceptive function is located throughout the lumbar spine. Proprioceptive training must be an important part of a complete exercise program.

Basic Stages of the Manual Therapy Lesion
(Grimsby 1988)

1. **Collagen/Tissue Trauma**: Acute injury, surgery, degenerative joint disease, repetitive strain, postural strain or hypo/hypermobile joint. This may be an acute injury or a slow progression that appears to have an insidious onset related to gradual degeneration.

2. **Receptor Damage**: Afferent signals are lost or altered from direct structural damage to mechanoreceptors, a loss or restriction in the neural pathway, or reduced feedback from receptors imbedded in non-mobile capsules. Type I mechanoreceptors are more easily damaged than type II, as they are located more superficially on the joint capsule, while type II mechanoreceptors are deeper in tissue. The pain free but restricted spinal segment will have a reduction in afferent input from lack of collagen elasticity changing motor performance within its motor field.

3. **Reduced Muscle Fiber Recruitment**: Abnormal central processing of afferent signals from cutaneous, articular and muscle/tendon receptors. Altered central feedforward facilitation to alpha motor neurons (extrafusal muscle fibers) and gamma motor neurons (Intrafusal muscle fibers). End result of includes altered reflex responses for proprioception and kinesthesia, motor weakness, motor delay and/or poor timing. Central spinal segmental dysfunction, both with and without pain, alters central motor programming.

4. **Tonic Fiber Atrophy/Loss of Phasic Power**: Reduced motor recruitment resulting in initial lack of recruitment, leading to atrophy over time. Tonic muscle fiber, the multifidus in the cervical spine, is initially more affected by type I mechanoreceptor loss and influences of the type IV mechanoreceptor (pain) system. Phasic muscle fiber atrophy, or inhibition, may occur with more significant tissue damage that includes type II mechanoreceptors, and with overall reduction in higher level activity.
5. Reduced Anti-Gravity Stability: Reduced recruitment of the tonic system results in loss of dynamic arthrokinematic control of joint motion, static postural stability/alignment and central balance mechanisms. Central stability at the lumbar spine and pelvis is reduced, which may alter the static and dynamic alignment of the hip, knee and ankle.

6. Motion Around Non-Physiologic Axis: Loss of dynamic control increases the neutral zone of function for the joint, increasing the range of the instantaneous axis of motion. Altered mechanics for the biomechanical chain of the lower limb. Reduced tonic function creates an abnormal relationship between tonic (arthrokinematic) and phasic (osteokinematic) muscles. Compensatory motor recruitment occurs, leading to abnormal mechanics.

7. Trauma/Acute Locking/Degeneration: Altered axis of motion leads to abnormal tissue stress/strain, resulting in further tissue and receptor damage. Hypermobile joints are prone to acute locking. Joint degenerative changes occur over time.

8. Pain/Guarding/Fear-Anxiety of Movement: The type IV mechanoreceptor responds to tissue damage with pain signals and tonic reflexogenic muscle guarding. Psychological influences of pain my lead to altered motor patterns and reduced effort. Overall effect is reduced tissue tolerance, abnormal joint/tissue loading, reduced afferent feedback, altered feedforward efferent drive and reduced function (Grimsby 1988).

Early emphasis for coordinating the abdominals involves recruitment of the more tonic portions: the transverse abdominis (TrA) and obliquus internus (OI) (Wohlfart et al. 1993). The two basic techniques used to recruit these muscles are abdominal bracing and hallowing (Richardson et al. 1992). Bracing involves a contraction in which the abdominals flare laterally, while hallowing draws the umbilicus toward the spine (Richardson et al. 1992). It has been argued that hallowing can destabilize the spine by narrowing the base of support of the guy-wires and some authors have gone as far as claiming TrA isolation creates dysfunctional spines and “these unfortunate patients become paralyzed by their own hyper-analysis of what their transverse is doing” (McGill 2004). As a part of the normal tonic arthrokinematic system, these muscles are involuntarily recruited prior to active loading of the spine or the movement of an extremity (Hodges and Richardson 1997). Consistent with the Manual Therapy Lesion, the more tonic muscles of the spine are affected with low back pain (Hides et al. 1994, Hodges and Richardson 1996).

From a clinical standpoint, muscle isolation training in early motor learning is not emphasized during rehabilitation. Having appropriate tonic muscle recruitment is imperative but no single muscle or muscles are the most important. Focus is placed on timing and recruitment within a normal pattern of movement. The key muscles for dynamic stabilization during functional tasks may change throughout the task, depending upon the pattern of movement being performed.

Barnett and Gillear (2005) compared different types of abdominal sit-ups to determine which type more preferentially recruited the TrA and OI. Performing an abdominal hallowing and curl was the most effective technique. For a majority of subjects, performing a brace and hold, followed by a curl or a hallowing with a rotational curl also recruited the TrA and OI first. A straight curl, without an initial hallowing or bracing, selected the rectus abdominis first.

Eversull et al. (2001) investigated and described the neuromuscular neutral zones (NNZ) in the lumbar spine in terms of activity patterns at different lumbar levels, and rate of tension/elongation of viscoelastic structures. The authors defined NNZ as “the lumbar displacement or tension threshold below which muscles remain reflexively inactive.” The NNZ concept describes the complex and adaptive sensorimotor feedback loop originating from afferent receptors located in viscoelastic tissue
The recovery pattern of reflexive muscular activity after continuous passive, cyclic loading of tissue requires at least 15 to 20-minute rest after a 50-minute episode of cyclic loading to produce most of the possible recovery of reflexive muscular activity. Full recovery was not expected until after two hours of rest (Gedalia et al. 1999).

Stimulation of the mechanoreceptors in the supraspinous ligament will create stabilizing contraction in the lumbar spine multifidi (Solomonow et al. 1998). Receptors in discs, interspinous ligaments, anterior and posterior longitudinal ligaments and facet joints may also contribute to this recruitment. The authors identified a reflex arc of EMG activity in the lumbar multifidi (LM) from mechanoreceptors. They concluded that therapy for muscle strengthening had the potential to improve spinal stability and to decrease pathological situations associated with episodes of spinal instability. The decreased lumbosacral position sense in the patient group might have been due to an altered paraspinal muscle spindle afferent and central processing of this sensory input (Brumagne et al. 2000). The lack of return of multifidus after injury, and the wasting that has been found, might be partly due to the muscle spindles’ role in reflex inhibition. The muscle spindle input from LM was crucial for accurate positioning of the pelvis and lumbosacral spine in a sitting position (Brumagne et al. 1999).

As with other regions in the body, in the spine, coordination and motor learning represent two separate but equally important functional qualities that are addressed though out exercise progressions. Motor learning involves the cognitive process of acquiring a new skill. With lumbar patients and clinical practice this is most often a muscle isolation approach. Coordination training may involve this but the focus is to dose exercise at a level that allows for many repetitions to obtain neurological adaptation or coordination. This is accomplished by having the patient focus on the motion itself. To achieve proper coordination all aspects of dosage...
are relevant including: appropriate resistance, angle of resistance and appropriate repetition dosage. Both approaches can be effective and should not be looked at as one being superior over another. The pathoogy will determine which approach is most effective, along with the patient’s learning style and their body awareness. Matching the exercise style to the patient should be more effective than attempting to force the patient into only one way of approaching a clinical problem.

Coordination requires cooperation from two different stabilizing systems: the global (more phasic) and the local systems (more tonic). These two systems differ histologically, biomechanically, metabolically and neurologically. The muscles in the lumbo-pelvic region that would be considered local would include the following: lumbar multifidus (Bogduk 1992), posterior fibers of the psoas (Bogduk 1992), the medial fibers of the quadratus lumborum (McGill 1992), the transverses abdominis and some fibers of the internal oblique abdominals (Snijders 1995). These local, or arthokinematic muscles of the spine, are more involved with stability at the segmental level and are generally located closer to the axial skeleton and axis of motion. More tonic, arthokinematic muscles, also possess a greater proprioceptive function, obviated by the significantly greater density of muscle spindles (Nitz 1986, Peck et al. 1987, Peck et al. 1984).

The global, or osteokinematic muscles are active in relationship to the direction of movement that they create. For example, the rectus abdominis is active with trunk flexion while the TrA is active with flexion, extension and extremity movement. Coordinated segmental motion is the result of tonic muscles co-contracting in an early feed forward, non-directional manner, while the phasic muscles are direction specific more responsible for moving the bone or body segment (osteoainematic motion).

The local arthokinematic muscles possess a greater predominance of Type I, or slow twitch muscle fiber, making them more oxidative from a metabolism standpoint. Characteristically this group of muscles, particularly the LM and TrA, is active regardless of the direction of motion (Pauly 1966), and show electromyographic activity prior to the primary mover creating osteokinematic movement (Hodges et al. 1997a/b/c, Moseley 2002).

Concepts involving altered recruitment have been presented prior to the research on the TrA. Janda (1977) described the dysfunctional motor system of a patient with weak abdominals and shortened back extensors. He provides an example of the tightness in the extensors inhibiting the abdominals and treatment of abdominal strengthening being futile. In this case, addressing the abnormally high tone in the erector spinae is necessary before it is possible to get normal muscle facilitation in the abdominals (Janda 1978).

In addition to the examples of recruitment changes and loss of coordination in pathology, there is impressive evidence of segmental atrophy following collagen and receptor damage in the psoas and the LM. Dangaria et al. (1998) found a significant correlation between cross-sectional areas of the psoas and the level of disc herniation. There is very predictable atrophy ipsilateral to unilateral sciatica due to disc herniation. Hides et al. (1994) examined the cross-sectional area of the lumbar multifidus in 26 patients with acute unilateral low back pain and 51 normal subjects to assess the differences between the groups. They used real-time ultrasound throughout the lumbar spine and detected statistically significant evidence of lumbar multifidus wasting ipsilateral to the side of their symptoms in patients with acute unilateral low back pain. The scans revealed that marked asymmetry occurred in each patient and was isolated to one vertebral level. The speed of onset and localization indicated that this wasting was not the result of disuse atrophy, and they theorized that it was the result of pain or other local inhibition. In follow up studies, based on these subjects, the author determined that without exercise, the recovery of the LM was not spontaneous (Hides et al. 1996). In addition, with one and three year follow ups, it was
determined that the subjects in the control group suffered an increased number of recurrent episodes of low back pain with greater levels of severity compared to the exercise group (Hides et al. 2001). During the first year, the patients in the control group were 12.4 times more likely to experience recurrence of LBP compared to the patients in the exercise group. In years two and three the control group was still 5.9 times more likely to suffer recurrences of LBP than the exercise group. It is possible that the muscle wasting measured in this study was present prior to the onset of acute low back pain, potentially predisposing the group toward low back injury. A follow up study with a porcine model alleviated this possibility, finding segmental multifidus wasting within 72 hours following disc injury (Hodges et al. 2006).

Subjects with spinal pathology can present with many different examples of muscle inhibition and dysfunction. To focus excessively on individual muscles is to miss the big picture of stability combined with coordination. It has been determined that there are many different muscles that provide stability to the spine depending on the loads imposed (Kavcic et al. 2004). All of the muscles are vital players in the symphony that is ultimately responsible for producing spinal stability and coordination.

Abnormal Motor Patterns
Identifying movement pattern dysfunction is a necessary step in identifying which types of exercises to prescribe. General active, passive and resisted testing may elicit basic directional information and indicate the muscle groups in dysfunction. Directions of motions that are limited and/or painful actively, but are notably improved with passive lumbar range of motion testing, are suggestive of motor deficits. Often limitations in motor performance are an issue of dosage; the level of resistance of the trunk is too high for the functional level of the muscles involved leading to compensation. Applying basic unloading principles to spinal training can significantly improve the range that can be trained.
Changes in Motor Function with Low Back Pain

Structural Changes:
- Histological changes in muscle fiber atrophy (Lehto et al. 1989, Mattila et al. 1986).
- Reduced cross sectional area of LM at level of symptoms, and to a much lesser degree above and below the level of symptoms, due to pain inhibition (Stokes et al. 1992b, Hides 1994).
- Denervation of the LM with instability (Sihvonen and Partanen 1990).
- Slow twitch hypertrophy with fast twitch atrophy in pathological LM on side of symptoms in acute and chronic LBP (Stokes et al. 1992a).
- Positive correlation between paraspinal muscles atrophy and self-reported disability in CLBP (Alaranta et al. 1993).
- Atrophy of the LM with lumbar radiculopathy (Campbell et al. 1998).
- Higher percentage of type I fibers and lower percentage of Type IIA and IIB (Bajek et al. 2000).
- The relative percentage of slow twitch fibers increase both with age and pathology (Jowett et al. 1975).

Performance Changes with LBP:
- Increased fatigue speculated with higher risk of injury (Sparto et al. 1997).
- Reduced strength from smaller unilateral cross sectional area (CSA) and the lower percentage of type II fiber in the LM (Zhao et al. 2000).
- Extensor weakness with sciatica (McNeil et al. 1980).

Bracing
In cases of spinal instability, external bracing or orthoses, have been used to control symptoms. Celestini et al. (2005) compared the use of bracing with a second group that received bracing and
stabilizing exercises. Both groups had some overall improvement, but the group with bracing and exercise had a higher level of improvement in symptom reduction, neuromuscular control and lifestyle. Over time this group used less medication, relied less on the lumbar brace and tended to resort to using the home exercise program to assist in controlling symptoms.

**Motor Testing**

Testing motor performance is a helpful step in prescribing exercise. Identifying reduced motor performance supports the use of more specific selection criteria for the initial exercise program. Testing may not only involve the lumbar spine, extremity and balance performance can also be included. Motor testing is not diagnostic, but may assist in the development of clinical predictive rules for the use of certain types of exercises. For example, in the case of lumbar instability, Hicks et al. (2005) identified testing criteria that best predicted a successful outcome with the prescription of stabilization exercises. The key physical tests were identified as straight leg raise, lumbar mobility testing, aberrant motions during lumbar range of motion and the prone instability test. Individual tests may provide specific information as to which muscles should be trained, or what functional quality is lacking (i.e., timing, endurance or strength). Many basic tests are available to assess performance. Each may involve a different or unique emphasis as to what exactly is being tested.

**Side Support Test**


**Post Surgical Changes in Motor Performance:**

- Decrease in trunk strength following discectomy (Kahanovitz et al. 1989, Hakkinen et al. 2003a/b).
- Loss of proprioception and postural control did not improve following discectomy, requiring exercise therapy post operatively (Leinonen et al. 2003).
- Poorer surgical outcomes correlation with size of Type II muscle fibers of LM, more fatty deposits in LM and more denervation of LM (Rantanen et al. 1993).

**Figure 5.36:** The patient is positioned in side lying, legs extended, resting on the lower elbow for support with the top foot in front of the lower foot (McGill 1998). The patient
is instructed to lift the hips off the table with only the elbow and feet remaining in contact, holding the position as long as possible. The test is performed bilaterally, scored as time held per side. This test is simply a timed motor performance test to establish a level of function, or to track improvement with training. Poor performance of the lower abdominal is seen by the patient flexing the hips and trunk slightly and/or rotation of the pelvis or upper thoracic spine. The ability to breathe diaphragmatically during the test is also assessed, as the patient should be able to breathe normally with the diaphragm during isometric work of the lower abdominals.

Extensor Endurance Test

Figure 5.37: In prone, the patient is asked to hold the sternum off the floor for as long as possible (McGill 1998). A small pillow is placed under the lower abdomen to decrease the lumbar lordosis, the cervical spine is maintained in maximum flexion and the pelvis is stabilized through gluteal contraction. The performance time is recorded in seconds, with the patient is asked to hold this position as long as possible, not to exceed 5 minutes. This test is simply a timed motor performance test to establish a level of function, or to track improvement with training. Muscle bulk of the gluteal muscles and lumbar multifidi can also be assessed during the test, with atrophy identified visually or through palpation.

