

REHAB SUMMIT



CROSS COUNTRY
EDUCATION

Athletic Rehab Institute Presents

Kinetic Chain Recruitment
Lower Extremity Stabilization

FUNCTIONAL REHABILITATION

- Mobility – range of motion
- Recruitment – neuromuscular control
- Stabilization – tri-plane functionality

Three Phases of Rehabilitation

- Pre-functional – Mobility
- Return to Function – Recruitment
- Return to Activity – Tri-Plane Stabilization

*Orthopedic
Kellomäki
Institute*

Evidence-Based Practice (EBP)

- A method of integrating clinical expertise with the best available evidence from clinical research to make decisions about the care of individual patients

Reference: Harrison AD. An Evidence-Based Approach for Patients with Patellofemoral-Pain Syndrome. ATT 11(2), 2006 6-10

Cleland J., Noteboom J., Whitman J., Allison S. A Primer on Selected Aspects of Evidence-Based Practice Relating to Questions of Treatment, Part I: Asking Questions, Finding Evidence, and Determining Validity. J Orthop Sports Phys Ther 2008;38(8):476-484

Levels of EBP

- Research report or original research with systematic reviews
- Case-control studies or reports
- Expert opinions leads to clinical commentary
- Application = Therapeutic Value

Open Kinetic Chain

Open Kinetic Chain	Clinical Definition
<p>The distal segment is free to move in space and may produce an unpredictable movement pattern.</p>	<p>The foot is free with motion of the knee occurring independently of the hip and ankle in an unpredictable movement pattern. Examples include knee extensions and hamstring curls.</p>

Reference: Steindler and DeCarlo, M.

Considerations for Single Plane Movement Patterns

- Protective ROM of Compression
- Soft Tissue Protection for Time Constraints of Healing
- Angle of Recruitment

Closed Kinetic Chain

Closed Kinetic Chain	Clinical Definition
<p>The distal segment is fixed within the kinetic system and will produce a predictable pattern of motion.</p>	<p>The foot is fixed with motion at the knee accompanied by motion at the hip and ankle occurring in a predictable movement pattern. Examples include leg press, squats, and step-ups.</p>

Reference: Steindler and DeCarlo, M.

A Comparison Between Open and Closed Chain Rehabilitation

Open		Closed
Free	End Segment	Fixed
Mostly Concentric	Muscle	Eccentric, Concentric
Confused	Gravity	Used
Single	Planes	Tri-Plane
Non-Functional	Exercise	Functional
Lab-Like	Feel	Life-Like
Distal to the Joint	Motion	Both Proximal and Distal

Reference: Gray, G.: Chain Reaction Seminars

What is True Closed Kinetic Chain?

- Distal segment meets considerable external resistance that restrains free motion
- Original engineering definition involved fixtures of both the proximal and distal ends of the kinetic link system
(Steindler, 1955)
- True closed kinetic chain movement patterns do not technically exist in the human body. Except in isometric exercises where no movement of the proximal or distal segments occurs.
- ***Clinical Definition: Exercise Remains Fixed distally***

References: Dillman, et al. 1994; Palmitier, et al. 1991; Rivera 1994; Ellenbecker & Davies 2001

Lower Extremity CKC Exercise Facilitates Functional Movement Patterns - EMG Based Co-Contraction

- Multi-planer isometric, concentric, and eccentric contraction
- Produces a co-contraction of the quadriceps and hamstrings
- Contributes to reduced shear forces
- Promoting Concurrent Shifts – Simultaneous Con/ECC Contraction at opposite ends of muscle.

