The Knee Extensor Mechanism: Stability and Optimal Function*

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* I have no financial relationship with any commercial entity related to orthopedic surgery

CME Objectives

1. Diagnose and treat conditions that cause patellofemoral instability and pain
2. Use nonoperative and surgical treatment to improve patient symptoms and satisfaction
3. Identify candidates for treatment utilizing new technology and evidence to optimize outcomes

Specific Objectives

1. Describe interdependency of patellofemoral, tibiofemoral and overall lower limb mechanics
2. Discuss the consequences of:
   - Rotational and Coronal Plane limb alignment
   - Weak proximal lower limb control
   - Trochlear Dysplasia
   - Patella Alta

3. Describe sagittal mechanics of PFJ in cases of:
   - Iatrogenic patella infera and infrapatellar contracture
   - Patellar (tuberosity) distalization for treatment of alta
4. Describe anatomical factors in patellar constraint
5. Describe indications, principles and limitations of MPFL reconstruction
To understand the PFJ, you must consider the whole limb and its extensor apparatus.

The patella enhances extensor moment, reducing tibiofemoral contact pressures for any given value of extensor torque.

\[ R = P + L \]

Resultant vector “R” is sum of body weight and muscle balance.

\[ P = \text{Body Weight} \]

\[ L = \text{the sum of the lateral muscle pull, of which the Q-Angle is an important part.} \]

“P” (body weight) and “L” (lateral muscle pull) combine to yield resultant “R”. Too Much Weight ‘P’ Or Too Limped ‘L’

Normal R @ medial

Lateral vector
The Following Conditions Displace “R” Medially:

- Varus Malunion
- Congenital Varus
  - Femur
  - Tibia
- Lat Ligament Laxity
- ACL Laxity
- Medial Cartilage Loss
- Limb Ext Rotation
- Medial Shift of the Tibial Tubercle

Is this Related to the PF Joint?

Iranpour found the trochlea to be a perfect circle (Red Arrow) which lies perpendicular to the KJA (flexion-extension axis) (Blue Arrow) in the coronal plane and in line with the mechanical axis. 

Trochlear Axis = Green Arrow

Thus varus-valgus malalignment results in trochlear malalignment

The Importance of Limb Alignment

R. Teitge, M.D.

- If a pulley points straight ahead the “rope” will stay in the pulley and mechanical efficiency is maximum
- If the pulley twists sideways beneath the rope, the rope will ride up the sidewall of the pulley, wear more, become frayed and fail in less time than if it is aligned well within the groove
- Since the trochlea is aligned with the knee joint axis, the position of the knee joint axis is critical to the alignment of the quadriceps
Aspects of Alignment:

Problem: There is a Person Attached to the Limb


Abnormal loading as a potential factor in the genesis of patellofemoral pain
*Dye, Sports Med Arthroscopy Rev, 2001*

- Pain readily reproduced with activities that require quadriceps contraction

Excess ETT  Excess ETT  Excess Fem Ant

Photo Courtesy of Chris Powers
Subject specific 3D PFJ model

Optimization Routine to Establish Vasti & Patellar Ligament Forces

Chen, Scher & Powers, J Appl Biomech, 2010

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<table>
<thead>
<tr>
<th>PFP Force</th>
<th>Control Force</th>
</tr>
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<tbody>
<tr>
<td>Walking</td>
<td></td>
</tr>
<tr>
<td>6.4</td>
<td>8.0</td>
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<tr>
<td>(1.8)</td>
<td>(2.1)</td>
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<tr>
<td>Descent</td>
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<td>20.9</td>
<td>27.7</td>
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<td>(2.3)</td>
<td>(2.9)</td>
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<tr>
<td>Ascent</td>
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</tr>
<tr>
<td>28.2</td>
<td>34.5</td>
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<tr>
<td>(3.1)</td>
<td>(4.1)</td>
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<tr>
<td>Running</td>
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<tr>
<td>41.2</td>
<td>51.6</td>
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<td>(4.2)</td>
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<tr>
<td>Average</td>
<td></td>
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<tr>
<td></td>
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</tbody>
</table>

Chen & Powers (in press)