Active Sit-Up Test

Figure 5.38: The patient is positioned in supine with the knees flexed 90°. The soles of the feet are flat on the floor with the examiner holding them down with one hand. The patient reaches up with the fingertips of both hands to touch (not hold) both knees (Waddell et al. 1992). If the patient cannot maintain this position for five seconds, the test is positive. This test is simply a timed performance to establish a level of function, or to track improvement with training.

Active Bilateral SLR Test

Figure 5.39: In supine, the patient is asked to lift both legs together six inches (15.24 cm) off the examining surface and hold for five seconds (Waddell et al. 1992). Both heels and calves should not touch the examining surface during the test. The test is positive if the patient cannot maintain this position for five seconds. This test is simply a timed motor performance test to establish a level of function, or to track improvement with training.

Prone Instability Test

Figure 5.40a,b: The patient lies with the trunk on the examining table, flexed at the hips, with the feet resting on the floor. The patient relaxes while the examiner applies posterior to anterior pressure to the lumbar spine, recording any pain provocation (McGill et al. 1999). The patient then
lifts both legs off the floor, holding the table to maintain position while posterior compression is applied again to the lumbar segments. The test is positive if pain present during the resting test position subsides in the second position while muscles are contracted. This test is an indicator that enough muscle function is present to control an unstable segment.

Sorensen Test
The Sorensen Test is a timed test for isometric capacity of the trunk extensors ability to sustain an antigravity position (Biering-Sorensen et al. 1984). The subjects lie prone, with the pelvis at the edge of a plinth and the lower limbs fixed. The body is maintained in a horizontal position with the trunk off the edge of the plinth for as long as tolerated. The test is terminated if the torso deviates more than six degrees from the stable position for longer than six seconds.

The Spremnem test has been used to measure endurance for lumbar extensors (Chok et al. 1999), but is actually measuring isometric endurance. To improve isometric endurance, strength training is required, not endurance training or isometric holding. Isometric endurance is limited by blood flow. As intramuscular pressure increases, from the tension of muscle contraction, circulation decreases. With contraction below 20–25 percent of maximum, circulatory compromise does not occur, and the activity can be sustained. If the body weight exceeds this percentage, circulatory compromise occurs, causing fatigue with isometric holding. Repetitive strength training, rather than isometric holding, will increase the lifting capacity. A fixed body weight would then fall closer to the relative 20–25 percent of maximum contraction, allowing for longer isometric holding times.

Lumbar Extension Cross Patterns
More subtle alterations in motor patterns of the trunk can prevent a gradual progression in motor training as an abnormal firing pattern is occurring related to improper timing of muscles and/or compensations. Visual assessment of movement may identify more global issues of limited mobility or strength through the hips, pelvis and thoracic spine that may prevent normal movement through the lumbar spine. Subtle changes in timing or limited recruitment of the lumbar multifidi may require more direct visual observation, palpation or surface EMG to identify. Janda (1999) described a series of abnormal firing patterns of the hip, pelvis and lumbar spine with a simple prone hip extension test. Janda’s theory stated that with a prone hip extension of the right hip, the recruitment order for posterior muscle groups should occur in the following order: right hamstring, right gluteus maximus, left lumbar erector spinae, right lumbar erector spinae, left thoracolumbar erector spinae and lastly right thoracolumbar erector spinae (Janda 1992). Vogt and Banzer (1997) also felt a consistent firing pattern was noted with prone hip extension but in a different order: ipsilateral lumbar erector spinae, semitendinosus, contralateral lumbar erector spinae, tensor facia latae and gluteus maximus. Bullock-Saxton et al. (1993) compared hip extension in pain free subjects concluding that muscle onset times were almost simultaneous. Lehman et al. (2004) performed a similar EMG study on muscle firing patterns for prone hip extension in 14 asymptomatic subjections, finding no consistent order of activation for the biceps femoris, contralateral erector spinae and ipsilateral erector spinae. The authors also concluded that the prone hip extension test is not sufficient for a diagnostic test due to physiological variation, feeling
that an overlap between normal and potentially abnormal activation patterns may exist. The clinical application of the prone hip extension test is somewhat lost in these previous investigations. The intention of the test is not to be diagnostic. Identifying weakness in muscle, altered firing patterns or gross muscle impairment is not diagnostic, but simply a clinical impairment finding from specific motor tests. True tissue diagnosis is made from a thoughtful process of evaluating all the tissues with the available tests, eliminating those tests that are negative and coming to a hypothesis for a pathological description.

The clinical application of the prone hip extension test is somewhat lost in these previous investigations. The intention of the test is not to be diagnostic. Identifying weakness in muscle, altered firing patterns or gross muscle impairment is not diagnostic, but simply a clinical impairment finding from specific motor tests. True tissue diagnosis is made from a thoughtful process of evaluating all the tissues with the available tests, eliminating those tests that are negative and coming to a hypothesis for a pathological description.

The value of the prone hip extension test, in a more simplistic sense, is to observe gross motor performance. The order of muscle recruitment may not be as significant as notable asymmetries in performance and compensatory firing of upper thoracic and dorsal scapular musculature. Poor coordination of anterior abdominal muscles, including the transverse abdominis, may lead to an extension or a shear moment in the lumbar spine or loss of rotational stability during the test. Late activation gluteus maximus may be significant when coupled with weakness in muscle testing or weight bearing functional testing. The actual timing between muscle activation is measured in milliseconds and may not relate to the actual gross motor performance. Hodges and Richardson (1997) attempted to make a similar claim in timing issues related to the transverse abdominis firing prior to lifting the arm and when in dysfunction the muscle fired late. Again the timing is in milliseconds and the clinical relevance must incorporate all other evaluative findings. These types of observations and tests may assist in guiding which muscles are emphasized during coordination training and may simply be used as retests for performance improvement. Observation of abnormal motor performance is not diagnostic but should be used in assisting exercise design. Abnormal firing patterns may resolve after normalization of joint restriction, resolution of muscle guarding or resolution of pain (Grimsby 1991, Janda 1997).

Figure 5.42: Prone hip extension test. The patient lies prone with the arms at the side and the simple instruction of lifting the leg while keeping the knee straight. The normal firing pattern for right hip extension would be 1) right hamstrings, 2) right gluteus maximus 3) left lower lumbar multifidi, 4) right lower lumbar multifidi, 5) left upper lumbar multifidi, 6) right upper lumbar multifidi, with no participation of thoracic paraspinal muscles or dorsal scapular muscles (Janda 1999).

The value of the prone hip extension test, in a more simplistic sense, is to observe gross motor performance. The order of muscle recruitment may not be as significant as notable asymmetries in performance and compensatory firing of upper thoracic and dorsal scapular musculature. Poor coordination of anterior abdominal muscles, including the transverse abdominis, may lead to an extension or a shear moment in the lumbar spine or loss of rotational stability during the test. Late activation gluteus maximus may be significant when coupled with weakness in muscle testing or weight bearing functional testing. The actual timing between muscle activation is measured in milliseconds and may not relate to the actual gross motor performance. Hodges and Richardson (1997) attempted to make a similar claim in timing issues related to the transverse abdominis firing prior to lifting the arm and when in dysfunction the muscle fired late. Again the timing is in milliseconds and the clinical relevance must incorporate all other evaluative findings. These types of observations and tests may assist in guiding which muscles are emphasized during coordination training and may simply be used as retests for performance improvement. Observation of abnormal motor performance is not diagnostic but should be used in assisting exercise design. Abnormal firing patterns may resolve after normalization of joint restriction, resolution of muscle guarding or resolution of pain (Grimsby 1991, Janda 1997).

Figure 5.43: An example of an abnormal pelvic cross pattern as described by Janda (1997). Firing order is altered to: 1) hamstrings, 2) gluteals, 3) ipsilateral lower multifidi, 4) ipsilateral upper lumbar multifidi, 5) contralateral lower lumbar multifidi (delayed) and 6) contralateral upper lumbar multifidi (delayed).
and coordination during a motor performance. Certainly many alterations in the pattern of firing may exist in normal subjects, but an even greater variation can be seen in symptomatic patients. The classic bird-dog exercise is so commonly used for early back training. The true functional applications of this exercise can be argued but if an abnormal firing pattern is occurring, this exercise may continue to reinforce abnormal movement.

Comparing performance on both sides may assist in determining if abnormal motion is occurring. Providing assistance to the exercise may create a significant change in the firing order, performance and pain levels suggestive of the firing pattern being a contributing factor to dysfunction. Principles of STEP involve dosing exercises below 40% of 1RM when emphasizing coordination training to allow for a higher number of repetitions. The resistance of the leg during prone hip extension may exceed 1RM for some of the participating muscles, requiring compensation of other muscles or altered order of recruitment. Shoulder elevation with motor dysfunction is associated with abnormal firing of scapular muscles and the rotator cuff leading to abnormal elevation of the scapula and humeral head. Providing a pulley assist to lighten the weight of the arm can instantly normalize the coordination in the performance. The same unloading concept can be applied to spinal training. Dosing the resistance to a lower level may allow for a normal pain free pattern for high repetition training for coordination. Once the pattern is coordinated a faster progression to endurance and strength training can be made.

Using the prone hip extension test does require the clinician to at least consider the motor timing

Figure 5.44: An example of an abnormal pelvic cross pattern as described by Janda (1997). Firing order is altered to: 1) hamstrings, 2) ipsilateral lower multifidi, 3) ipsilateral upper multifidi, 4) contralateral multifidi (delayed), 5) contralateral multifidi (delayed), 6) absent or delayed gluteals. Absent or reduced gluteus maximus strength and activation is postulated to decrease the efficiency of gait and is associated with chronic low back pain (Janda 1992, Janda 1996).

Abnormal Recruitment Pattern 3
Hamstring
Ipsilateral upper multifidi
Contralateral multifidi (delayed)
Contralateral multifidi (delayed)
Absent gluteal muscles and Multifidi
Late firing of ipsilateral multifidi

Abnormal Recruitment Pattern 4
Hamstrings
Absent gluteals
Ipsilateral lower multifidi
Ipsilateral upper multifidi
Absent/diminished contralateral muscle recruitment
Ipsilateral of upper trapezius

Abnormal Recruitment Pattern 5
Hamstrings
Gluteals
Ipsilateral lower multifidi
Ipsilateral upper multifidi
Contralateral multifidi (delayed)
Contralateral multifidi (delayed)
Contralateral upper trapezius

Abnormal Recruitment Pattern 6
Hamstrings
Gluteals
Ipsilateral lower multifidi
Ipsilateral upper multifidi
Contralateral multifidi (delayed)
Contralateral multifidi (delayed)
Pelvis rotates (right) as contralateral multifidi and transverse abdominis can not stabilize with left rotation moment

Figure 5.45a,b: The bird-dog exercise for hip and lumbar extension. Limited hip extension mobility or the presence of an abnormal pelvic cross pattern (as previously described) can reinforce abnormal motor recruitment of lumbar musculature.
Deep Abdominals / Hip Flexors

Anterior muscles of the trunk contribute to lumbar stability and function. Weakness, or inhibition, of these muscles is not uncommon in both chronic and acute low back pain. The lumbar multifidus, quadratus lumborum and erector spinae are tonic muscles, frequently in reflexive spasm or guarding in the presence of low back pain. Muscle spasm of the posterior extensors can lead to reciprocal inhibition of the anterior deep abdominals. The deep abdominal muscles include the external oblique, internal oblique and the transverse abdominals. The greater the level of pain and subsequent guarding of the posterior tonic extensors, the more difficult it is to recruit these anterior flexor muscles. For this reason, treatment should initially focus on resolving the cause of pain and reducing the posterior muscle before trying to recruit and retrain the abdominal muscles (Basmajian 1979). Frequently, resolution of pain and guarding will lead to normal, or significantly improved, recruitment. Difficulties with motor learning for up-training previously inhibited muscles may resolve when the source of inhibition is reduced.

The ability for the transverse abdominis muscle (TrA) to provide adequate stability to the vertebral column is hard to quantify, as the muscle is paper thin and not directly attached to lumbar vertebra. Indirect influence on vertebral motion is transmitted through the thoracolumbar fascia or related to increasing intraabdominal pressure.

Some rehabilitation programs attempt to teach the patient to isolate this muscle from the other deep abdominal. The process of motor learning for isolating individual muscles is difficult and counter-intuitive. Isolating an individual muscle is not consistent with normal movement patterns and is not necessary in the overall program of stabilization training for the spine. Providing a mild deep abdominal contraction is a component of normal function and has obvious clinical benefits in retraining spinal stability. This approach is crucial in Stage II when isometrics are introduced with a hypermobility or to protect a joint from moving around a non-physiological axis with a hypomobility. Complimentary research has supported a gentle isometric bracing, rather than a hollowing, of the deep abdominals without placing more responsibility on the TrA (McGill 2001). Bracing involves only a tightening of the abdominal wall without a change in the wall profile. Hollowing involves pulling the anterior abdominal wall posterior, sinking the stomach toward the spine. According to McGill (2001), this reduces stability in the spine. Bracing is easier for patients to learn, as it is a more natural motor response. Bracing should be a precursor to spinal motion but not as an aggressive, hard, isometric performance. Normal stability requires as little as 15 percent of a maximum voluntary contraction for stability. Excessive bracing creates too much stiffness, reducing necessary motion for the delicate modulation for movement. It is imperative that adequate coordination ensures that the muscles are modulated so that the spine can change its stiffness to match the demands of internal and external forces on the body.
Dysfunction of the TrA should not be considered in isolation, but as a breakdown in an overall movement pattern. Weakness, inhibition and/or poor timing of the TrA can be a component of dynamic instability in the spine, but should be considered in the larger motor pattern involving many muscles throughout the trunk and pelvis. Rather than muscle isolation, early emphasis is placed on coordination, or the execution of a particular skill, of the lumbopelvic region. Rather than learning the motor skill of isolating a muscle unnaturally, the focus is on recruiting the muscle in a normal pattern of movement. Motor learning refers to the process of acquisition, or acquiring the skill and can be achieved quickly over a period of hours or may require days, months, or years. Motor learning has three phases: acquisition, consolidation and retention (Blazquez et al. 2004). The cognitive processes of motor learning involve verbal instruction, imitation, imagery and mental practice (Annett 1994).

The goal of achieving coordination for new movement patterns leads to consideration of the best way a patient can learn. The approach for recruiting the TrA focuses on internal attention, which can be detrimental to the performance of a well-learned skill as well as learning new skills (McNevin et al. 2000). Attention focused internally toward the lower abdominals will disrupt a normal bracing maneuver by the entire lower trunk and degrade the learning process of the transfer or lift. An exercise set up with movement goals that accomplish the desire recruitment pattern will improve coordination more efficiently. Some level of internal awareness of body position and abdominal tightening may be necessary, but directing full attention internally toward specific muscles can disrupt the execution of automated skills and can have a degrading effect on the learning of new skills (McNevin et al. 2000).

Hollowing is an appropriate technique for motor learning for isolation of the TrA, but not necessarily for normal stability or function. Bracing is the more natural and functional approach for the abdominal contribution toward dynamic stability. In some cases an initial approach directed internally toward isolation of the TrA with hollowing type exercises may be a necessary first step in a progression. An approach of bracing should, however, be the emphasis and eventual progression for all spinal stabilization training. Exercises can be designed to naturally recruit the deep anterior muscles without an internal focus but through an external resistance that naturally recruits these muscles. With the focus more on performance of an activity that naturally recruits certain fiber directions, motor learning can address functional movements and occur more quickly. Care should be taken to avoid directing exercise too much toward learning specific rehabilitation exercises versus learning more functional movements.