*Reference: DeCarlo M, Porter D, Gehlsen G, Bahamonde R.
Electromyographic and Cinematographic Analysis of the Lower Extremity
During Closed and Open Kinetic Chain Exercise. Isokinetics and Exercise
Science. 2(1), 1992 24-29.*

OKC vs. CKC EMG

- A comparison of Quadriceps muscle activity during Open Kinetic Chain vs. Closed Kinetic Chain Exercises
 - Quadriceps EMG Activity – Isometric Contraction at 30°, 60°, and 90°
 - Results: OKC at 30°
 - Results: CKC at 60° - 90°

Reference:

*Campolo, M., Clements, C., Bakatsias, S., Robustelli, F., Skripak, R.
Poster Presentation APTA PT 2005, Boston*

Set-up For True CKC

Calcaneal Control

“Heel to big toe concept”

Clinical Application of True CKC Loading

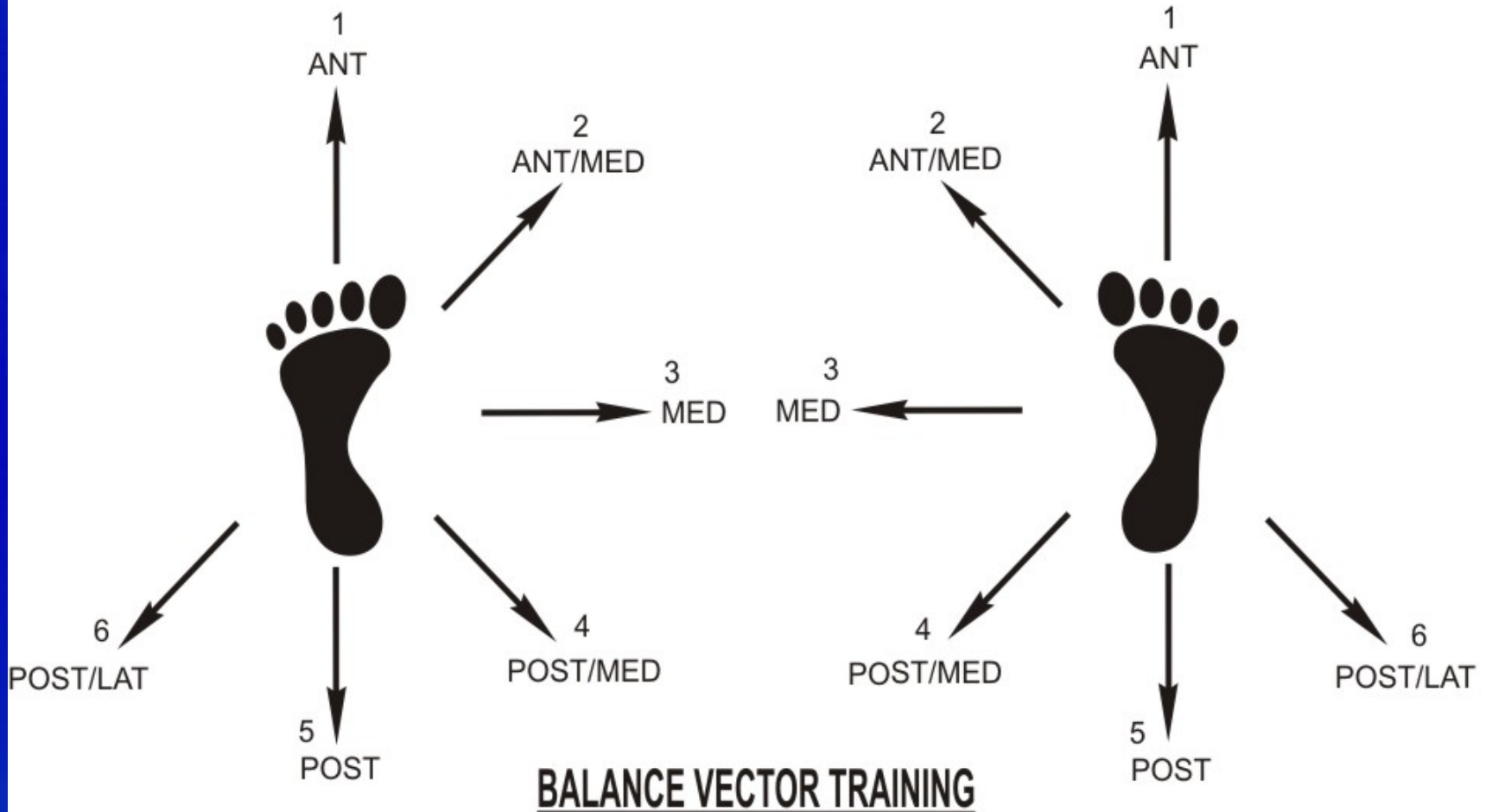
- Standing Terminal Extension – STE
- Leg press – total gym – distal end fixed
- Squat movements – mini squats with balance
- Step-ups – lateral & retro
- Plyo-toss on level surface
- Static – hold lunge – squat lunge
- Wall slides