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Resultant PFJRF: Running

Chen & Powers (in press)

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Subject specific 3D PFJ model

Optimization Routine to Establish Vasti & Patellar Ligament Forces

Chen, Scher & Powers, J Appl Biomech, 2010
Dynamic Q-angle During Stair Descent

39.1° vs. 24.2°
p = 0.01


“Dynamic Q-Angle”

- Proximal factors
  - Hip adduction
  - Hip internal rotation

- Distal factors
  - Pronation
  - Tibia internal rotation

Courtesy of Chris Powers

Predictors of the “Dynamic Q-angle”

Four variables combined explained 70.3% of the variance in average dynamic Q-angle:

1. Knee frontal plane motion (40.1%)
2. Knee transverse plane motion (13.8%)
3. Patella ligament orientation in the frontal plane (9.1%)
4. Vastus lateralis frontal plane orientation (7.3%)


Hip Adduction

Courtesy of Chris Powers
Hip Rotation

Courtesy of Chris Powers

Weight bearing MRI

25°

PFP subject (right leg)

15°

Control subject (left leg)

Souza & Powers, JOSPT, 2010

Hip Internal Rotation

PFP vs. Control

Drop Jump  Running  Step Down

Souza & Powers, JOSPT, 2009

Femoral IR: Weightbearing MRI

PFP vs. Control

Souza & Powers, JOSPT, 2010
Trochlear Shape and the Importance of Patellofemoral Engagement
To a Considerable Extent, Trochlear Shape and Patellar Height Govern both Patellofemoral Constraint and Distribution of Load

Ward et al, JBJS (Am), 2007

Trochlear Dysplasia

Ward et al, JBJS (Am), 2007

Tecklenberg, Dejour et al. KSSTA 2006
Ward et al, JBJS (Am), 2007

Distalization for Pain
Al-Sayyad & Cameron, CORR, 2002

Distalization for Recurrent Dislocation
Simmons & Cameron, CORR, 1992
The French Experience
*Fithian, et al, Tech Knee Surg 2007*

Models of patella infera without contracure or adhesion do not show changes in PF contact stress or motion loss

- Van Eijden, 1987
- Singerman, 1994
- Upadhyay, 2005


Consider the Mechanics of Infrapatellar Contracture Syndrome

*Paulos Am J Sp Med 94*


Percent Reduction in Knee Ext Force
Patellofemoral (In)stability

Depends on trochlear constraint and other passive limits of patellar motion relative to femur, i.e. the depth of the track and the strength of the medial tethers

Anatomy of Patellar Constraint:

- Elements of passive stability
  - Trochlear constraint* (Senavongse, Farahmand et al. 2003)
    - Depth, length (height)
    - Patellar engagement
  - Capsular ligamentous tethers, especially MPFL (Hautamaa, Fithian et al. 1998)
Soft Tissue Stabilizers vs. Lateral Displacement: (in decreasing order of importance)

- Medial patellofemoral ligament (MPFL)
- Medial patellomeniscal ligament (MPML)
- Medial patellotibial ligament (MPTL)
- **Lateral** patellofemoral ligament (LPFL)

*Hautamaa 1998; Burks, Desio 1998; Nomura 2000; Amis 2003*

Endpoint, or Checkrein (MPFL) Depends on Knee flexion Angle

**Dynamic elements**

- Simulated muscle tension has little effect on patellar mobility, regardless of flexion angle
  *(Senavongse, Farahmand et al. 2003)*

* Courtesy: E. Nomura, M.D.*
Pathologic Anatomy of Patellar Dislocation:

- The “Traditional View”: Trochlear dysplasia is fundamental in episodic patellar dislocation (Dejour, Walch et al. 1990; Fithian et al 2007)

- But medial retinacular deficiency also is present (Bassett, 1976; Fithian, et al, 1995; Teitge et al, 1996)

- Current Consensus View: Patellar stability is result of combined effect of passive constraints (trochlear constraint and retinacular ligaments)


- Prospective cohort of 189 patients (125 first-time, 64 with prior history of patellar instability)
- 2 to 5 year FU
- 17% instability after first-time dislocation
- 49% instability in patients with prior history
- Among first-time dislocators:
  - Recurrence rates not related to measured laxity or MRI finding of MPFL injury
Medial Retinacular Laxity: Checkrein (Endpoint) at 0° Flexion

Who is Ideal Candidate for MPFL Reconstruction?