Figure 5.48: TrA hollowing performed in quadruped. The weight of the organs on the abdomen wall provides feedback for contraction of the TrA muscle. The patient is instructed to exhale and pull the umbilicus toward the spine. The can be practiced in alternative postures, such as sitting and standing.

Figure 5.49: Stabilization training during the functional motion of transferring from sit to stand. Whether TrA hollowing or abdominal bracing is preferred, practice can involve many other functional motions such as rolling transfers and lifting.
The deep hip flexors also play a key role in spinal stability. Weakness in the psoas and iliacus often relate to spinal dysfunction. Iliacus and psoas activation is not consistent with spinal movement but primarily hip flexion (Juker et al. 1998). The iliacus has been shown to stabilize the pelvis in contralateral hip extension during standing, while the psoas is selectively involved in contralateral trunk loading situations, requiring stabilization of the spine in the frontal plane (Andersson et al. 1995). The iliacus also produces hip flexion but working alone without the psoas creates an anterior pelvic tilt, forcing the spine into lumbar extension. The psoas counteracts this anterior tilting moment. A weak or inhibited psoas can lead to excessive anterior tipping or shearing. The psoas provides minimal spinal segment stability and shear stiffness but only in the presence of hip flexion torque (McGill 1998).

In some cases, excessive tone is present in the hip flexors, preventing normal movement and creating secondary pain from muscle guarding. An elevation in tone of the hip flexors may be directly related to pain and spinal facilitation or related to compensation for weak lower abdominals. These muscles often test short with muscle length tests but this is largely due to elevated resting tone. Directly training the hip flexors (as above) may be helpful with acute guarding to increase circulation and reduce tone but if they are over active, compensating for lower abdominal weakness, than a combination of down training the hip flexors while up-training the lower abdominals is most efficient.

Reducing hip flexor contribution to cranial trunk flexion (sit-ups) has largely focused on the position of the hip. The more common approach is to flex the hip to shorten the hip flexors in attempt to make them actively insufficient. The position of the hips and lower quarter is not as important as whether an extensor pattern or flexor pattern is facilitated in the lower limbs during the movement (Janda 1996). Hooking the feet to stabilize the lower limbs recruits a flexor pattern of ankle dorsiflexors, knee flexors and hip flexors (psoas and iliacus). Sit-ups performed in this position emphasize the hip flexors rather than the lower abdominals. Creating an extensor pattern would more effectively inhibit the hip flexors to allow for trunk flexion to be performed to a greater extent by the lower abdominals.
working more independently. This down training approach of the hip flexors is particularly effective in the presence of a hypermobile spondylolisthesis or disc pathology with shearing that are prone to excessive extension.

Figure 5.55: Sit-Overs with a ball. If an incline board is not available, an attempt to create an extensor pattern for cranial flexion can be made with a fitness ball. The feet are placed against a wall in a plantar flexed position with the knees flexed for quadriceps facilitation. The trunk is angled on the ball in an incline position to facilitate the hip extensors during cranial flexion. The coordination challenge on the fitness ball may be too high for early training and cannot easily be adjusted for the level of resistance but can be a successful home option when an incline board is not available. The fitness ball approach will be easier than the slant board due to the recoil of the ball assisting the trunk motion.

Motions and Directions

The initial movement directions of the Stage 1 exercises are chosen based on contraindications, tissue presentation, presence of pain, direction of joint restriction or hypermobility, muscles in guarding and/or muscle performance issues. Selecting specific exercises and directions should follow a logical thought process. Hypomobile joints are mobilized toward the end range, where hypermobile joints may be protected while mobilizing adjacent restrictions and/or muscles.

Some authors suggest that either flexion or extension biased exercises are of equal benefit (Elnaggar et al. 1991). Motion should be considered in all planes related not only to the pathology but functional requirements. Combined motions in diagonal patterns are necessary with daily activities, work and sport. Rehabilitation should have the end goal in mind for progressing exercises through all
planes of motion. A thorough evaluation should make the initial choices for motion self-evident. Long et al. (2004) demonstrated that matching subjects’ directional preference and pain free planes of motion significantly and rapidly decreased pain, medication use and improvements in all other outcomes. In this study, subjects were compared to two other groups, one of which performed exercises in the opposite direction of the preferred motions. The third group performed evidence-based exercises commonly prescribed, including multidirectional, midrange lumbar exercises and stretches for the hip and thigh muscles.

Descarreaux et al. (2002) compared the effectiveness of two home exercise programs at decreasing disability and pain related to subacute and chronic nonspecific low back pain. A specific (individualized) exercise program was compared with a program of commonly prescribed exercises for low back pain. Both groups demonstrated some improvement, but only the members of the group who received specific exercises significantly reduced their level of pain and disability.

A tissue based approach to exercise is to first move away from pain, or in the direction of preference of the patient. Motion is safely performed away from injured tissues but repetitive motion provides cellular stimulus for repair. When muscle guarding is present, exercises are chosen to train into the guarded pattern, emphasizing local vascularity and resolving abnormal tone. For the lumbar multifidi in guarding, this would be a pattern of extension, ipsilateral side bending and contralateral rotation. Low level training to bring in more oxygen allows for full elongation of the muscle to improve segmental motion in the range of flexion, contralateral side bending and ipsilateral rotation. When specific motor deficits in timing, coordination, endurance or strength are discovered, these muscles are selectively trained to improve their function. Emphasis on training muscles for dynamic stabilization is then considered. For every increase in range of motion gained, exercise is performed to stabilize this new range.

Hypomobile Joint Concepts
Active movements for mobilizing hypomobile ranges involve slow movement with a low demand on coordination. Emphasis is not on concentric work toward the restriction, but rather concentric work away, with subsequent eccentric work toward the restriction. A slow eccentric motion toward the restriction, addressing both contractile and noncontractile tissue that may be involved in the restriction is incorporated. In the example of mobilizing shoulder abduction, it is more effective to perform adduction with an eccentric return into elevation, than to perform active abduction toward the restriction. For the spine, the same pattern is performed concentrically away from the restriction, with an eccentric return toward the restriction. The motion is toward the end range but kept in the pain free range to prevent an increase in muscle guarding, adding to the limitation in motion.

Hypermobile Joint Concepts
Hypermobile joints lack the passive collagen structures to limit motion, as well as having reduced neural recruitment of muscles associated with stabilization. It is initially crucial to avoid exercising into the end range collagen tension in the direction of the hypermobility. The range of training is from a mid length of collagen tension toward a shortened range, avoiding end range strain. Whether the pathology involves a hypermobility facet, unstable disc, nerve impingement or just pain, the range...
of motion avoids end range strain to these tissues. Motion begins from neutral, moving away from the contraindication. Exercises may be initiated in a different plane than the primary plane of contraindication, but when in the same plane, motion is away from pain. Repetitive motion in the same plane as the pathology will provide the optimal stimulus for tissue repair but the end range of tension is avoided to prevent further pain or excessive tissue strain. As tissue tolerance and motor control improves, the range of training will gradually increase.

**Basic Sequencing of Direction of Tissue Training:**

- Movement is initiated in the pain free planes of motion.
- Movement away from pain in painful plane of motion.
- Hypomobile: movement away with eccentric return toward end range.
- Hypermobile: movement away with eccentric return to neutral only.
- Movement toward pain, but not into painful range.

**Dynamic Stabilization**

Dynamic stabilization implies that the motor system is functioning properly to control the axis of motion of a joint or joint system. The primary local muscle for segmental stabilization of the lumbar segments is the multifidus muscle. This predominantly tonic, arthrokinematic muscle, has the appropriate lever arms to control normal motion and abnormal shear. Eccentric function of the right multifidi will decelerate flexion, right rotation and left side bending. With rotation, bilateral multifidi are working in synergy, one side concentric and one side eccentric (Donisch and Basmajian 1972). This is why these muscles are considered to function as dynamic ligaments. Despite being on opposite sides of the axis of motion, the opposing multifidi are seen as synergists, not antagonist. Synergy with the tonic transverse abdominis and obliquus internus are also part of the normal movement synergy for coordinated and stabilized motion. The remaining portions of the abdominals, the long extensors and muscles of the hip coordinate the osteokinematic motion of the trunk.

The axial attachments and vertical orientation of the LM leave it poorly suited to contribute to the motion of lateral side bending or rotation in terms of providing torque. The muscles best suited for trunk rotation are the oblique abdominals. Because of the flexion moment associated with these abdominals, the erector spinae might be involved as an antagonist to flexion. In a similar function, the authors speculated the LM were acting as “anti-flexors” to balance the anterior sagittal rotation produced by the flexors.

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**Figure 5.57:** This drawing helps illustrate how the right and left LM will be active during rotation. In the example of left trunk rotation, the primary mover would be the right external oblique abdominal and the left internal oblique abdominal. Because of their fiber orientation, their contraction would provide a flexion moment in addition to left rotation. As the multifidi are primarily extensors, they will fire bilaterally to counter the flexion moment of the abdominals. The right LM would fire concentrically to assist with rotation while the left LM fire eccentrically. The deep multifidi serve the arthrokinematic function of controlling the segmental motion while the osteokinematic abdominals rotate the trunk.
In the clinical example of a hypermobile lumbar segment in flexion and right rotation, initial training focuses on the right side multifidus. This muscle will be targeted as it is not only inhibited due to receptor damage and pain from the pathology, but is also the primary stabilizer of the segment into the pattern of hypermobility. Initial training focuses on concentric work (CW) to recruit the muscle and resolve guarding. The range of training avoids the hypermobile range of the joint, while training any or all of the three motions of the multifidi. Training is from neutral to end range left rotation, from neutral to extension and/or from neutral to right side bending. The patient's tolerance or pathology determines the plane(s) to be initially trained. Performing repetitive motion in these limited ranges provides a safe level of tissue stress and strain to maintain and repair collagen and cartilage of the right facet, ligaments and portions of the disc under load.

If these same motions are performed from both a cranial and a caudal direction than at least six exercises can be safely performed acutely without concern of overstretching damaged collagen, while providing a high number of repetitions for pain inhibition, tissue repair, vascularity and coordination. This three dimensional example is for the purpose of outlining the training direction concept. For different clinical conditions, focusing on only one plane, or a combination of only two planes, may be effective. The patient's presentation and evaluation findings should guide the selection of directions and ranges to train. This example focuses on the posterior muscles, but incorporating the tonic contributions of the transverse abdominis and hip musculature would also be built into the program as well.

The Manual Therapy Lesion refers to altered or lost feedback due to mechanoreceptor damage from the primary pathology. This in turn, reduces the normal recruitment of the tonic muscles that control the axis of motion for a spinal segment. A major component of achieving dynamic stabilization is sensitizing the remaining afferent receptors in the systems to aide with motor control. Sensitizing the muscle spindles in the local tonic muscles is part of the progressive training process. Initial emphasis on concentric work away from the pathology focuses on recruitment, timing and resolution of guarding. Isometric was not initially trained as it reduces circulation, does not provide tissue stimulus and is not efficient for developing coordination. Stage 2 adds isometric work (IW) to allow an increase in resistance, and improved efficiency at developing sensitization of muscle spindles. Isometric work is initially performed in the shortened position of the multifidi, later progressed to the mid and lengthened range.

Figure 5.58a,b: Concentric work from neutral to left rotation, emphasizing the right side multifidus for Stage 1 training of a right rotation hypermobility.

Figure 5.59a,b: Isometric work of the right multifidus for left rotation: Stage 2 training of a right rotation hypermobility. The spine is positioned in a range from neutral rotation to full rotation way (left) from the pathology (right rotation hypermobility). In the beginning position(a) the weight stack is at rest with one foot forward. The patient steps back lifting the weight stack while maintaining the trunk position. After a hold time the patient steps forward resting the weight stack.
example of right rotation hypermobility, the right side multifidus is emphasized through this training of CW away, IW toward and EW toward. The opposing side multifidus also needs to be trained, working concentrically toward right rotation. The trunk is moved toward the pathological range, but not into it, with a one to two second pause in this position before returning to the start position. This isometric pause at the end assists in the training of recruiting additional motor units at the pathological range where they are needed. Remember that because of their arthrokinematic nature, both sides multifidi are always working, so this is performing a short duration co-contraction for stabilization.

The goal of Stage 4 is to achieve a coordinated synergy between all tonic and phasic muscles, around a physiological axis through a full range of motion. Exercises should involve more diagonal patterns, or functional patterns. Simulation of work, sport or activities of daily living should be built into the program. Basic dynamic stabilization has been achieved by Stage 4, with emphasis shifting from coordination for stabilization to elevation of endurance, strength and power in this newly stabilized range.

Summary of Basic Stabilization Progression
- Concentric work away (Stage 1)
- Isometric work (Stage 2)
- Eccentric work toward (Stage 3)/ Concentric work toward (Stage 2-4)
- Functional motion patterns through full range (Stage 3 and 4)

Hundreds of options exist for back exercises. The specific exercises chosen will dictate which muscles are working, the functional quality trained, specific dosage for the functional quality desired and the range of motion trained. Understanding dosage and progression concepts allows the clinician to customize, modify or invent exercises specific to the individual patient presentation. Below are just a few basic examples of common exercises but the
reader should focus on the dosage and progression concepts and apply them to the hundreds of exercises available. The exercise chosen does not determine the training outcome, it is the dosage and exercise design that determine the outcome.

**Extension Training**

Stage 1 emphasizes active motion for recruitment and coordination. Whenever tolerated, emphasis is on motion of the lumbar spine, rather than direct isometric work in the spine or indirect through extremity motion. Resistance is reduced to allow for high repetitive motion with pain or excessive fatigue. Fatigue with repetitive back extension has been shown to result in up to 75 percent reduction in erector spinae muscle force, with compensatory elevation in the latissimus dorsi and external oblique muscles (Sparto and Parnianpour 1998).

Caudal extension allows for direction motion at the lower lumbar spine for mobilization or local muscle training with reduced load. When extension is painful, as potentially with spinal stenosis or with nerve root pathologies, the range of training is limited from caudal flexion to neutral, avoiding painful end range extension. A roll under the pelvic can position the involved segment or region in flexion, with the active motion returning to neutral only. As mobility improves, the extension range can be increased until pain free end range extension is achieved. Exercise for spinal stenosis has been recommended as a form of conservative treatment (Bodack and Monteiro 2001). Flexion exercises are more commonly advocated for spinal stenosis because of the spinal canal and neuroforaminal narrowing produced by lumbar extension (Fast 1988, Fritz et al. 1997, Sikorski 1985), although some authors have also advocated using lumbar flexion and extension exercises (Nagler and Bodack 1993). The direction of motion should not be set by the pathology, but dictates more the range that is trained. The therapist must have the ability to design an exercise in any direction that is pain free and can be dosed for what ever training quality that is desired while maintaining the safety of the injured tissue(s).

**Flexion Training**

Active flexion initially addresses mobility, pain, tissue tolerance and/or coordination. Previously, concepts regarding lower abdominal recruitment were addressed with motor control issues specific to their recruitment. Here the emphasis is on gross motion of flexion in an attempt to improve tolerance and performance. Isometric stabilization exercises are performed at a later stage, when the emphasis is only on improving motor performance.
Whether initiating motion caudally or cranially, the goal is to perform segmental flexion through all lumbar segments.