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Heel to Toe Mini Squat

Sagittal Plane 1-5
Transverse Plane 2-4-6
Frontal Plane 3

5 seconds
5 reps
3 planes



Electromyographic Analysis of Single Leg Closed Chain Exercises: Thigh Muscles

- One-legged squat 66% MVIC
- Step-ups 50% MVIC
- Concentric activation was not significant at the moment arm angle of 90°, 60° or 30° for either squats or step-ups.
- Eccentric quadriceps activation was greater at 30° for step-ups and 90° from the squats
- Not significantly different at 60° of knee flexion
- Hamstrings activation was 74° MVIC for squats and 59° MVIC for step-ups.
- Therapeutic value for use of lateral and forward step-ups is supported

Functional Lower Extremity Exercises

Not True Closed Kinetic Chain

- Balance Board
- BOSU Assisted to unassisted
- Balance vectors on uneven surfaces – Balance pad
- Steppers & elliptical machines
- Plyo-toss on balance pad and BOSU
- Squats on uneven surfaces
- Dynamic lunges
- Fitter – slide boards, versa climber
- Leg press machines that distal platform moves

Proprioception

- The perception of joint and body movement as well as position of the body or body segments in space (*Sherrington, 1906*)
- Proprioception refers to position sense and movement sense arising from joint mechanoreceptors

References: Hiemstra, Lo, Fowler 2001; Beard, Dodd, Trundle 1994

Clinical Outcome Principles of Using CKC Loading

- Functional Recruitment
 - Co-contraction
- Improved proprioception
- End product of training
 - Tri-plane joint stabilization

Vital Five Program – CKC Function

- Mini squats – single plane → Co-contraction
- Balance vectors – tri-plane → proprioception
- Leg press – double to single leg → recruitment
- Lateral step-ups → quadriceps dominant
- Squats on uneven surface → preturbation

Neuromuscular Activation with Heavy Resistance Exercises

- Strength adaptations – 40% to 95% of maximum intensity (*Fry 2004*)
- Generally agreed intensities of at least 60% for strength gains (*Kraemer, et al. 2002*)
- Study includes: EMG Based Data
 - Quadriceps setting
 - Manual lateralization of patella
 - Rhythmic stabilization
 - Pelvic Bridging
 - Heavy Resistance exercise
 - Squats with weights
 - Horizontal leg press
 - Isolated knee extension

Neuromuscular Activation with Heavy Resistance Exercises

- Results: EMG activity was greatest for open kinetic chain leg extension
- Ranking of the exercises based on EMG amplitudes
 1. Leg Extensions
 2. Leg Press
 3. Squat
 4. Quadriceps Setting

Muscle Recruitment Based on EMG Values

- Hamstrings
 - Highest EMG value with open chain curls
 - Co-contraction – squats and leg press were similar in value
 - Pelvic bridging also indicated co-activation of acceptable value
- Gluteus Maximus
 - Highest EMG value in squat & leg press
 - Moderate EMG value in pelvic bridging exercise
- OKC – high EMG values
 - Leg extension (quadriceps)
 - Leg Flexion (hamstrings)
- CKC – high EMG values
 - Squat
 - Leg Press

Electromyographic Analysis – Surface EMG that Scored 40% MVIC or Higher

- Core muscles: Lumbar Multifidus, External Oblique, Rectus Abdominus
 - Side-bridge
 - Prone bridge
 - Unilateral bridge
 - Bridge
- Hip muscles: Gluteus Medius, Gluteus Maximus
 - Side bridge
 - Unilateral bridge
 - Lateral step-up
 - Quadricep UE/LE lift

Electromyographic Analysis – Surface EMG that Scored 40% MVIC or Higher

- Thigh Muscle: Vastus Medialis Obliquus (VMO), Hamstrings
 - Lateral step-up (VMO)
 - Lunge (VMO)
 - Unilateral bridge (Hamstrings)
 - Quadricep UE/LE lift (Hamstrings)

