Anatomy and Biomechanics of the Meniscus

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Outline

- Anatomy
- Structure – Function
- Load transmission – Meniscal motion
- Meniscal ligaments
- Tears – Tear management
- Summary – The importance of the meniscus
Menisci

Intraarticular knee structures
  - Semi-lunar (axial)
  - Wedge-shaped (coronal/sagittal)
  - Fibro-cartilaginous (type I Collagen)
Anatomy – Meniscal Ligaments

- Meniscal ligaments
  - Insertional
  - Anterior Intermensical (AIL)
  - Mensicofemoral (MFLs)
  - Deep Medial Collateral (dMCL)
Histology – Strength

- **Histology**\(^1\)-\(^3\)
  - **Tissue bulk**: circumferential fibre bundles (Type I)
  - **Surface**: Meshwork of thin fibrils/ radial tie fibres

- **Strength – Tensile modulus**\(^4\)
  - Hoop: \(~110\) MPa
  - Radial: \(~10\) MPa

(Taken from: Petersen & Tillmann, 1998, Anat Embryol)

\(^1\)Petersen & Tillmann, 1998, Anat Embryol
\(^2\)Bullough et al, 1970, JBJS-Br
\(^3\)Beaupre et al, 1986, CORR
\(^4\)Tissakht & Ahmed, 1995, J Biomech
### Tensile properties of intra-articular tissues (in MPa)

<table>
<thead>
<tr>
<th></th>
<th>Tendon</th>
<th>Ligament</th>
<th><strong>Meniscus</strong> (circumferential)</th>
<th>Labrum (circumferential)</th>
<th>Cartilage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>500-700</td>
<td>300</td>
<td><strong>110</strong></td>
<td>30-60</td>
<td>2-20</td>
</tr>
</tbody>
</table>
Meniscus functions

- Reduce contact stresses
- Load spreaders
- Shock absorbers
- Stability
- Lubrication
- Proprioception
- Nutrition
Structure – Function

- Fluid phase – compression
  - Water content ~75%
  - Low permeability
  - Low compressive and shear moduli

- Hence the meniscus
  - traps the fluid allowing fluid-pressure to build up
  - is very deformable
  - can accommodate high loads
Axial load transferred through the joint is converted into **meniscal hoop stresses**

The meniscus:
- conforms to the femoral condyles
- increases its circumference
- translates outwards
- spreads the load over a large contact area
- hence reduces the stresses on the underlying cartilage

Insertional ligaments are key

70-99% of the joint load is carried by the menisci

*1Seedhom & Hargreaves, 1979, Eng Med*
Load spreaders

- Increase contact surface area
- Reduce contact stresses


Loss of a meniscus

- Meniscectomy results in\(^1\-^3\):
  - Cartilage to cartilage contact
  - Less conformity
  - Decreased contact area
  - Increased contact stresses (up to 200\%\(^1\))
  - Increased shear stresses

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\(^1\)Baratz et al, 1986, AJSM
\(^2\)Seedhom & Hargreaves, 1979, Eng Med
\(^3\)McDermott et al, 2008 in press, KSSTA

(Taken from: McDermott et al, 2008, KSSTA)
Shock absorbers

Compressive modulus varies according to:
- location (anterior > posterior)
- strain rate (increases)
- species

Modulus at 12% strain:
- Equilibrium: 83 kPa axial, 76 kPa radial
- 32%/sec (physiological): 718 kPa and 605 kPa

Fluid film lubrication also contributes to shock absorption.

Joint stability

- **Anterior drawer**
  Medial meniscus posterior horn stabilises anterior drawer in anterior cruciate deficient knee (Shoemaker JBJS 1986)

- **Posterior**
  MFLs are secondary restraints to posterior drawer\(^1\)

- **Rotational**
  Meniscal construct is a restraint to tibial rotation\(^2\)

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2. Wang & Walker, 1974, JBJS-Am
4. Hollis et al, 2000, AJMS
Insertional Ligaments

- Anchor menisci on tibial plateau
- Control meniscal motion
- Prevent excessive meniscal extrusion
- Loss of one completely de-functions the meniscus