Spinal compression increases with activation of the psoas during hip flexion torque. Pathologies in which compression with flexion is a precaution, such as advanced osteoporosis, can still be trained with reduced forces in a non-weight bearing posture. Caudal flexion supine with bilateral hip flexion focuses on a smooth transition between the hip flexors and lower abdominals. Motion should not stop at the end of hip flexion range nor should there be a pause before transitioning to flexion through the lumbar spine. A supine position may still be too heavy a resistance to perform a coordinated pattern. Performing hip flexion and caudal trunk flexion in a declined position may be necessary to reduce load to the muscles and compression to the spine. Progression through later stages would involve moving toward horizontal and eventual incline positions. Standing hip flexion training may also be performed unilaterally with cuff weights or pulleys strapped to the ankle.

**Side Bending Training**

Initial motions of training are determined by patient tolerance. Side bending may be an available motion to train. The lumbar multifidi and quadratus lumborum work more arthrokinematically, while the erector spinae, abdominals and latissimus perform the osteokinematic trunk motion. Side bending caudally may be more effective for mobilizing restricted motion, as motion occurs directly at the limited segments. For intraforaminal or compression pathologies, motion can be controlled from neutral to the contralateral side to avoid tissue provocation.
A hip hike is performed from below. The top leg can be supported on a rolling bolster to support the leg in line with the trunk and remove friction from dragging the leg. To increase the resistance for side bending, a pulley can be added at the ankle with a horizontal force moment.

Figure 5.68: Resisted lumbar caudal side bending in side lying. The exercise is performed as previously described with the addition of a resistance from a wall pulley at the ankle.

Figure 5.69a,b: Cranial side bending on a slant board, over a roll. Cranial side bending can also be performed over a bolster. A slant board can be used to reduce the overall load to allow for high repetition motion.

Rotation Training
Rotation is a key motion to train for motor recruitment and tissue tolerance. Rotation is more often the least painful motion in lumbar pathology (Faugli/Holten 1996), often making it one of the easiest directions to start training. With horizontal positioning, rotary motions can safely provide the optimal stimulus for tissue repair to all segmental tissues of the spine. Though the multifidus muscle is a primary extensor, it is the key arthrokinematic stabilizer during rotary motion. The horizontal fibers of the transverse abdominis are naturally facilitated in a stabilizing function for rotary motion and would be recruited in the normal spine prior to movement as a pre-movement stabilizing contraction (Hodges and Richardson 1997).

Figure 5.70: Hip Roll—Caudal supine left rotation. The patient is supine with the hips flexed to 45° and the knees at 90°. A bolster is placed under the feet, if necessary, to place the lumbar spine in neutral or slight flexion. The knees are eccentrically controlled out to the side with a concentric return to neutral. Emphasis is placed on the concentric return initiated from the lower abdominals and lumbar spine, not the hip and thigh muscles. The patient is instructed to breath out while bracing or hollowing the lumbar spine prior to initiating motion of the lower limbs. As little rotary mobility is available at each lumbar segment, the knees do not need to move far to the side to effectively train tissue and motor performance. Beginning with a “10 and 2” position on a clock is a good initial guideline, progressing in range as tolerated and/or necessary.

Figure 5.71: Supine hip abduction (horizontal abduction). The patient is in supine with resistance placed around the knee. The patient performs hip abduction, with emphasis on the gluteus medius. Increasing the hip flexion will reduce the contribution of the tensor fascia lata. The lumbopelvis juncture can be allowed to rotation, for a mobilizing force, or be held still for a stabilizing for at the lumbosacral juncture.

Sidelying cranial rotation is a commonly used early form of rotation training, as the position can easily be adjusted for safety and comfort. The locking section of this chapter offered several examples for protecting tissues by using bolsters and coupled forces to allow early and safe training. Cranial
rotation in side lying will emphasize the multifidus on the bottom side, though both sides are always working in synergy. Rotation is not pure, as the axis for motion is no longer the central spine, but the contact of the body on the table. Progressing to sitting and standing postures will allow for a more pure rotational motion and motor recruitment.

Figure 5.72: Sidelying cranial rotation with anterior resistance. Left rotation (pictured) will emphasize the right side multifidus. The hips and knees are flexed to stabilize the position and should not move during the exercise. The patient lies on the strap to fix one end, while the other end is attached to the pulley. To avoid shoulder and/or cervical irritation, the strap can be placed directly over the trunk, under the arm. A free weight can be used, rather than a pulley, but the muscle recruitment changes to the opposite side after passing vertical.

Figure 5.73: Sidelying cranial rotation with anterior trunk muscle emphasis. The exercise is similar to the previous one, with the resistance changed to the posterior side. This will emphasize the anterior muscles, as well as joint mobilization on the eccentric phase.

Figure 5.74: Sidelying caudal rotation with anterior resistance. Caudal rotation emphasizes direct motion in the lumbar region, with greater recruitment of the left side multifidus, with relative right rotation (pictured – motion listed for cranial segment). The top leg remains extended to form an axis of motion, while the bottom leg is flexed for stability. Facilitation of the lower abdominals (transverse abdominis) is enhanced with a horizontal resistance in the fiber direction, and with the initial bracing prior to initiating the motion.

Figure 5.75a,b: Sidelying caudal rotation with posterior resistance. The exercise is performed as previously shown with resistance anterior. A posterior force moment will further emphasize the anterior abdominal muscles during caudal rotation, but also creates a synergistic co-contraction of the lumbar multifidi.

Local Muscle Endurance

Hyperactivity of paraspinal muscles in chronic low back pain has been attributed to reflex-spasm response to pain (Collins et al. 1982); however, support for this theory is considered somewhat ambiguous (van Dieen et al. 2003). Marras et al. (2001) has shown a greater compressive load on the spine associated with higher levels of paraspinal muscle activity. Excessive spinal loading has been suggested to impede tissue self-repair (Kumar 1990) and decreasing load tolerance over time (Brinckmann et al. 1988, Callaghan and McGill 2001). Elevated resting paraspinal muscle activity shown in individuals with chronic low back pain is one such mechanism of increasing load, prolonging tissue recovery (Chiou et al. 1999, Ambroz et al. 2000, Lariviere et al. 2000, Marras et al. 2001). Healey et al. (2005) demonstrated that subjects with elevated paraspinal muscle activity from chronic low back pain had increased compression on the intervertebral disks and diminished ability to recover the height lost through loaded exercise. Rodacki et al. (2003) found similar results in
Pain signals for any lumbar pathology result in an increase in sympathetic efferent response, causing vasoconstriction, reducing microcirculation to tonic muscles in guarding. These tonic muscles rely on oxygen as a primary fuel source. Ischemia associated with chronic muscle guarding is best treated with active exercise dosed to increase local circulation, while not producing additional energy depletion. Too low of a resistance does not require an increase in local circulation, while too high a resistance increases intramuscular pressure reducing circulation. Between the two extremes is the range of training to maximize local circulation. A reduction in the blood flow starts as early as 30 percent of MVC and by 70 percent of MVC the blood flow is likely entirely cut off, although quadriceps circulation has been cutoff at only 20 percent of MVC (Edwards 1972). Maintaining blood flow is necessary for muscle protein synthesis (Biolo et al. 1995). In the presence of chronic muscle guarding active training is performed to the tonic muscles in guarding dosed in a range from 55–65% of 1RM to improve local circulation.

Pure concentric training, with removal of the eccentric phase, is effective in improving circulation. Concentric exercise has been shown to increase capillary density not associated with eccentric work (Hather et al. 1991). Performing concentric and eccentric work together with the muscle constantly loaded maintains an intramuscular pressure that results in a reduction in blood flow. The use of an eccentric stop wheel on a wall pulley with early training for vascularity can improve the efficiency of training. If an eccentric stop wheel is not available, allowing the weight stack to come to rest with each repetition, and the muscle to fully relax, will improve local blood flow through the muscle during training. In severe guarding, resting one to two seconds between each repetition will be more effective in oxygen restoration.

Figure 5.76: The eccentric-stop wheel attachment for the wall pulley spins for the concentric phase only. During the eccentric phase the wheel is blocked from turning, creating a friction to lower the weight and remove the need for muscle contraction during the weight lower phase.

The lumbar multifidi are typically the primary tonic muscle in guarding with acute lumbar pathology. The muscle can be selectively trained for local vascularity to increase local circulation and provide oxygen for fuel for recovery. For example, the right multifidi performs extension, right side bending and left rotation. All three of these motions can be performed caudally and/or cranially. All of these motions can be trained with any number of exercise options with the dosage set for vascularity (60% of 1RM for three sets of 24 repetitions). Other commonly guarded muscles such as the piriformis and the psoas can be addressed with a similar approach for vascularity to provide oxygen and normalize resting tone. Specific exercises chosen may relate to the least painful planes of motion, safest for participating tissues, easiest to coordinate, easiest to reproduce at home or related to any number of contraindications for motion in certain planes. With proper exercise design and

pregnant women with chronic low back pain; the control group recovered 93.8 percent of stature that was lost during exercise, whereas the chronic low back pain group recovered only 54.4 percent. Resolving muscle guarding is considered an important step to normalize tissue loading, allowing for repair processes, but also for reducing symptoms, improving mobility and normalizing motor patterns. This can be achieved by dosing exercises specifically to improve local circulation and endurance. Endurance training of lumbar extensor muscles has been shown to reduce symptoms and improve function in the initial three weeks of training (Chok et al. 1999).
dosage muscle guarding associated with ischemia can be resolved within the treatment session resulting in a significant improvement in mobility and reduction in symptoms. As muscle guarding is resolved the neurological inhibition of the opposing antagonistic muscles reduces which may result in a significant improvement in their performance for early coordination training. For examples, resolving muscle guarding in the multifidi, a primary extensor muscle, may improve weakness or poor coordination in the antagonistic lower abdominals without direct training of the anterior muscles.

Respiration

Normalizing respiratory patterns is a fundamental component of lumbar spine rehabilitation. Breathing patterns have an impact on oxygenation for reducing pain levels, energy during performance and recovery. With attachment to the spine, the diaphragm also contributes to the dynamic stability of the lumbar spine. The trunk has three functional diaphragms: the glottis, the diaphragm muscle and the pelvic floor. All three work in synergy as a co-contraction during isometric stability of the spine. With normal respiration, the diaphragm contracts downward, creating a negative pressure to fill the lungs. The pelvic floor is reflexively inhibited during contraction of the diaphragm. During high level sport activity, the diaphragm may be working with increased intensity and frequency, but the pelvic floor may also need to contract at a high level for spinal stability. These opposing concepts are easily coordinated in the normal spine, but can breakdown in the pathological state.

Initial training may simply be to emphasize diaphragmatic respiration, without accessory muscles of respiration contributing. Though thought of as a simple task, it is often impaired in the chronic back pain patient. Proper breathing patterns should be established prior to more complicated coordinative, endurance or strengthening exercises to provide proper oxygen and to avoid reinforcing abnormal patterns of respiration. When a patient is attempting to learn a new exercise with a coordination challenge, and mental challenge, the first compensation is to stop breathing during this learning process. Cueing the patient to breath is frequently necessary during the acquisition phase of a new skill.

Figure 5.77a,b: Diaphragmatic respiratory training. In supine, the patient places one hand on the lower abdomen and one hand on the sternum. The patient is instructed to feel the abdominal hand rise during inspiration, without motion of the sternum. Breathing through the nose during inspiration and out the mouth during exhalation may enhance the performance and learning process.
Nerve root pathologies would have obvious influence on afferent signals affecting balance. Somatosensory deficits due to tissue and receptor damage may play a less obvious role in balance deficit in the presence of normal neurological conduction of lumbar nerve roots.

Assessment of lumbar and cervical patients should begin without shoes on a flat stable surface. Tissue injury in the spine or periphery can affect posture due to abnormal signals from the somatosensory system. Mechanoreceptor damage will alter afferent input affecting normal motor recruitment. Conflicting afferent input may be created in the presence of pain and muscle guarding. Mechanoreceptors in the joint capsule at rest report an absence of joint motion while muscle spindles, in the state of acute or chronic muscle spasm, report tension or motion. This confusion can manifest in many ways: altered movement patterns, altered postural tone, altered kinesthesia, vertigo and loss of balance or dizziness.

Initial Dosage for Balance Training

- Balance—30 seconds to two minutes per exercise.
- Greater than five minutes of training on to three times daily.

Balance improvements in chronic low back pain can be enhanced with specific and customized exercise programs (Kuukkanen and Malkia 2000). A progression of balance testing for the spine is performed with assessment of trunk sway and perceived stability of the patient. Cervical movements during the testing, even for the lumbar patient, assess the ability to integrate postural reflexes associated with somatosensory system of the cervical spine. Identifying specific directions of cervical movements that create balance deficits can assist in determining retraining exercises.

Patients with chronic low back pain have been shown to have impaired psychomotor speed and,
Among females, impaired postural control (Luoto et al. 1996). Postural control reaction time improved without specifically training it. This implies that LBP caused not only peripheral problems but also impaired functioning of the central nervous system (feedforward mechanisms). A correlation between proprioceptive dysfunction and LBP was also established. A slight difference was found between the groups in the slow corrections of posture, suggesting that the central nervous system’s processing of the responses was somewhat different in the patients with LBP (Luoto et al. 1998). The differences found in this study suggested that the differences in postural corrections might be non-cortical. Impaired postural stability is considered one factor in the multi-factorial problem of chronic back pain.

**Adjunct Training**

Treatment should focus on the person, not the diagnosis. Intervention addressing only the region of pain may miss important impairments in other regions that are a part of the overall pathology. The biomechanical model addresses joint mobility and range of motion in all joints in the biomechanical chain. This involves the sacroiliac joints, entire lower limb, thoracic and cervical function. Restricted hip mobility in extension places in increased torque at the lumbosacral juncture during many functional motions and patterns. Loss of mobility of the thoracic spine in extension and/or a forward head position of the spine can alter overall posture of the lumbar spine. Many causes for reduced mobility exist, with many potential areas distal to the lumbar spine. Evaluation and passive treatments may address these, but exercise may also need to directly address some of these impairments. The other chapters in this text offer mobilizing exercises and concepts for these regions.

The neurophysiological model addresses movement patterns, with muscles not only crossing the lumbar spine, but affecting the trunk or lower limbs. Inhibition of normal movement patterns leads to compensation in posture, movement and performance. Central balance training is also a component of this model. Normalizing balance and stability of the lower limb with heel contact during gait and/or running can significantly reduce the impact load to the lumbar spine. The manual therapist, the hip is part of the functional unit of the pelvis and lumbar spine. Addressing motor deficits in the lower limb, with emphasis on the hip, may be a primary need for the back patient.

**Myofascial Stretching Techniques**

Addressing limited mobility of muscle or fascia in Stage 1 focuses on passive manual therapy techniques. Stretching exercises are not commonly prescribed in the presence of pain and muscle guarding. The facilitated segment model teaches us that a painful segment will elevate the resting tone of muscles innervated by that level. Pathologies affecting the L4, L5 and S1 nerve roots result in
an elevation of the resting tone of the hamstrings, or a reduced ability to lengthen. This is considered a symptom, not a primary cause of low back pain. Fisk (1979) demonstrated a single lumbar spinal manipulation resulted in an immediate significant increase in hamstring length, without any direct stretching to the muscle. Stage 1 addresses the reasons for pain, which in turn will reduce the neural drive for tone, improving functional hamstring length. More specific stretching concepts are applied later in the exercise progression.

Home Exercise
Establishing a home exercise program is necessary to achieve early training goals. Selective tissue training, pain inhibition and coordination all require hundreds of repetitions, preferably multiple times daily. In later stages, frequency and duration of training may decrease, but adherence to a set program is still necessary to achieve meaningful long term outcomes.