Electromyographical Analysis of Lower Extremity During Unilateral Weight-bearing Exercises

- Exercises that were tested
 - Unilateral wall squat
 - Unilateral mini-squat
 - Forward step-up
 - Lateral Step-up
- Muscles tested
 - Gluteus Maximus
 - Gluteus Medius
 - VMO
 - Biceps Femoris - Hamstrings

Electromyographical Analysis of Lower Extremity During Unilateral Weight-bearing Exercises

- Results:
 - All muscles recorded acceptable levels of activation above 45% (range 37% to 86%) for these closed kinetic chain exercises.
 - Biceps Femoris scored the lowest activation with less than 20%
 - Highest activation % for all exercises was the wall squat

References: Ayotte, Stetts, Keenan, Greenway 2007

Patella Femoral Stabilization

Functional Exercise Progression

- Historical issues concerning rehabilitation
- Open kinetic chain
- Closed kinetic chain
- Functional progression

Patella – Femoral Syndrome

- Anterior Knee Pain
- Patella – Mal-Alignment Syndrome
- Lateral Patellar Compression
- Patella – Femoral Pain syndrome (PFPS)
- Patella-Femoral Dysfunction Syndrome (PFDS)
- Chondromalacia

Historical Factors Affecting Patella-Femoral Rehab

- Neuromuscular Control
 - VMO Insufficiency
 - VMO Insertion angle 55 deg.
 - VMO action through ROM
- Tight Lateral and Posterior Structures
- Q-Angle/Joint Geometry
 - Males = 12 degrees
 - Females = 15 degrees
- Patella Posture
- Hip – core weakness

Reference: Wilson, T. The Measurement of Patella Alignment in Patella Femoral Pain Syndrome: Are We Confusing Assumptions With Evidence: J Orthop Sports Phys Ther 2007, 37(6): 330-341.

Current EBP Treatment Recommendation

- Quadriceps recruitment
- Hamstrings over quadriceps co-contraction
- Strengthening of hip musculature
- Manual therapy
- Taping – bracing for decompression
- Foot orthotics

Kinetic Chain Recruitment – Summary (PF)

Open Kinetic Chain

- Co-contraction – hamstrings over quadriceps – decompression
- Standing/side-lying hip strengthening (Abductors for core)
- Quad set (+) – high level VMO recruitment
- Low angle terminal extension $15^{\circ} \rightarrow 0^{\circ}$
- Short arc quads $90^{\circ} \rightarrow 45^{\circ}$ – flexion movement arm protection

Knee Version

Version of the knee is determined by measuring the angle between the line joining the posterior tibial condyles and the line joining the posterior femoral condyles on the CT scan of the knee in full Extension.

Static Rotation of the tibia with respect to the femur in extension (Version of the knee)

Patients with Anterior Knee Pain

- Increase in External Rotation of the tibia 7° compared to 1° (Asymptomatic)
- External Rotation causes lateral pulled patella - Compression Syndrome
- External Rotation will translate the tubercle 5 to 10 mm laterally , increasing the Q angle.

Clinical Relevance

- Strengthening the medial hamstrings
internal tibial rotators, semimembranosus,
semitendoninosus, satorius
- Hamstrings stretching – Biceps Femoris,
Iliotibial band, lateral Retinaculum

Exercise Application

- Functional Hamstrings Lengthening with medial rotation of the femur
- Co-Contraction of the Hamstrings over the Quads with minimal flexion moment angle.