• Ideal patient:
  – Episodic patellar dislocator (EPD) with little or no pain between episodes
  – May report functional impairment when asked, **but** …
    • It is only the occasional dislocations or subluxations that precipitate the consultation

• **Beware of:**
  – **any** pain that is not directly caused by these brief, occasional instability episodes
  – Pre-existing arthritis
  – The permanently dislocated or habitually dislocating patella

MPFL Reconstruction: Indications and contra-indications

• **Indications:**
  – Episodic lateral patellar instability due to excessive laxity of medial retinacular patellar stabilizers
  – Documented MPFL laxity by physical examination, stress radiography, EUA

• **Contra-indications:**
  – Absence of retinacular laxity
  – Chronic pain
  – Significant patellofemoral arthrosis
  – The permanently dislocated or habitually dislocating patella

Surgical Objectives

• Re-establish check-rein against lateral patellar motion (Bassett, 1976)
• Re-establish normal limits of passive patellar motion

<table>
<thead>
<tr>
<th>Test</th>
<th>Normal Subjects† N=94</th>
<th>Cadavers ‡ N=17</th>
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<tbody>
<tr>
<td>5 lb Medial</td>
<td>9 ± 3</td>
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<td>5 lb Lateral</td>
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†Fithian et al, 1995 ‡Hautamaa et al, 1998
Objectives of Patellar Stabilization

1. Checkrein vs. lateral displacement
2. Normal motion limits (7-9mm)

### MPFL Reconstruction

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Journal</th>
<th>No</th>
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<tr>
<td>Avikainen</td>
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<td>Clin Orthop</td>
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<td>AMT</td>
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<td>Ellera Gomes</td>
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<td>Nomura</td>
<td>1993, 1994</td>
<td>ChubuSaisei (Japanese) Sakegaku (Japanese)</td>
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Technical Complications of MPFL Reconstruction

- Loss of ROM
- Arthrofibrosis
- Recurrent instab
- “Medial instab” (?)
- PF arthrosis
- Patellar fx
- Graft rupture
- Hemarthrosis
- Implant pain


MPFL Reconstruction: Technical Principles

Medial PF Overload

patella  
medial  
trochlea

Courtesy of Matthew Bollier, MD
Errors in Femoral Tunnel Placement

In Vivo Positioning Analysis of MPFL reconstruction
Servien E et al 2011

Clinical study- analyzed femoral tunnel position on post-op xray and MRI; correlated with clinical outcomes

Determined femoral tunnel position intra-operatively by visual inspection

69% in good position on xray
65% in good position on MRI

No correlation between subjective IKDC score/ ROM and fem tunnel position

Patellar Tilt:
A Sign of Soft-Tissue Imbalance and Trochlear Depth

In Conclusion…

• Patellofemoral, Tibiofemoral and overall Lower Limb mechanics are strongly interdependent
• The following have predictable consequences:
  – Trochlear Dysplasia
  – Patella Alta
  – Rotational and Coronal Plane limb alignment
  – Weak proximal lower limb control
In Conclusion...

- Sagittal mechanics of PFJ are not adversely affected by patellar (tuberosity) distalization for treatment of alta
- Anatomical factors in patellar constraint:
  - Trochlear engagement
  - Medial retinacular ligaments (primarily MPFL)
- Indications and limitations of MPFL reconstruction
  - The specific objective of MPFL reconstruction is to reduce lateral patellar mobility to maintain the patella within the trochlea
  - This is a stabilizing procedure; effects on pain are unpredictable

Some Thoughts on the Future

- Alignment: assessment and treatment
  - Static vs. functional
  - Identify and correct the source of overload
- Restoration and Resurfacing
  - Restore or construct subchondral foundation
  - We have the ability for anatomic 3D reconstruction; trochleoplasty with or without resurfacing?
- Instability
  - Classification based on clinical findings
  - Treatment refinements

Thank You!