Providing specific instructions is necessary in teaching home exercise, but more detailed information does not necessarily improve adherence (Raynor 1998). Lack of time on the part of the patient is one of the most common reasons for lack of adherence (Sluijs et al. 1993, Dean et al. 2005). It is important for patients to identify time to carry out the prescribed exercise, but physical therapists must recognize that they have a role to play in helping patients manage their time (Dean et al. 2005). Working with the patient to identify their life priorities can assist the therapist in designing individually tailored programs in a way that does not interfere with these priorities. Exercises programs can be designed around work schedules, childcare issues, a current fitness program or built into daily activities. Creating rapport is also critical for establishing a therapeutic relationship that promotes adherence to home exercise programs (Dean et al. 2005).

Friedrich et al. (2005) determined that motivational strategies to improve adherence to home exercise does improve disability outcomes for chronic low back pain, compared to home exercise without motivational approaches. Techniques used included providing clear instructions, emphasizing the importance of regular and consistent exercise for reducing the pain and likelihood of recurrent episodes, enhancing each patient’s internal locus of control, providing positive feedback, reward and punishment strategies, written contract, posting written contract at home and maintaining a daily exercise log.

Patients that are expected to independently adjust equipment and perform exercises during supervised sessions demonstrate improved adherence to long-term home exercise programs (Hartigan et al. 2000). Requiring independence in the clinical setting provides patients with an opportunity to practice and master exercise techniques.

Section 2: Stage 2
Exercise Progression
for the Lumbar Spine

Stage 2 progressions are determined by improvement in functional qualities being trained in Stage 1. Often there is an overlap between exercises addressing both Stage 1 and 2 concepts within one training session. Indications for progression include a decrease in pain, improved joint mobility, improved range of motion, resolving muscle guarding and improvement in coordination or motor learning. Improvements in coordination may be demonstrated with an increased speed with a given exercise. The basic goals for Stage 2 are to stabilize the gained range of motion, improve muscle endurance, develop faster coordination, progress the functional body position with each exercise and increase the overall volume of training.

A program of 8–12 exercises, of two to three sets each, is not uncommon. Speed is increased, not weight, to emphasize fast coordination and to increase the relative resistance of the exercises. The exercises from Stage 1 may be carried over, but the
desired functional qualities will shift with these changes. Isometric contractions within the mid to inner range of motion are also introduced to help fix strength. The following are examples of Stage 2 exercises dosed for specific functional qualities.

**Tissue and Functional States: Stage 2**
- Decreased active range of motion in tri-planar motions and end ranges
- Pain free at rest but painful with motion
- Partial weight bearing/loaded postures are tolerated
- Fair coordination in basic movement patterns
- Fair balance/functional status
- Palpation of involved tissues and pressure sensitivity of guarded muscles only moderately painful

**Basic Training Goals: Stage 2**
- Increased repetitions with increased exercises (5 to 10 exercises).
- Increase repetitions with additional sets (endurance).
- Increase speed (strength/endurance).
- Combined concentric and eccentric work for further tissue tension accommodation.
- Body/limb position changes from recumbent to more dependent.
- Planar motions with exercise to full range/partial range tri-planar.
- Remove locking or change to less aggressive types of locking.
- Histological influence of increased lubrication with increased speed.

**Increase Speed / Not Weight**

Frequently in physical therapy practice, increasing the weight with an exercise is often the first approach toward progressing an exercise. As coordination improves speed is naturally increased. This increase in speed creates greater resistance through inertia, making it unnecessary to increase the weight. Obtaining full, pain free range of motion should be the first emphasis, prior to increasing the level of difficulty. This may also include achieving full range in more challenging positions. Flexion with supine training is not the same performance as in standing. Once full range has been achieved, increasing speed of training, not increasing the resistance, creates an increased level of challenge. The addition of speed is the addition of inertia. Inertia, with acceleration and deceleration, is a force, and is therefore an added resistance. As an example, running requires a greater level of work than walking, though the weight of the body is the same for both performances. Speed will also further challenge coordination, which is speed specific. Initial training may have been below a functional level, with the increase in speed reflecting more of a functional demand.

Overall changes in body position, number of sets and repetitions, along with changes in speed provide a more aggressive training program. Each training session should involve a progression of at least one variable in at least one exercise. Progression is not from one list of exercise for Stage 1 to a second list of exercise for Stage 2. Each exercise is progressed as improvements are attained. Even acute patients with a low training state will benefit from a high volume,
CH. 5: EXERCISE REHABILITATION OF THE LUMBAR SPINE  SECTION 2

isometric work (IW) is associated with a higher level of resistance to improve sensitivity to stretch in the muscle spindles. Oxygen compromise with IW is no longer a concern. A higher peak torque is noted with IW than CW, allowing greater resistance for training. Joint motion does not occur with IW, making heavier resistance safe, which might otherwise not be coordinated with CW. The tonic muscle system associated with arthrokinematic control is still emphasized, using heavier weights with hold times for at least six to ten seconds with heavy resistance and up to 30 seconds with lighter.

The joint is initially positioned in mid range, where some level of structural stability exists. In later stages the joint will be positioned closer to the pathological range. More aggressive approaches to this utilization of IW are necessary in the hypermobile joints, while the hypomobile joint may achieve dynamic stability more rapidly due to less tissue and receptor damage. Isometric training is also associated with fixation of strength. Performing an isometric hold assists in creating a neurological fixation of a motor pattern, or specific muscle recruitment. As range of motion is gained, isometric hold times in the new range can fix muscle strength in this new range, improving stabilization more quickly than performing only high repetitions as lighter loads.

The application of IW may involve replacing one of the three dynamic sets with an isometric set. The second set is often replaced with one isometric set at a higher resistance, followed by the third dynamic set at the original lower resistance. Only one to three holds are performed with emphasis on neurological adaptation, not structural changes in muscle tissue.

**Dosage for Isometric Work**

- *Isometric hold in mid range as second set between first and third dynamic sets, 80% of 1RM 6–10 second hold.*
- *Two to five isometric holds can be performed toward pathological range*

More classic examples of back exercises involving co-contraction of trunk muscles for isometric stabilization are added in Stage 2. The trunk is stabilized against gravity, external resistance or during extremity movements. These exercises do not address the primary functional need of the patient as defined by Stage 1 criteria related to tissue repair, mobility, resolving muscle guarding and coordination. The focus is more on heavier load co-activation with isometric holding. Resistance is often high, with hold times of only 10 seconds. This type of dosage is more consistent with strength training, as opposed to coordination or endurance training, which are necessary qualities to attain prior to strength training.

Early dosage for strength training may account for some of the studies assessing exercise for acute low back pain having minimal positive effects. Strength qualities in larger phasic muscles does not address recruitment and coordination of tonic, arthrokinematic, muscle. Pure isometric exercises with higher loads are of more significant benefit in Stage 2, providing many options for tonic and phasic muscles to work together with higher loads.
Bridging exercises can be progressed to involve distal fixation with proximal motion and stabilization. The feet can initially be placed on a fixed surface, such as a step or bolster. A further challenge is to place the feet in a sling, requiring a greater level of co-activation to stabilize the proximal trunk. Initial exercises may support the lower limbs several centimeters off the floor, with a gradually progression to higher levels.
Figure 5.85: Bridging on a fitness ball, knees flexed. The upper thoracic spine and shoulders are supported on a fitness ball with the knees flexed. The pelvis is elevated to take the lumbar spine from flexion to neutral. The exercise emphasizes the lumbar extensor muscles with secondary influence on the hip extensors. In this position the patient can also be instructed to lift one heel off the ground while maintaining a neutral lumbar spine and avoiding rotation of the pelvis.

Figure 5.86: Bridging on a fitness ball, knees extended. The lower legs and ankles are supported on a fitness ball with the neck, shoulder and upper thoracic spine on the floor. The pelvis is elevated to take the lumbar spine from flexion to neutral. The exercise emphasizes the lumbar extensor muscles with secondary influence on the hamstrings and gluteal muscles.

Figure 5.87: Kneeling stabilization with upper limb support on a fitness ball. The forearms are positioned on a fitness ball, while in an upright kneeling position. Weight is transferred onto the ball rolling it forward. The patient leans forward maintaining a neutral lumbar posture while maintaining normal respiration.

Figure 5.88: Forward knee lumbar stabilization. From a sit-kneel position the trunk is flexed forward from the hips while maintaining a neutral lumbar spine. The arms are then flexed forward to 90° and the knees are slowly extended. If the psoas muscle cannot fully lengthen, an increase in lumbar lordosis occurs prior to reaching an upright kneeling position. Motion is stopped when neutral cannot be maintained.

Figure 5.89a,b: Kneeling stabilization with upper limb slings. Two lines from the same sling support the arms. The patient begins in an upright kneeling position. Transferring the weight onto the sling, the patient leans forward, maintaining a neutral lumbar posture.

Figure 5.90a,b: Lateral bridge. Isometric stabilization of the lumbar spine is performed at an incline with the elbows supported on a wall. A slant board allows specific progressing dosing of increased resistance working toward a horizontal position in side lying. The shoulders, ribcage and pelvis are maintained in alignment.
Performing abdominal training with trunk flexion exercises increases compressive forces, being too aggressive for early training in pathologies related to disc or vertebral compression. Use of the lateral bridge exercises is a safe substitute to reduce loading while providing significant recruitment of the abdominal muscles. The side bridging exercise has been shown to produce up to 100 Nm of abdominal torque with much lower spinal loading (Axler and McGill 1997).

<table>
<thead>
<tr>
<th>Primary Muscle Group</th>
<th>Exercise</th>
<th>Criteria for Progression</th>
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| **Transversus Abdominus** | Abdominal bracing  
|                      | Bracing with heel slides  
|                      | Bracing with leg lifts  
|                      | Bracing with bridging  
|                      | Bracing in standing  
|                      | Bracing with standing row exercise  
|                      | Bracing with walking  | 30 repetitions with 8-s hold  
|                      |                                                                      | 20 repetitions per leg with 4-s hold  
|                      |                                                                      | 20 repetitions per leg with 4-s hold  
|                      |                                                                      | 30 repetitions with 8-s hold, then progress to 1 leg  
|                      |                                                                      | 30 repetitions with 8-s hold  
|                      |                                                                      | 20 repetitions per side with 6-s hold  |
| **Erector spinae/ Multifidus** | Quadruped arm lifts with bracing  
|                      | Quadruped leg lifts with bracing  
|                      | Quadruped alternate arm and leg lifts with bracing  | 30 repetitions with 8-s hold on each side  
|                      |                                                                      | 30 repetitions with 8-s hold on each side  
|                      |                                                                      | 30 repetitions with 8-s hold on each side  |
| **Quadratus Lumborum** | Side support with knees flexed  
|                      | Side support with knees extended  | 30 repetitions with 8-s hold on each side  
|                      |                                                                      | 30 repetitions with 8-s hold on each side  |
| **Oblique Abdominals** | Side support with knees flexed  
|                      | Side support with knees extended  | 30 repetitions with 8-s hold on each side  
|                      |                                                                      | 30 repetitions with 8-s hold on each side  |

Table 5.5: Stabilization exercises with suggested criteria for progression, as described by Hicks (2005).

Figure 5.91a,b: Lateral bridge is progressed from an incline position to a horizontal lateral plank position. To reduce difficulty both knees can be flexed, or just the bottom leg, but the knees are kept inline with the pelvis and shoulders. Separating the feet also increases the base of support to reduce the need for rotational stabilization. To increase the difficulty the patient can horizontally rotate the top arm forward and backward. Turning the cervical spine may also increase the rotary stabilization challenge of the trunk.

Figure 5.92: Lateral bridging with proximal sling fixation. The exercise can be performed bilaterally and unilaterally (Stuge and Vollestad 2007).

Figure 5.93a,b,c: Wall-Rolls. A progression of the plank exercises is to perform both lateral and relative prone plank positions can be performed in a rolling sequence in standing against a wall (McGill 2002). The lumbar spine is held in neutral during the change in positions.
Figure 5.94: The incline prone bridge (plank) for lumbar bracing training. The shoulders, ribcage and pelvis are maintained in alignment. The patient should be instructed to maintain normal breathing, rather than breath holding. Flexing at the hips, lifting the pelvis up, is a common compensation for weak lower abdominals. The patient is instructed to lower the pelvis in line with the shoulders and feet, unless pain is reproduced. Raising the pelvis may initially be used to assist the patient, with a gradual progression to horizontal. Incline positions using a wall, table or slant board allow for a correct position during lower training states.

Figure 5.95: Incline prone bridge on a fitness ball. The ball can provide a slight incline, to reduce the relative load compared to a prone position. The labile surface provides an additional challenge for lumbopelvic stabilization.

Figure 5.96a,b,c: Side bridge-rolls prone. A progression of the plank exercises is to perform both lateral and prone plank positions in a rolling sequence. The lumbar spine is held in neutral during the change in positions. The patient is instructed to lift the elbow slowly off the wall, rather than push off. The motion should be initiated from the lower trunk, rather than pushing off with the shoulder girdle.

Figure 5.97: Isometric stabilization training of the trunk with overhead quick press. The patient stands with the lumbar spine in neutral and slightly flexed knees. A bar is pressed overhead with quick motions. Emphasis is placed on the trunk remaining stable during the motion.

Figure 5.98a,b: Standing arm row. The patient stands with the lumbar spine in neutral and slightly flexed knees. A pulley handle is lifted bilaterally while maintaining a neutral lumbar spine. Lack of stability results in an extension moment of the lumbar spine as the arms are raised. The exercise can also be performed with free weights, though the torque on the back is not as significant. Elastic resistance will produce a greater torque at the end range, but shoulder limitations may require adjustment in tension that provides little resistance at the beginning of the motion. Resistance should be kept light, with a limited arm swing, to avoid excessive torque in the lumbar spine and reduce the risk of disc injury.

Figure 5.99: Standing pull down, lumbar stabilization. The
The trunk remains in line with the lower limb, with the nose over the front foot. The lumbar extensors work isometrically to hold the trunk against gravity. When performed correctly the front hip feels most of the work, with little effort at the knee. When performed incorrectly the trunk remains vertical with an extended lumbar spine and the work felt at the knee, not the hip.

Figure 5.103a,b: The hack squat initially is performed with isometric stabilization of the lumbar spine, without flexion of the lumbar segments. Abdominal bracing stabilizes the lower lumbar segments during a functional squat motion.

Figure 5.104a,b: Sitting rowing for isometric back extensor training. Sitting removes the need to coordination the pelvis and lower limbs with back stabilization required in standing positions. The patient sits with the pelvis rotated anterior to achieve a neutral lumbar spine. Cable rowing or elastic resistance is used for a rowing motion for the upper limbs while the lumbar spine maintains a neutral position.

Motion and Directions

From the standpoint of tissue tolerance and pain, the basic motions of Stage 1 are progressed in terms of range of motion and by adding the directions that were avoided. Full range of motion and coordination are the goal of Stage 2, allowing progression to more functional strength training.
Extension
Back extension exercises, whether with active motion or isometric holding, have long been shown to be beneficial in the treatment of low back pain (Davies et al. 1979). Cranial lumbar extension is a classic exercise for training the lumbar extensor muscles. The Roman chair exercise has been utilized in both the clinic and health club settings for back training. This exercise does not isolate the lumbar extensors, but is coupled with the hip extensors. Even the biceps femoris muscles are connected via the sacrotuberous ligament and thoracolumbar fascia (Vleeming et al. 1995). The importance of the gluteus maximus and the biceps femoris to the force production during trunk movement has been demonstrated (Clark et al. 2002, Kankaanpaa et al. 1998, Vleeming et al. 1995). Clark et al. (2003) studied the recruitment patterns of the lumbar and hip extensors as it relates to fatigue during Roman chair extension, finding that the maximal degree of lumbar muscle activation to be around 85 percent. They also observed a reduced recruitment of the lumbar paraspinal musculature occurring at approximately 55 percent of maximal fatigue with a concomitant increase in hip extensor muscle activity. Robinson et al. (1992) has also reported similar decrements in lumbar paraspinal muscle activity with fatiguing trunk extension exercise. Clark et al. (2002) suggested that dynamic Roman chair exercise, due to muscular failure and fatigue, does not allow for maximal muscle activation of the lumbar paraspinal muscles. This statement may be true for strength training in isolation for the lumbar extensors, but is effective for training the functional synergy between the lumbar spine and hip extensors. The exercise can also be adjusted to reduce the load, allowing for coordination and endurance training, reducing the early fatigue of the lumbar extensors.