Reference:

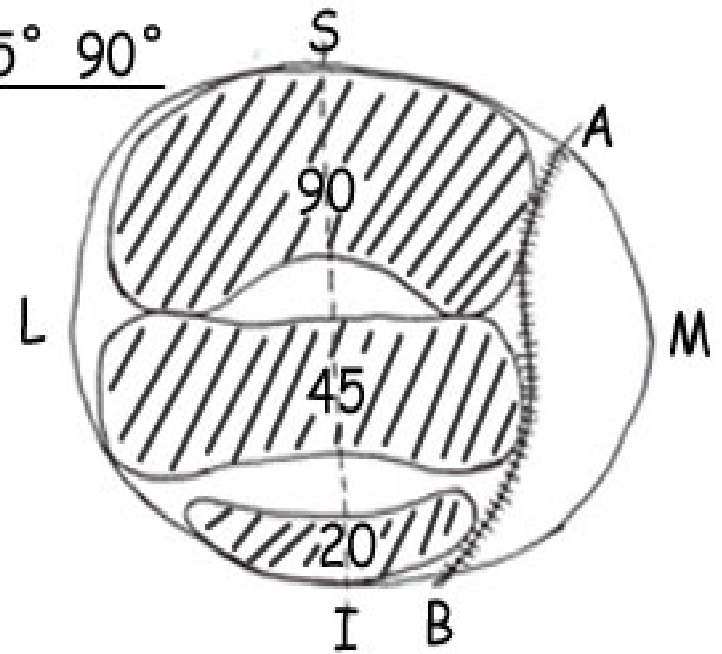
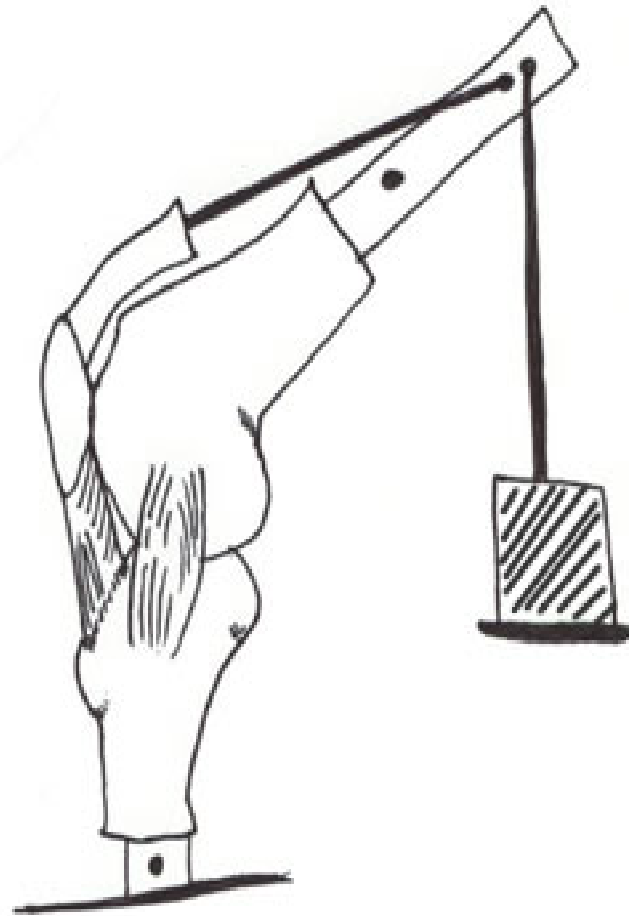
Eckhoff DG, Brown AW, Kilcoyne RF, Stamm ER. Knee version associated with anterior knee pain. Clin orthop 339 : 152-155, 1997.

VMO:VL EMG Ratio Arc Of Motion

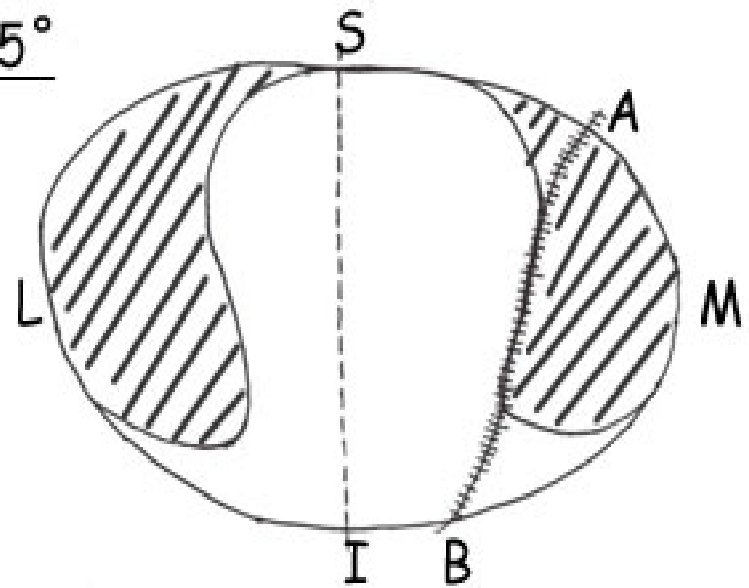
- 60 – 85 degree are greater than 35 – 60 degree
- 60 – 85 degree are greater than 10 – 35 degree
- 35 – 60 degree are greater than 10 – 35 degree