- Tensile modulus in human

\[ \begin{align*}
\text{Medial} &: \approx 165 \text{ MPa} \\
\text{Lateral} &: \approx 90 \text{ MPa} \\
\text{Anterior} &: \approx 75 \text{ MPa}
\end{align*} \]

\[ ^{1}\text{Haut-Donahue & Hauch, July 2008, ESB} \]
# Meniscal Ligaments

<table>
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<tr>
<th></th>
<th>MFLs</th>
<th>AIL</th>
<th>dMCL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Occurrence</strong></td>
<td>92% ¹ <em>(at least one MFL)</em></td>
<td>75% ⁵⁻⁷</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Function</strong></td>
<td>Secondary restraints to posterior drawer²</td>
<td>??</td>
<td>Secondary restraint to valgus at 60-90° flexion⁸</td>
</tr>
<tr>
<td><strong>Relation to meniscal function</strong></td>
<td>MFL-deficiency results in 10% increase in contact stresses³</td>
<td>Controls meniscal motion in conjunction with the insertional ligaments (?)</td>
<td>Restrains excessive mobility of the medial meniscus ?? Contact stresses ??</td>
</tr>
<tr>
<td><strong>Tensile properties</strong></td>
<td>Modulus ~ 250 MPa⁴ \ i.e. similar to the major knee ligaments</td>
<td>??</td>
<td>??</td>
</tr>
</tbody>
</table>

¹Gupte et al, 2003, Arthroscopy  
²Gupte et al, 2003, JBJS-Br  
³Amadi et al, 2008, KSSTA (accepted)  
⁵Kohn & Moreno, 1995, Arthroscopy  
⁶Nelson & LaPrade, 2000, AJSM  
⁷Berlet & Fowler, 1998, AJSM  
⁸Robinson et al, 2006, AJSM
Meniscal motion

- Through knee flexion the menisci translate
  - outwards
  - posteriorly

Geometrical considerations

- The **medial** tibial plateau is **concave**
- The **lateral** tibial plateau is **convex**
- Therefore the medial meniscus is crushed on the tibial rim in deep flexion
  (injury 3:1 cf lateral meniscus)

(Taken from: Vedi et al, 1999, JBJS-Br)

(Taken from: Yao et al, 2008, J Orthop Res)
Lubrication

- Mobile meniscus helps lubricate the knee
- Articular cartilage has many modes of lubrication
Proprioception

- Receptors in insertional attachments: MT and MFL
- Ruffini endings and pacinian corpuscles
- Meniscectomy or meniscal tears reduce proprioception

Pathological states
Meniscal tears

- Circumferential
  - parallel to the load-bearing fibres
  - small effect on meniscal function
- Radial – Vertical
  - cut across the load-bearing fibres
  - large effect on meniscal function
- Flap
- Bucket handle
- Horizontal cleavage
- Complex
Meniscal tear management

- Repair
- Partial meniscectomy
- Total meniscectomy
- Allograft transplantation
- Implants (?)
- Tissue engineering (?)

(Taken from: Arnoczky & Warren, 1983, AJSM)
Repair

- Type of tear
- Age of tear
- Age/medical status of patient
- Location of tear
Meniscetomy Stresses

Removal of meniscus:
reduce surface area of contact>>>increased contact stresses

Does repair restore meniscal stress function???
No long term studies
Meniscectomy consequences

Lateral meniscectomy results in OA; also probably medial

Late degenerative changes after meniscectomy. Factors affecting the knee after operation. PR Allen, RA Denham, and AV Swan. JBJS 1984
Links between osteoarthritis and biomechanics

- Abnormal kinematics cause \textit{initiation} of osteoarthritis\textsuperscript{1,2}
  - Injury
    (eg ACL-deficiency – meniscectomy)
  - Increased laxity
    (eg excessive meniscal extrusion, meniscal ligament resection)

- \textbf{Progression} of osteoarthritis with load\textsuperscript{1,2}
  - Increased load in areas that are not optimised to accommodate it
    (eg cartilage areas covered by the menisci\textsuperscript{3})
  - Shear
    (eg non-conforming femoral condyles with tibial plateau)

\textsuperscript{1}Andriacchi et al, 2004, Ann Biomed Eng
\textsuperscript{2}Andriacchi & M"undermann, 2006, Curr Opin Rheumatol
\textsuperscript{3}Thambyah et al, 2006, Osteoarthr & Cartilage
Meniscal replacement - artificial

- Products exist
- Require suture
- Normal mechanics
Meniscal transplant

- Normal articular cartilage
- Technically demanding
- Fixation issues: either suture to capsule OR bone plugs
- Normal mechanics
- Reduced degenerative change

Khon et al
Verdonk et al
Whats new

- New prostheses
- Suture techniques
- Location of repairable tears
Main function of the menisci is **load bearing**

This relates directly to the meniscal structure

The insertional ligaments are key in meniscal function

The meniscus-meniscal ligament construct works harmoniously under load to **protect** the cartilage

Clinical management should aim at **preserving** the function of the meniscus-meniscal ligament construct
Anatomy and Biomechanics of the Meniscus

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