To adjust the amount of resistance with back extension exercises the axis of motion can be set more cranial. The peak angle of the table is set more cranial on the trunk to reduce the amount of body weight on the cranial side of the axis of movement. The arms can be placed behind the back shifts more body weight caudally, reducing the load, or behind the head (as pictured) to increase the load. A further reduction was achieved with the Stage 1 option shown on a slant board to position the body more vertically. An alternative approach to reducing weight is to adjust the table more vertically.
positioning. Hip rotation can easily be adjusted for cranial extension exercises, with internal rotation emphasizing back muscles, while external rotation will emphasize the hip musculature.

If concern exists over minimizing the contribution of the hip extensors during lumbar extension, changing to a sitting position is an effective option. Sitting significantly increases the compression to the lumbar discs, and is therefore not recommended early in rehabilitation of acute disc pathology. For disc pathologies, it may be more appropriate to wait until Stage 3 or 4 training to utilize sitting postures for cranial extension training.
without any support, can allow for excessive lumbar extension during the motion. The patient must be able to dynamically control the lumbar extension moment with the abdominal muscles. Weakness in the lower abdominals and lumbar multifidi may lead to pelvic rotation, seen as the ASIS on the ipsilateral side of the leg lift moving down toward the table. A towel roll can be placed under the ASIS to passively stabilize the pelvis and assist the motion. The towel can also be placed on the opposite side with the patient instructed to push down into the towel to fix the lower abdominals prior to lifting the leg.

Figure 5.114: Caudal extension with unilateral limb extension on labile surface. Once coordination is achieved on a stable surface, performing the same exercise on a fitness ball provides an increased stabilization challenge.

Figure 5.115: Mule Kick. Hip extension for back training can also be performed in standing with the upper body supported on a table. This position will limit extension in the lumbar spine, as the back is flexed with the hip extending from a position of lumbar flexion to lumbar neutral.

**Flexion**

Flexion training in Stage 2 may progress in range of motion and slight increases in speed to increase the relative resistance. Brief isometric holds during the mid phases of sit-up exercises can also increase the amount of muscle work, as well as challenging active respiration during an isometric hold.
Flexion training may focus on coordination of a larger pattern. Performing short-range diagonals into a flexion pattern with a wall pulley can begin the process of establishing coordination for a full functional pattern in later stages. A lighter pulley weight may also serve to unload the weight of the trunk during the eccentric phase of flexion, assisting with the muscles of trunk extension. Heavier loads will emphasize abdominal and hip flexor activation.

**Figure 5.118**: Spine shoulder extension (eccentric elevation) on a fitness ball. The patient is supine on a fitness ball with the lumbar spine maintained in neutral. With a bar or free weights the arms are elevated over the head.

**Figure 5.119**: Free weights allow for asymmetrical arm motion, introducing a rotary components to lumbar stabilization challenges.

**Figure 5.120a,b**: Lumbar flexion diagonal with pulley assistance or resistance. Range of motion is kept short, less than from shoulder to knees. A lighter pulley resistance will assist the lumbar extensor muscles during the motion, while heavier resistance will emphasize flexor muscles of trunk and hip for resisted flexion trainings.

**Side Bending**
Progressing side bending exercises to partial and full weight bearing represents a more functional training position to involve not only back muscles, but also
contributions from the hip musculature. Weight bearing is also a progression for improving tissue stress and strain tolerance.

Figure 5.121: Cranial side bending on slant board to reduce resistance. A bolster for the axis of motion can be set at the rim of the pelvis to involve the entire lumbar spine, or set at a specific spinal level to prevent side bending caudal to the roll. Increasing the angle and/or moving with bolster more cranially will reduce the load.

Figure 5.122a,b: Hip hiking standing – pulley assist. The hip hike works primarily the hip abductors on the stance side and the quadratus lumborum on the opposite side. A pulley assist will reduce the body weight to allow for pain free coordinated motion.

Figure 5.123a,b: Hip hiking standing – free weight assist. To assist the motion a pulley can produce a force cranially on the stance side, or a free weight can be held in the hand on the opposite side of the joint axis.

Figure 5.124: Lumbar side bending in sidelying. The hips and knees are flexed to 90°, with the mid thigh on the edge of the table. The feet are rotated from the floor to the ceiling to create a side bending moment in the lumbar spine.

Figure 5.125: Lateral bridge on fitness ball. From a sidelying position, with the feet and lower legs on a fitness ball, the pelvis is lifted off the floor. The pelvis should remain in alignment with the shoulders, with the lumbar spine in neutral. The labile surface of the ball increases the challenge for stabilization.

Rotation
With improvement in acute symptoms, tissue tolerance and mobility, rotation training focuses more on progressing motor performance. If recruitment, timing and coordination are established, using a higher resistance with the same exercises will develop qualities within the muscles, such as increased capillaries for endurance or improve strength qualities. Non-weight bearing training with increased resistance emphasize muscle qualities without increasing tissue strain. Progressing to weight bearing exercises places more demand on tissue tolerance, as well as advancing toward more functional activities. The process of beginning work or sport simulation begins at a low level.
oblique abdominals are the prime mover. Motion should be initiated with the eyes and head turning, with the trunk following through.

Adjusting the resistance is only one way to modify and exercise. The flexibility of a wall pulley allows for any force vector during an exercise. Performing the same standing trunk rotation can have different emphasis depending upon what vector the pulley is set at and how the body reacts to that force.

Figure 5.126: Hip roll with pulley resistance. Transverse resistance from the pulley will recruit the oblique abdominal muscles, as well as the multifidus for arthrokinematic control of the lumbar segments. In a normal spine, the transverse abdominis will be recruited as well. The more phasic oblique abdominals provide the primary torque for rotation. Eccentric control occurs as the knees move to the right, with emphasis on the concentric return beginning at the more cranial segments in the lower thoracic spine, moving toward the lower lumbar segments, with the pelvis moving last. If the motion is initiated at the knees, rather than the lower thoracic spine, then emphasis is placed on hip muscles of adduction and abduction.

Figure 5.127a,b: Resistance for the supine hip roll can be created by crossing the knees, moving body weight lateral.

Figure 5.128a,b: Standing left cranial rotation, pulley resistance. The patient stands facing the pulley with the knees and hips slightly flexed. Left rotation emphasizes the right multifidus, though both sides work in synergy and the oblique abdominals are the prime mover. Motion should be initiated with the eyes and head turning, with the trunk following through.

Figure 5.129a,b: Standing left trunk rotation with a cranial resistance inclined up and forward. The force moment creates a motor response for extension and rotation but the incline vector increases the relative range of extension that is performed, as opposed to pure rotation. This option may be desired in a stiff back attempting to gain range into extension. Another reason for this selection may be a functional requirement of combined extension and rotation, such as a tennis serve.

Figure 5.130a,b: Standing left trunk rotation with a horizontal resistance. A horizontal force moment will emphasize pure rotation of the trunk with little to sagittal plane motion in flexion or extension. From a motor standpoint, this setup may be desired to recruit muscles of rotation while reducing the demand for muscles of extension (i.e., recruiting the multifidi and transverse abdominus for rotation while minimizing the contribution of the long trunk extensors). Additionally, the emphasis may simply be on improving gross rotation range. Lastly, progressing to strength training for trunk rotation to address functional requirements.
and posterior muscles occurs, with both tonic arthrokinematic and phasic osteokinematic muscles working in synergy. Anterior resistance will place greater emphasis on the posterior muscles, while a posterior resistance will emphasize anterior muscles.

Figure 5.131a,b: Standing right trunk rotation with a force vector to emphasize recruitment of the lumbar left lumbar multifidi (LM). The pulley line is set at a vector to naturally recruit the LM, without cognitive effort. The “external cue” for training can improve the facilitation of LM that may be in a state of atrophy or inhibited by pathology. The force line is set at a decline to address the extension moment of the LM. The line is lateral to the right to emphasize the left side bending component of the LM. A pure rotational motion is performed to emphasize the rotational vector of the multifidi without recruiting the long extensors of the trunk.

Figure 5.132a,b: Standing right trunk rotation using a wrap around strap attachment. The end of the belt is secured by the left hand in front of the pelvis. The belt wraps around the trunk in a vector similar to the left side lumbar multifidi. A combined extension and right rotation moment is performed.

The exercise itself does not determine the training outcome. It is the dosage and the exercise design that will determine the training outcome. The same exercise can be dosed anywhere on the continuum from mobilization, to strength and to power. Adjusting the weight and repetitions will determine which of these functional qualities is attained with training. Beyond simple dosage concepts, the design of the exercise can be adjusted to emphasize gross range of motion, specific muscle fiber recruitment or pertain to specific functional patterns. Functionally, a co-contraction of anterior and posterior muscles occurs, with both tonic arthrokinematic and phasic osteokinematic muscles working in synergy. Anterior resistance will place greater emphasis on the posterior muscles, while a posterior resistance will emphasize anterior muscles.

Figure 5.133a,b: Standing trunk rotation, posterior pulley resistance. The patient stands with the back to the pulley, knees and hips slightly flexed, arms crossed and holding on to a pulley handle. The lower limbs remain stable while a cranial rotation movement is performed.

With the pulley line set perpendicular to the trunk, emphasis is on range of motion, gross mobilization or training general functional patterns of rotation. The same motion can be performed, but the movement of the arm created by the line of the pulley can be adjusted to facilitate specific muscle fibers. Internal attention focusing on a person’s own body movement can be detrimental to the performance of a well-learned skill as well as in learning new skills (McNevin et al. 2000). Having the patient try to feel specific muscle recruitment during the training process can slow the learning process. External attention, focusing on the body’s reaction to an external force or object is a more efficient approach. Having the patient attempting to focus on firing specific lumbar multifidi muscles during the rotational motion is not as efficient as setting the pulley line to act as an external resistance that the body has to respond to with specific muscle recruitment. This is done all the time with free weights placed in the line of fiber direction to recruit muscle with simple cardinal plane motions. Attempting to recruit the multifidi requires the pulley line to be set in a vector that will recruit the muscle as an extensor, side bender and rotator. As
the pulley line comes from the opposite side of the axis of motion, resistance is set perpendicular to the fiber direction, rather than in line with the fiber direction, creating a natural recruitment emphasis of the lumbar multifidi during rotation.

**Figure 5.134**: Standing left cranial rotation with pulley resistance for right multifidus emphasis. The pulley line is set inferior and to the left to create a moment arm that naturally requires increase recruitment of the right multifidus muscles.

**Figure 5.135a,b**: Standing trunk rotation with pulley line adjusted for emphasis of the transverse abdominis. A pelvis high horizontal resistance is in line with the fibers of the transverse abdominis. The patient performs a cranial rotation moment fixating the pelvis and hips.

**Figure 5.136a,b**: Standing trunk rotation with pulley line adjusted for emphasis on the lower abdominals. The pulley is set posterior, inferior and to the right to emphasize the right internal obliquus and the left external obliquus. The transverse abdominis will still be recruited first as the initial tonic stabilizer.

**Figure 5.137a,b**: Sitting cranial rotation with posterior resistance through a bar. The patient is in sitting with a neutral lumbar spine. A bar is held anteriorly, attached to a pulley. Cranial rotation is performed while stabilizing the lumbar spine. The bar increases the lever arm, creating a greater torque moment through the shoulders and trunk.

**Figure 5.138a,b**: For all standing rotation exercises, pelvic stabilization through the lower limbs is required. If the patient cannot initially control the pelvis and lower limbs an external block with a pulley T-bar across the sacrum removes the stabilization requirement. Perch-sitting on a tall bench will also serve as an external stabilization, which also allows extension/rotation exercises facing the pulley. As coordination improves, the support for the pelvis is removed. A horizontal line of resistance will emphasize more transverse fiber directions of spinal muscles.

**Figure 5.139a,b**: Caudal rotation on a rotation plate. The patient is standing on a rotation plate, knees slightly flexed and the lumbar spine in neutral. The arms stabilize the
Joint Locking (Coupled Force Locking)
As discussed in Stage 1, joint locking utilizes coupled forces to lock spinal segments from motion with facet compression. With hypermobile segments, ligamentous locking (countercurve) techniques cannot be used, as taking up slack of collagen in hypermobile segments may cause additional tissue damage. The opposite direction of facet compression with coupled forces is the safe alternative. Joint locking techniques can be utilized in sitting, allowing a progression of tissue loading from side lying postures.

Rather than changing body position, an alternative progression might be changing the locking procedure to a less restrictive version requiring more demand on the patient to coordinate the movement safely. If the patient has developed adequate coordination, artificial and spinal locking may be removed with a progression to coordinative locking. For example, a hypermobility into right rotation of L5/S1 may have been locked into left rotation using coupled force locking during exercises. As a progression, the coupled force locking is removed, allowing the joint to participate in the exercise. Coordinative locking involves eccentric coordination of the trunk left rotators (oblique abdominals and right side multifidi) into right rotation. The patient controls the motion toward the pathological range. This concept may apply to exercises in lying, sitting or standing postures. This change in locking is an important progression and it is never necessary to retreat to artificial locking once coordinative locking has been achieved.

If a patient is ready to progress to Stage 2 but still lacks the necessary coordination, spinal or artificial locking may still be necessary, particularly if the patient does not have full pain free range of motion. If locking is needed in this stage, it is generally tolerated well in a weight bearing position. Below are examples of specific exercises using different locking techniques.
Ligamentous Locking (Counter Curve Locking)
With lower lumbar contraindications to exercise, using counter curve locking concepts may allow for a faster progression into more aggressive body positions or exercises. Counter curves may involve one plane of motion where opposite curves are performed caudal and cranial. Different planes of training can also be effective in locking motion; i.e., flexion in the lower lumbar spine while training rotation from above. Taking up collagen slack in flexion from below will reduce the available range for rotation coming from above.

Ligamentous locking is also practical for using one plane of motion to tighten and protect segments while training in another plane of motion. One example in the lumbar spine would be flexing from below, taking up collagen tension in the posterior elements (supraspinous and interspinous ligaments, ligamentum flavum, facet joint capsules). This tension would lock the spine from participating in other directions of movement, rotation for example. It may be necessary to palpate the spinous processes to assess segmental motion to ensure that the desired locking is taking place.

Figure 5.142: Flexion from below and extension from above. This example would suit the patient with a contraindication concerning extension in the lower lumbar and needing extension training in the upper lumbar segments. The patient is instructed to reach the elbows forward and up to initiate a cranial extension moment.

Figure 5.143: Performed as above without the bolster in the abdomen. This is a common home exercise version performed on a chair. The patient continues to perform a caudal-to-cranial motion with a caudal flexion counter-curve.

Figure 5.144a,b: Flexion from below by adducting the hips with knees together will provide ligamentous locking. To flex higher segments in the lumbar spine the feet can be placed on a stool to increase the degree of hip flexion and secondary lumbar flexion. Training from above into right or left rotation either from anterior or posterior resistance can be localized above the level of ligamentous locking.