Reference: Szczepanski, TL, Gross, MT, Duncan PW, Chandler JM: Effect of Contraction Type, Angular Velocity, And Arc of Motion on VMO = VL EMG Ratio. JOSPT 14: 256-262, 1991.

20° 45° 90°



135°



Contact areas on the Patella as a function of Knee Flexion

- Inferior Pole - $20^\circ \rightarrow 0^\circ$
- Central Medial and Central Lateral Poles
 $45^\circ \rightarrow 20^\circ$
- Superior Medial and Superior Lateral Poles
 $90^\circ \rightarrow 45^\circ$

Reference:

Goodfellow J, Hungerford DS, Zindel M : Patellofemoral joint mechanics and pathology. J. Bone Joint Surg 588(3) : 287-290, 1976

PF Pain - LE Biomechanics

- “under weight bearing conditions it appears the femur is rotating up underneath the Patella”
 - *Christopher M Powers, PhD, PT*
- “The difference in knee internal rotation wasn’t coming from the tibia, but from the femur”
 - *Tracy Dierks, PhD*
- “Hip strength deficit”
 - *Nicholas Institute of Sports Medicine and Athletic Trauma*
- “Internal rotation of the femur and pelvis contributes to patello-femoral pain”
 - *Ron Hruska, PT*

Reference: Foster JB. Patello-Femoral Pain Research Refocuses on Hip Biomechanics. Biomechanics. January 2007. 53-56

Clinical Applications of Hip Strength

Research Reports

- 18 Female subjects with PFPS mean age 23.9 ± 2.8 years generated hip strength torque
 - 24% less – external rotators
 - 26% less – hip abductors

(Bolgla, Malone, Umberger, UHL 2008)

Clinical Applications of Hip Strength

Research Reports

- Female subjects age 12 – 35. Significant impairments in isometric strength of their hip abductors – 27%, hip extensors – 52%, and hip external rotations – 30%
- Compared to the weaker limbs of the control subjects

(Robinson & Nee 2007)

Clinical Applications of Hip Strength

Research Reports

- Runners with PFPS. 21 Runners, 5 male, 15 female
 - Isometric hip abduction and external rotation pre & post prolonged run.
 - Subjects displayed weaker hip abductor

(Dierks, Manal, Hanill, Davis 2008)

Therapeutic Value of this Research

- Proximal strengthening of the hip core
- Eccentric emphasis of Abduction and external rotators
- Open kinetic chain
 - Hip abduction – standing and side-lying
 - Side-lying clam
- Closed kinetic chain
 - Wall squats
 - Lateral and front step-up

Reference: Ayothe, Stetts, Keenan, Greenway 2007

Kinetic Chain Recruitment (PF)

Closed Kinetic Chain

- Mini squats – double to single - co-contraction
- Balance vectors – tri-plane – emphasize transverse plane
- Leg press – range of motion short-arc to long-arc
- Lateral step-ups/lunges – VMO advanced training
- Wall slides squats – single leg – high level recruitment

Balance Vector Training

- Sagittal Plane – Less Difficult: Vector 1 and 5
- Transverse Plane – More VMO Recruitment
– Vectors 2, 4, and 6
- Frontal Plane – More Difficult: Vector 3

Anterior Cruciate Ligament Rehabilitation

*Arthrolab
Rehab
Institute*

Phases of ACL Rehab

- I Pre-Functional
- II Return to Function
- III Return to Activity

Functional Progression – ACL

Pre-functional – phase one

- Mobility
 - Full normal extension
 - Flexion as tolerated – but not pushed
 - CPM is for extension not flexion
 - Patella mobility – all direction
 - Hip mobility to assist with core stabilization