Figure 5.145: Cranial rotation training in extension with lumbar locking with flexion from below. The degree of flexion from below can be controlled by the degree of hip flexion on the left in this example. The locking occurs with the counter curve of flexion from below, preventing the spine from participating in rotation from above.
Caudal coupled force locking techniques can be performed in standing, though they are much more difficult to design. The simplest version is to apply basic countercurves from below to facilitate motion or block motion. By standing with the feet staggered, one forward and one backward, a caudal rotation is created rotating the pelvis. This approach is only effective for the lower lumbar region. If this rotation matches the rotation from above, then motion is facilitated. This is used most commonly when trying to mobilize the full end range from above and below. If the caudal rotation is set opposite to that occurring from above, then there is a block of rotation at the lower lumbar segments.

With standing countercurve locking the easiest progression is to move the foot position gradually toward an even alignment of the feet, reducing the relative counter rotation from below. As the position moves toward a normal stance position, a greater demand is placed on the motor system for dynamic control of the motion. Stage 3 will attempt to remove all locking, other than coordinative locking, which by definition is dynamic motor control for stabilization.
Balance exercises can be progressed as necessary to return to a level of safety, or work to even more challenging levels, should the patient's functional demands require high end balance performance. The use of labile sitting surfaces for clinical exercise has been suggested (Manniche et al. 1991, Norris 1995). The use of a labile surface for balance training may be enough of an added challenge for previous Stage 1 exercises for bilateral and unilateral stance. Cervical motions or upper limb reach activities can also be performed with a labile surface. A labile sitting surface, such as a gym ball or air cushion, theoretically creates an increased challenge for muscles of lumbar stabilization.

The sitting position itself, however, removes the contributions of the hip joints and pelvis to overall lumbar mobility and stability. Standing requires a much greater demand than sitting on this complex system of muscles crossing the lumbopelvic region. O’Sullivan et al. (2006) demonstrated that labile sitting did not result in increased EMG activity of the lumbar multifidi, transverse fibers of the internal oblique and the iliocostalis lumborum. As sitting on a labile surface does not represent a functional requirement for most patients, and does not create a significant muscular challenge, it may not be the most efficient progression for stabilization training.

Standing may represent a greater functional challenge. Snijders et al. (1995) found that the activity for the internal oblique muscles is higher in sitting compared to lying supine, but standing activity was even greater. Standing may represent a more functional position, as well as a more natural posture for recruiting the tonic components of the abdominals for stabilization training. Standing on a labile surface does create a postural sway challenge, requiring synergistic action of the muscles of the lower limb, pelvis and lumbar spine to maintain a center of gravity. Not all labile surfaces emphasize the same things. Balance examples below outline variation is standing challenges for different emphasis of training.

Static balance training may be less functional than balance activities that include movement of the extremities. Upper extremity motions during balance training focuses the patient on extremity movements while postural reflexes function at a more subconscious level. Excessive bracing during standing balance activity is an abnormal motor response to instability. This can be monitored by palpating the lumbar multifidi during balance training activities. As arm motions move through
cardinal planes, the lumbar multifidi should contract as relax in response to different movement vectors. An abnormal response would be bilateral multifidi splinting throughout the activity.

**Figure 5.152a,b:** Frontal plane motion with pulse bar during heel-toe stance. The bar is moved back and forth in the frontal plane while balance is maintained. The feet may begin in a normal shoulder width position, progressing to the heel-toe position. A light wooden dowel, weight bar or pulse bar can be used. The pulse bar has rolling weights inside that roll to the end creating an end position thrust requiring more of a reactive response for lumbar stabilization.

**Figure 5.153a,b:** Transverse plane rotational motions with a pulse bar, feet in heel-toe position.

**Figure 5.154a,b:** Sagittal plane motions with a pulse bar, feet in shoulder width position.

**Aerobic Exercise**

Stage 2 is marked by a reduction in acute tissue pain, with improved tolerance to stress and strain. As soon as the back tolerates normal standing and walking, an aerobic component to rehabilitation should be added. Mannion et al. (2001) found low impact aerobics to be an effective intervention for chronic low back pain patients. Subjects had a better one-year follow up than patients treated with three months of standard physical therapy. Even aerobic leg cycling for people with chronic low back pain has been shown to reduce pressure pain perception for up to 30 minutes (Hoffman et al. 2005). Simple walking will provide a mechanical stress to the lumbar spine to improve general circulation, as well as build low-level endurance. Normalizing segmental mobility or hip mobility is a precursor to beginning an effective walking program. Limited hip extension will cause an excessive shear or torque at the L5/S1 juncture. In this case, walking may be an irritant and slow the rehabilitation process. Lamoth et al. (2004) found that induced pain and fear of pain have subtle effects on erector spinae EMG activity during walking. The global patterns of EMG activity and trunk kinematics were found to be unaffected. Arendt-Nielsen et al. (1996) demonstrated unilateral alterations in EMG activity in chronic low back pain patients, as well as controls in which...
pain was induced by bolus injection of 5 percent hypertonic saline. Musculoskeletal pain modulates motor performance during gait via reflex pathways. Altered gait observed in patients with low back pain is likely a complex evolved consequence of a lasting pain, rather than a simple immediate effect (Lamoth et al. 2004).

Walking should begin at a normal to slow speed, with normal stride length and arm swing. Swinging the arms is a natural counter balance that reduces forces across the lumbar spine. Holding on to hand rails on a treadmill can change this normal pattern and be less effective. Initially, holding on may be for safety purposes, which can be a necessary compromise. Pathologies that do not tolerate extension, or have pain with compression, should initially avoid down hill walking. Walking down hill biases the lumbar spine in extension and may aggravate these conditions. Conversely, using a slight incline on a treadmill may bias flexion, making a walking program more tolerable.

Walking may begin daily for as little as 10 minutes. Time can be increased as long as no adverse symptoms result. Increasing up to 20–30 minutes should be the goal, but may be progressed gradually over weeks. With poor coordination of the muscles for lumbar stability, or a poor training state, fatigue in the lumbar spine may occur during the walking program, but not be perceived by the patient. As muscles fatigue, greater forces are transmitted into the non-contractile tissues, which may irritate the primary tissue pathology. Any level of increased symptoms during walking, right after walking or the next morning are signs of too long a duration of training. When tissue tolerance allows, walking provides a multitude of positive stimuli to the lumbar spine. The act of walking provides a gentle pumping of lumbar and abdominal muscles to aid in the removal of waste products from guarded tissue. The facets joint cartilage can benefit from the compression/ decompression and gliding associated with rotation and slight flexion and extension. The non-contractile connective tissues, including the annular fibers of the disc can receive an optimal stimulus of modified tension to stimulate fibroblast activity and increased tissue strength.

The elliptical trainer is a common aerobic machine found in health clubs. This machine allows for the walking motion but removes impact forces by removing heel strike. This may be effective in allowing for training degenerative joint pathologies in the lower limbs. Some back patients may also perceive less irritation when using an elliptical trainer, versus normal walking. But by removing heel strike on the elliptical trainer, the normal forces that assist in recruiting muscles in the hip and lumbar spine during walking are reduced. This change in motor firing may aggravate the back patient, and it should not be assumed that the lower impact load from the elliptical is a better training environment than normal walking.

Section 3: Stage 3 Exercise Progression for the Lumbar Spine

Progression to Stage 3 concepts is again done one exercise at a time, as specific functional qualities are attained. By this time in the treatment cycle complaints of pain have been replaced with a more generalized discomfort, except possibly with excessive range or activity. Edema and muscle guarding have resolved with Stage 2 training. Full cardinal plane range of motion is a signal to move to Stage 3 concepts, with more aggressive full range diagonal patterns. The patient may still lack full active range of motion in more complex movement patterns but basic levels of recruitment, timing and coordination have normalized. Complaints usually relate more to an inability or limitation to activities of daily living, work duties or participating in sports. If joint restrictions were present at the beginning stages, they have normalized with an emphasis shifting toward stabilization. If the initial finding was of joint hypermobility than the progression focuses on dynamic stabilization through the full range of physiological motion.
As basic clinical signs and symptoms are resolving, Stage 3 focuses primarily on improving motor performance, elevating the training state and returning to normal functional activities. Resistance is increased to improve strength. Coordination may still be part of the training program, but this relates to more complex and functional patterns of movement. Eccentric concepts for dynamic stabilization can affect the design and work order of each exercise.

**Basic Outline: Stage 3 Hypomobility**
- Increase weight (60%–80% of 1RM), decrease repetitions (strength)
- Eccentric/Concentric exercises to stabilize new range
- Tri-planar motions in available range (PNF patterns)
- Isometrics to fix strength in gained range

**Dosage**
As strength training becomes more of an emphasis, resistance is increased with a subsequent reduction in repetitions. Though the initial focus for motor performance was on timing, coordination and endurance, studies have shown that patients with chronic low back pain have deficits in trunk strength (Addison and Schultz 1980, Brady et al. 1994, Kahanovitz et al. 1989, Mayer et al. 1985, Mayer et al. 1989, McNeill et al. 1980, Nachemson and Lindh 1969, Novy 1999, Smith 1985).

Emphasis of training remains on the posterior muscles, as the loss of extensor strength is greater than that of flexor strength (Addison and Schultz 1980, Kahanovitz et al. 1989, Mayer et al. 1989, McNeill 1980). Strengthening in Stage 3 should reflect a functional need of not only anterior and posterior trunk muscles, but also arm and leg strength as well.

**Isometric Stabilization**
Isometrics are used in Stage 3 into the hypermobile range. This allows higher dosages of strength to be utilized with lower coordinative demands. Isometric training may include the entire trunk with bracing activities, such as performing plank exercises or upper extremity weight training. Additionally, isometric work may specifically focus on the lumbar multifidi in vectors of instability for more segmentally specific stabilization training. This will help to fix strength and sensitize muscle spindles of the LM for greater dynamic stability.

**Tissue and Functional States- Stage 3**
- Full arthrokinematic and osteokinematic motion with cardinal planes
- Full weight bearing/loaded postures are tolerated
- Joint may be painful with excessive repetitions
- Edema has resolved
- Muscle guarding has resolved
- Palpation of primary tissues negative, provocation tests negative, trigger points may be positive to deep palpation
- Fair to good coordination in planar motions
- Fair to good balance/functional status
- May have reduced fast coordination, endurance, strength, power
The unilateral stance creates a cross pattern, or torsion, from the rib cage to the pelvis. To increase the torsional moment, the exercise can also be performed using only the opposite upper extremity.

The patient stands with a neutral lumbar spine, slightly flexed hips and knee. The bar is repeatedly pressed overhead at a fast rate, requiring quick responses from the lumbar spine to avoid an extension moment on the lift phase.

Performing the resisted elevation with one arm completes the cross pattern from the left foot to the right shoulder.

Figure 5.157a,b: Unilateral straight arm row with opposite unilateral stance, or toe-touch stance. Performing the resisted elevation with one arm completes the cross pattern from the left foot to the right shoulder.

Figure 5.158a,b: Shoulder flexion for lumbar stabilization training, unilateral stance position. Lifting the opposite arm will facilitate a diagonal cross pattern for training the stance leg gluteals, cross over to the opposite side multifidi to the opposite shoulder. Lifting the ipsilateral arm (left arm pictured) will be more challenging to the non-stance leg, as synergistic action of the gluteals does not assist the lumbar multifidi in stabilizing the pelvis.

Figure 5.159: Unilateral standing lat pull for lumbar stabilization, as a progression from bilateral stance. The patient is standing with the lumbar spine in neutral with the stance knee slightly flexed. Starting with the pull down bar on the thighs, the bar is raised to shoulder height and returned. The lumbar spine is held in neutral by the abdominals, avoiding the extension moment at the top position of the bar.

The patient stands with a neutral lumbar spine, slightly flexed hips and knee. The bar is repeatedly pressed overhead at a fast rate, requiring quick responses from the lumbar spine to avoid an extension moment on the lift phase.

Figure 5.160: Ballistic military press for lumbar stabilization.

Figure 5.161: Lateral plank, straight arm with the addition of hip abduction.

Figure 5.162: Prone plank stabilization can be progressed by lifting one hand, lifting one foot, reaching forward or lateral,
Eccentric Stabilization

Stabilization should not be considered an isometric performance of holding a joint position, but a dynamic performance of controlling the joint’s instantaneous axis of motion through full range of motion. Movement toward a direction of instability is controlled with agonists and antagonists working in synergy. The agonists perform concentrically, moving the body part toward the pathological range, while the antagonist decelerates the motion eccentrically in preparation for a concentric return. Emphasis is placed on training this eccentric function to decelerate motion by changing the work order. Concentric to eccentric performance is switched to eccentric to concentric performance. The joint is positioned away from the direction of pathology, moving eccentrically first toward the pathology and then concentrically back to the start position. There should be no pause between the transition from eccentric to concentric work. As a plyometric performance, as in jump training, the stretch shortening cycle is utilized with a quick transition between eccentric and concentric work.

The most basic application of this concept is the simple hack squat motion. The exercise begins from a neutral standing position. A squat motion is performed, involving eccentric deceleration into flexion controlled by the posterior lumbar multifidus and erector spinae. At the end of the squat motion, a quick transition of concentric work is made with a return to the neutral starting position. This is a simple sagittal plane version of this concept. This concept of changing the work order moving toward the pathology can be applied to any plane of dysfunction and progress to combined planes with PNF diagonal patterns or more functional patterns.
followed by a quick acceleration back toward the right rotated start position.

Figure 5.166a,b,c: Eccentric stabilization training for flexion right rotation stabilization, emphasizing the right LM. The start position is extension and left rotation (relatively shortened position of the right LM), opposite of the pathological range. Eccentric deceleration is performed toward flexion and right rotation, but not into the pathological or painful range, followed by a concentric return to extension and left rotation. The transition from eccentric to concentric work should occur without a pause.

Figure 5.167a,b,c: Eccentric stabilization training for extension right rotation stabilization, emphasizing anterior abdominal muscles and the right LM. The start position is in flexion left rotation, opposite of the pathological range. Eccentric deceleration is performed toward extension and right rotation followed by a concentric return to extension and left rotation. The transition from eccentric to concentric work should occur without a pause.

Figure 5.168: Cranial trunk rotation with a weight bar for eccentric stabilization training of a left rotation hypermobility. The trunk starts in a right rotated position accelerating toward left rotation. Eccentric deceleration to the left is

Figure 5.169a,b: Plyoball toss for rotational stabilization training, eccentric emphasis. The patient stands lateral to a rebounder tossing the ball into a left rotation pattern. The ball is caught away from the body with outstretched arms requiring an eccentric deceleration toward right rotation (hypermobility in right rotation). The patient is instructed to catch the ball stabilizing the lumbar spine and pelvis from excessive right rotation. The concept can be performed in multiple patterns, following the pattern of instability.

Figure 5.170a,b: Sitting eccentric stabilization training for left rotation with a weight bar. The trunk starts in a right rotated position accelerating toward left rotation. Eccentric deceleration to the right is followed by a quick acceleration back toward the right rotated start position.
Motions and Directions

General back strengthening and conditioning offers any number of exercise options. The main emphasis should be to get off the floor and focus more on functional exercises and motions that address the individual’s needs. Direction of training may be specific, as in the case of stabilization training for hypermobility/instability, or may involve general conditioning. Increased resistance, with increased body position challenges and range of motion increases, make Stage 3 training more difficult but more functionally beneficial.
Figure 5.178: Step lunge with overhead stabilization. The patient stands with the lumbar spine in neutral and a posterior resistance in both hands from a pulley or elastic resistance. An anterior fall out lunge is performed while maintaining a neutral lumbar spine. This exercise is an aggressive challenge to the lower abdominals to prevent the extension moment created by the resistance. The fall out lunge position also creates a challenge to the spinal extensors, and posterior hip muscles on the forward leg, to hold the position against gravity.

Flexion

Figure 5.177: Caudal flexion, incline board. Stabilization through the arms will improve abdominal facilitation. A roll under the sacrum to bias flexion is not always necessary, but serves to assist the eccentric control of lordosis when lowering the legs. As coordination and strength improve, the roll can be removed. The work order emphasizes eccentric work followed by concentric work.

Figure 5.180a,b: The anterior lunge with upper reach using free weights. Again, emphasis of the movement is the right
hip muscles and posterior trunk. The anterior reach creates a greater extension moment, increasing the stabilizing demand on the low back and hip extensors. Performing the motion with only the opposite arm reaching forward (pictured) will also introduce a rotary moment requiring increased recruitment of the deep external rotators of the right hip, as well as the rotary components of the abdominals.

Side Bending
Basic lumbar side bending training can be performed standing with active side bending. The patient is standing with a neutral lumbar spine and the knee slightly flexed. A dumbbell is held at the side for resistance to the contralateral muscles of side bending. To emphasize mobility to the same side, the opposite arm rests at the side. To emphasize lengthening soft tissues on the opposite side, including fascial tightness in the latissimus dorsi, the hand is placed behind the head.

Figure 5.181a,b: Cranial side bending. Cranial side bending is progressed from vertical and incline to the most challenging position in horizontal.

Figure 5.182: Lateral lunge. This exercise dose not directly challenge lumbar side bending, but does train lateral hip strength. Improved lateral hip stability will assist stabilization of the pelvis in the frontal plane. Free weight and arm motions can be added for additional challenge.

Rotation

Figure 5.183a,b: Standing caudal right rotation (relative to cranial segment) with the rotation plate. The patient stands with the lumbar spine in neutral, slight flexion at the hip and knees. The shoulders are stabilized through the arm preventing upper trunk motion. The movement is initiated at the lumbar spine, not at the ankles.

Figure 5.184a,b: Caudal hip rotation can be progressed with an upper quarter weight moving in opposite direction of the knees. The leg is crossed over to increase the resistance by moving weight laterally. An additional challenge can be added by holding both feet off the ground while performing the exercise.

Figure 5.185: Standing right rotation with bar attached to pulley. Using a bar attachment increases the lever arm to increase the challenge for lumbar stabilization, as well as increase erector spinae recruitment in the thoracic spine. Eccentric emphasis continues by starting in full right rotation, decelerating into left rotation, followed by concentric return to the right.
Removal of Locking

By Stage 3 all coupled force locking, counter curve locking and artificial locking are removed. Emphasis is on coordinative locking; the patient dynamically controls the exercise without going into the painful or pathological range. Standing locking exercises performed in Stage 2, with a staggered foot stance to create caudal locking, are progressed by removing locking with a parallel foot stance requiring dynamic control.

Functional Balance Training

By Stage 3 the patient should have already achieved significant improvement in balance activities for basic activities of daily living. Should a higher level of balance be required for sport performance, continued balance challenges can be added. Performing all previous exercises with labile surfaces, eyes closed or both can provide a significant challenge. A balance component may be added to a previous exercise or movement pattern. For example, a hack squat could be performed for lifting training, but rather than standing on the floor, the feet may be on a labile surface. Lunges may be changed to have the foot land on a labile surface, rather than the floor. These challenges can be changed with each set of a three set exercise, having a variation in demand to reduce the monotony of the exercise. A balance challenge will reduce the ability to use a heavier load. If the real goal is strengthening for activities such as squatting or lunging, then a firm surface with heavier weights is a better functional choice.
Figure 5.189a,b: Catch and throw activities on a labile surface (BOSU). The patient stands on a labile surface while performing reactive exercises, i.e., catching and throwing a ball. Concentration on the activity focuses attention off the balance requirement of the exercise, attempting to train postural reflexes for lumbar and lower extremity stability.

Functional Exercises

Continuing the progression of more complex movement patterns, exercises should begin to duplicate more required functional tasks, work or sport performance. Issues of work order, speed and range of training may not be as relevant as training normal motion. Exercises can be customized to mimic specific work related tasks, such as lifting, pushing or pulling. More sport specific exercises may begin with functional patterns related to the sport performance, with eventual progression to sport simulation.

Figure 5.190a,b: Crate lifting. Functional lifting patterns for job requirements can be trained with free weights or crate lifting. The patient is instructed in proper lower extremity use for lifting, including flexing at the knees and hips. Depending upon the lifting pattern being utilized, emphasis may also be on pivoting through the feet and lower extremities, as opposed to twisting through the trunk. Previous training may emphasize on the squat and pivot prior to adding lifting.

Figure 5.191a,b: Diagonal patterns—50% range. As a progression from horizontal rotation to full diagonal lifting patterns, the pulley bracket can be lowered to knee height. The diagonal pattern is performed through half the range of motion. Emphasis may be placed on proper weight shifting, maintaining foot (left) pronation during the initial push-off, lifting with the hips and following through with the arms. As coordination is achieved, the bracket can be gradually lowered to floor level for full range of motion training.

Figure 5.192: Functional pushing motions with isometric lumbar stabilization using a double pulley. Work simulation for pushing motions can be performed with stabilization through the lower limbs or while walking forward, as in pushing a cart.

Figure 5.193: Functional pulling motions with isometric lumbar stabilization using a double pulley. Work simulation for pulling motions can be performed with stabilization through the lower limbs or while walking backward, as in pulling a cart.
Figure 5.194: Standing elastic rowing. Elastic resistance may be used for home training of functional pulling or pushing motions with isometric lumbar stabilization.

Figure 5.195: Deep squat and lift with pulley or cable system. The patient is instructed to maintain a neutral lumbar spine while performing a deep squat and anterior reach toward the pulley. Returning to a standing position is initiated with hip and knee extension, not trunk extension.

Figure 5.196a,b: Anterior lunge with anterolateral reach using free weights. The patient performs a fallout lunge, with the back knee extended, heel on the ground and trunk in line with the back leg. Free weights are lifted anterior to challenge the extensors and then rotated out laterally to provide a rotary challenge to the trunk and right hip.

Figure 5.197: Anterior fallout lunge with trunk left rotation – with a weight bar.

Exercise Classes

Stage 3 is marked by resolution of acute pain, improved tissue tolerance, normalization of range of motion and joint mobility. Coordination of basic movement patterns have been established, so training goals focus on more advanced stabilization and improving general conditioning. Exercises are transitioned into more functional movements. Patients may have worked through Stages 1 and 2 to be ready for Stage 3 concepts. Chronic back pain patients may begin therapy already at this level of function, and can bypass some of the early training concepts and move into more of a general conditioning program for the low back. Utilizing an exercise class or circuit program provides a group training environment in which several patients can be trained at the same time. Klaber Moffett et al. (1999) found the exercise class setting to be clinically effective and have better outcomes than traditional general physician management. The program was also more cost effective. Soukup et al. (1999) used the Mensendieck approach from Scandinavia that combines exercises and education in the prevention of low back pain. The program taught the participants ergonomic principles for movements of daily activities and improved their knowledge related to prevention of low back pain. The group setting is ideal for education issues in which a group can be trained at the same time, and benefit from each other in the learning process. Yoga has also been shown to improve function.
and reduce chronic low back pain, with benefits persisting for at least several months (Sherman et al. 2005). This study, however, compared yoga to a self-care book rather than a more specific lumbar rehabilitative program. Galantino et al. (2004) performed a controlled trial of Yoga reported improvements in flexibility, balance and disability, though findings were not statistically significant.

Physical therapy treatment involves more specific education and exercise training than general exercise classes. Biomechanical deficits and abnormal movement patterns are not best solved in generalized training programs. But once these clinical findings are resolved with specific manual and active training, the patient can be progressed into a more generalized exercise program that is consistent with their long term goals, time commitments, convenience and personal interest.

Section 4: Stage 4
Exercise Progression for the Lumbar Spine

Stage 4 is defined by resolution of primary clinical signs and symptoms. The patient has achieved full mobility and coordination with dynamic stability. Exercises include coordination of tonic and phasic muscle systems working in synergy through the entire range of motion around a physiological axis. Emphasis is on elevation of the overall training state, improving endurance and strength. Higher end power training may be necessary for more athletic goals.

Tissue and Functional States - Stage 4
- Full active and passive range of motion
- Pain free joint motion with exercise
- Good coordination
- Limitations in endurance and strength with functional performance

Resistance
Training for endurance and strength should be no less than 75% of 1RM, and up to 90% of 1RM for athletes. Increasing resistance is not only a factor of muscle performance, but must also consider tissue tolerance. Collagen and cartilage can take up to a year or longer to fully repair. Excessive loading early during rehabilitation may be tolerated by the motor system, but the underlying tissues may not yet be ready for high compression and/or tension associated with heavy resistance training. As weight is initially increased, speed may decrease slightly to allow for coordination at the new level of resistance. As performance improves, speed will naturally increase, as seen in earlier stages marking improved coordination. Higher resistance will increase the level of tissue stress and strain, further improving the tissue tolerance with more functional activities. Higher loads will also increase hypertrophy of muscle, making more permanent changes in strength and performance.

Basic Outline Stage 4
- Tri-planar motion through full range of motion around the physiological axis (coordination, endurance, strength, hypertrophy).
- Endurance, speed, hypertrophy, strength and power—80% of 1RM.
- Functional exercises and retraining for activities of daily living, sport and job activities.

Motions and Directions
In Stage 4 the exercises are functional and task specific. The long-term goals of the patient will determine the types of exercises in this stage. Long-term goals for return to activities of daily living, work or sport should predetermine the type of movements that should be trained by Stage 3. Similar patterns should already have been added in Stage 3 with a simplified form through reducing normal range of motion, speed, resistance or planes of motion involved. If the end goal is be able to
pick up the newspaper in the morning without needing to call the neighbor for assistance, you can imagine the Stage 4 exercises would look different than for someone returning to work lifting in a warehouse or performing pole vaulting.

All directions should be worked with coordination of concentric and eccentric contractions of tonic (arthrokinematic) and phasic (osteokinematic) muscle groups through the entire functional range of motion. Higher-level training should emphasize functional tasks but also address the key elements for the long term stabilization needs of the individual. One “best” exercise does not exist, but should be matched to the initial tissue injury and motor control issues.

Strength Training
As with all functional qualities, strength training is a function of dosage and not related to a particular set of exercises. Resistance is increased to 80% 1RM or greater with a reduction in repetitions. Exercises in this stage should involve multiple large muscle groups through greater ranges of motion. Increased time of rest breaks may be necessary for proper muscle recovery between sets, from up to one minute or greater.
Figure 5.205: End stage training caudal flexion on an incline board. The arms are fixated as the hips are flexed to a vertical position, performed with a smooth transition from hip flexors to lower abdominals. With the thighs in a vertical position, the back is extended lifting the knees toward the ceiling and then lowering the pelvic back down on the board.

Functional Movement Patterns

More functional and global patterns are necessary when returning to higher-level jobs and athletic activity. If the spine is not challenged to full range functional patterns, the patient is at risk of re-injury when returning to these activities. The tissues involved require progressive stress and strain through the functional ranges in which they will be challenged. The motor system requires a training progression to establish coordination through the full range of motion around a physiological axis. As this is achieved, progressive training involves strength training to elevate the training level to above the initial level that the patient was injured.
Figure 5.207: Pushing exercise as above with a double pulley, sport cord or elastic resistance. Elastic resistance will increase the challenge with an increasing resistance toward the end of the motion.

Figure 5.208: Changing the angle of the arms and the vector of pulley to above the head will increase the length of the lever arm from the resistance to the lumbar spine. This arm position creates greater involvement of the pectoral and upper abdominal muscles.

Figure 5.209: Functional pulling exercise for lumbar stabilization training. A speed pulley with two lines attached to a bar, allowing for functional simulation of pulling while walking backward. The lumbar spine is maintained in neutral throughout the performance, avoiding a flexion moment in the trunk or at the hips.

Figure 5.210a,b: Unilateral squat lift with trunk rotation. A further challenge for the squat lift motion is to perform the exercise unilaterally with rotation of the trunk.

Figure 5.211: Decline shoulder flys. The patient is standing with the trunk flexed forward at the hips, with the lumbar spine in neutral. Free weights are lifted out to the side.

Figure 5.212: Full diagonal patterns from extension and right rotation pattern of the trunk. Emphasis is placed on maintaining the left foot in neutral or pronation to allow for push off with the left lower limb during the lifting moment. Allowing the left heel to roll into supination while bending and reaching to the left does not allow the lower leg to push off, increasing the torque moment on the low back.
5. Exercise for the Lumbar Spine

**Figure 5.213a,b:** Full diagonal trunk pattern from extension and left rotation to flexion and right rotation. Emphasis is on pivoting through the hip joints to minimize the amount of motion in the lower lumbar spine.

**Figure 5.214a,b:** Trunk diagonal pattern of extension and right rotation with bilateral stance and unilateral left arm motion resisted by a pulley. The full range diagonal pattern can be performed through one upper extremity to increase the rotary torque through the trunk and to assist with load transfer through the shoulder to the pelvis. This pattern will emphasize anterior abdominal strength for trunk rotation.

**Figure 5.215a,b:** Trunk diagonal pattern with right unilateral stance and unilateral right arm motion resisted by a pulley. Unilateral stance will further challenge balance and stabilization from the lower extremity and pelvis through the lumbar spine to the shoulder. The right arm diagonal pattern will emphasize posterior muscles of the trunk and deep hip external rotators of the left lower extremity.

**Figure 5.216a,b:** Trunk diagonal pattern into flexion and right rotation, bilateral stance and unilateral left arm motion resisted by a pulley. Anterior abdominal and hip flexor muscles are emphasized, with force transfer from the shoulder into the trunk.

**Figure 5.217a,b:** Trunk diagonal pattern into flexion and right rotation, bilateral stance and unilateral right arm motion resisted by a pulley. The arm pattern emphasizes posterior lumbar muscles for rotation, while the flexion pattern emphasizes anterior abdominals and hip flexors.

**Figure 5.218a,b:** “Push-me, Pull-me’s” synergistic right trunk rotation multiple resistance. The patient is standing with the lumbar spine in neutral and the hips and knees slightly flexed. The left arm pushes forward as the right arm pulls backward. The trunk is allowed to rotate during the motion.
Exercise Post Treatment

Regular exercise after outpatient active treatment is related to better outcome in the long-term regarding both the recurrence of chronic low back pain and work absenteeism (Taimela et al. 2000). For chronic low back pain, benefit from a home training program have been shown to be as effective as the supervised dynamic strength muscle training program, yielded lasting improvement after at least one year of adherence. The adherence rates, however, were much better when the training was supervised at the start (Bentsen et al. 1997). Ljunggren et al. (1997) found no difference in sick leave comparing one year of supervised physical therapy exercise with a home exercise program. The home program however, did involve an initial training phase with physical therapy, a follow-up visit every six weeks to adjust the program and two telephone follow-ups. Motivation and program adherence can be enhanced by clinical visits, but the frequency of treatment can certainly be reduced, with emphasis on independent long-term training.

Figure 5.219a,b: "Pull and Punch". The patient pulls back with the right hand while punching forward with the left. Weight is transferred to the front foot during the movement.

Figure 5.220: Fallout lunge with barbell resistance. The fallout lunge is performed as previously described, with the back knee straight and the trunk flexed forward at the hips. A weight bar is placed on the shoulders to add resistance for strength training.

Figure 5.221a,b: Shoulder dead lift. The patient is standing with a neutral spine and a bar on the shoulders. The lumbar spine remains in neutral as the pelvis is flexed forward at the hip joints. The knees remain slightly flexed. This is an aggressive strengthening exercise for the hamstrings, hip extensors and lumbar spine.