Functional Progression – ACL

Pre-functional – phase one

- Recruitment
 - Core stabilization – swiss/plyo-ball exercises
 - Co-contraction hamstrings over the quadriceps
 - Leg control – standing SLR
 - Quadriceps isometrics – sub-max eccentric hamstrings control 30° → 90°

Hamstrings - Revisited

- Based on EMG studies
 - Hamstrings are more active at the hip during forward and backward walking, running and cycling
- Most hamstring injuries occur during the late swing phase of running
- Hamstrings create a posterior directed force on the tibia when the flexion angle is 30° or greater
- Hamstrings function as an eccentric control of hip flexion

Reference: Cipriani, D. Pulling Through. Training and Conditioning, Dec 2006. 13-19

Functional Progression – ACL

Pre-functional – phase one

- Tri-plane stabilization
 - Mini squats – double leg
 - Standing terminal extension (STE)
 - Balance weight shift exercises
 - Leg press sub-max double leg.

References: Gerber, etal. 2007

Functional Progression – ACL

Return to Function – Phase Two

- Mobility
 - Full ROM extension & flexion
 - Hamstrings – functional re-lengthening
 - Heel cord re-lengthening
- Recruitment
 - PRE – hamstrings $30^{\circ} \rightarrow 90^{\circ}$
 - PRE – quadriceps $45^{\circ} \rightarrow 90^{\circ}$
 - PRE – hip strengthening – all planes
 - Advanced core exercises – hamstrings – bridge-row
 - High speed isokinetics

Anterior Translation - ATT

- Least Amount of ATT – 75 Deg. Knee Flexion
- Maximum Amount of ATT 45 – 15 Deg. Flexion
(Based on Maximum Isometric Quadriceps Contraction)

References: Gross, MT, Tyson AD, Burns CB: Effect of Knee Angle and Ligament Insufficiency On Anterior Tibial Translation During Quadriceps Muscle Contraction: A Preliminary Report. J. Orthop, Sports Phys. Ther. 7: 133-143, 1993

Open- or Closed-Kinetic Chain Exercises After Anterior Cruciate Ligament Reconstruction?

- OKC and CKC Exercises both produce strains on the ACL in terminal extension
- OKC with increase of resistance does increase ACL strain
- CKC does not increase the ACL strain with increase load

Reference: Fleming, BC, Oksendahl, H, and Beynnon, BD: Exercise and Sports Sciences Reviews, Vol. 33(3) 134-140, July 2005.

Clinical Application of the Research

- OKC short arc flexion moment angle continues to be suggested ($90^{\circ} - 40^{\circ}$)
- Increase external compression (weights) with increase strain on the ACL toward extension
- Early use of CKC is still recommended

Functional Progression – ACL

Return to Function – Phase Two

- Tri-plane stabilization
 - Balance activities – balance board – BOSU
 - Progress to single leg squat on uneven surfaces
 - Balance vector – 3 planes
 - Leg press total gym single leg
 - Lateral step-up and lunges
 - Slide board – FITTER
 - Plyo-toss with squat

Reference: Risberg, Holm, Myklebust, Engebretsen 2007

Functional Progression – ACL

Return to Activity Phase 3

- **Mobility**
 - Any incomplete motion concerns mobilization as needed
 - Advanced functional LE re-lengthening
- **Recruitment**
 - Advanced quadriceps strengthening
 - Open kinetic chain progression

Functional Progression – ACL

Return to Activity Phase 3

- Tri-plane stabilization
 - Advanced plyo-toss on uneven surfaces – BOSU
 - Preturation training
 - Advanced balance vector training – eyes closed
 - Fitter, stepper, elliptical, versa climber, slide board for endurance training
 - Plyometric jumps – double to single leg
 - Lunges with weights
 - Sports Specific Training
 - Box Runs, Lateral Running, Retro sprinting, Vertical Jumps, Figure 8 run/cuts, running program.

ATHLETIC REHAB INSTITUTE

FUNCTIONAL PROGRESSION

Walk Program	20 Minutes	Treadmill-Retro (Backwards)
Jog Program	Goal 10-15 Minutes	Mix of Retro and Forward
Running Program	Straight Running 3-5 miles at 7/8 min/mile on track Goal: increase to sprint (Add any equipment once patient can sprint)	

Functional Progression for TKA

Pre-Functional – Phase One

- Mobility
 - Positional extension
 - Patella mobilization
 - Flexion as tolerated
- Recruitment
 - Hamstrings isometrics
 - Co-contraction hamstrings over quadriceps
 - Sub-max quadriceps isometric
 - Standing leg control – hip abduction
 - Frontal plane SLR
- Tri-plane stabilization
 - Closed kinetic chain mini squats – double leg
 - Standing terminal extension (STE)
 - Ambulation training

Functional Progression for TKA

Return to Function – Phase Two

- Mobility
 - Normal ROM
 - Acceptable patella mobility for superior and inferior glide and lateral to medial glides
 - Patella click test
 - Hamstrings and heel cord re-lengthening
- Recruitment
 - Open kinetic chain strengthening
 - Hamstrings curl – seated
 - Short-arc quads $90^{\circ} \rightarrow 45^{\circ}$
 - Terminal extension $20^{\circ} \rightarrow 0^{\circ}$
- Tri-Plane stabilization
 - Balance mini squats – 1 plane
 - Wall squats with or without ball
 - Leg press activities
 - Resistive STE

Functional Progression for TKA

Return to Activities – Phase 3

- Mobility
 - Normal ROM as possible
 - Manual mobilization of end range motion as needed
- Recruitment
 - Advanced open chain strengthening
 - PRE – hip standing SLR (all directions)
 - Terminal extension – PRE
 - Hamstrings/quadriceps PRE
- Tri-plane stabilization
 - Progressive balance vector training – 3 planes, single leg – eyes open
 - Uneven surface – balance training
 - Balance pad/BOSU
 - Lateral step-ups
 - PRE leg press activities

Kinetic Chain Recruitment – Summary (Ankle)

Open Kinetic Chain

- Manual Resistance – dorsi-flexors / eversion
- Thera-band resistance
- Isometric – all motions

Kinetic Chain Recruitment – Summary (Ankle)

Closed Kinetic Chain

- Single leg balance – heel to toe stance
 - Low level proprioception
- Bilateral mini-squats on balance board
- Balance vectors – tri-plane stabilization
- Plyo-toss with single leg balance
- Uneven surface training – balance pad/BOSU
- Plyometric training – trampoline to floor 3 planes

Proprioceptive Stimulation

Balance

- Dynamic joint stabilization
- Running gait – change of directions

Balance Training and Testing

- Single leg - eyes open
- Single leg - eyes closed
- Wobble board -- Balance Board - BOSU
 - Double leg
 - Single leg
- Balance Vectors – tri-plane

Reference: Trojian TH, McKeag DB. Single Leg Balance Test to Identify Risk of Ankle Sprains. British Journal of Sports Medicine. 2006; 40; 610-613.

Static and Dynamic Standing Balance

- Eyes Closed Static (ECS)
- Eyes Open Dynamic (EOD)
- Eyes Closed Dynamic (ECD)

Clinical Measurement Tool

Eyes Closed Dynamic time based testing is an appropriate and reliable clinical measurement in adolescents.

Reference:

Emery CA, Cassidy JD, Klassen TP, et al. Development of clinical static and dynamic standing balance measurement tool appropriate for use in adolescents. Phys Ther. 2005;85:502-514

Plyometric Training

Progressive in nature

- Increased number of exercises
- Increase repetitions and sets
- Decrease rest periods
 - Straight jumps -> Sagittal
 - Lateral jumps -> Frontal
 - Combination -> Transverse
- Frequency – three times a week
- Intensity – double leg jumps to single leg jumps
- Low intensity – 100 - 200 fast contacts
- Moderate intensity – 200 - 400 fast contacts
- High intensity – 400 – 600 fast contacts

What is Function?

- *Mobility – R.O.M.*
- *Recruitment*
 - *OKC – CKC Strengthening*
- *Tri-Plane Stabilization*
 - *– Neuromuscular Proprioception*