Graft Fixation in ACL Reconstruction

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The Silent Epidemic

- **100,000** new ACL injuries occur in the US per annum
- **> 75,000** ACL reconstructions per annum
- **$ 1,000,000,000**
The Jones Procedure as the “Gold Standard”?
Direct Repair

Marshall's modification
It fines tunes the screw home mechanism during terminal knee extension.

It provides a check to internal tibial rotation, thereby affording rotatory control to the knee.

Resists anterior tibial translation on the femur.

It is a secondary restraint to both varus and valgus forces in all ranges of flexion.

Prevents hyperextension of the knee.
Goals of ACL reconstruction

1) Abolition of pivot shift
2) A supple knee
3) Restoration to pre-injury activity levels
4) Long term preservation of integrity of a healthy knee joint
Current problems with ACL Reconstruction

1. Donor site morbidity
2. Impingement
3. Incorrect femoral tunnel placement
4. Graft Fixation
Currently ACL reconstruction does not:

1) Restore normal proprioception of the ACL
2) Reproduce the multi-stranded structure of the ACL
3) Restore normal knee joint kinematics
4) Preserve the articular integrity of the knee joint
Graft Fixation

Biological
- BPTB 6-8 wks
- Hams 12 wks

Mechanical

Direct
- Staples
- IFS

Indirect
- Endobutton
- Cross Pin
- Sutures-post
Graft Fixation

ACL reconstruction

Biological Fixation

Mechanical Fixation
Current methods of anchorage rely upon biological fixation occurring in bony tunnels before the ligament fails at a point of high stress concentration.
A time interval of unknown duration exists between 

**time zero** (when graft fixation is the weakest link)

and **adequate biologic incorporation** of the graft into the tunnel

(when the graft substitute tissue becomes the weakest link of the construct).

The duration of this period is unknown, but is longer for **soft-tissue grafts** than for grafts with **bone plugs**.
Graft fixation must resist slippage during cyclic loading during the first 2 months after surgery prior to conversion from mechanical to biologic fixation.

No graft can reproduce the normal insertion site.
Graft fixation is (not always) the weak link during this period

This is therefore a race against time
Forces Present in the Cruciate Ligaments During Activities of Daily Living

- Descending Stairs: ACL 445, PCL 262
- Level Walking: ACL 169, PCL 352
- Ascending Stairs: ACL 67, PCL 641
- Descending Ramp: ACL 93, PCL 449
- Ascending: ACL 27, PCL 1215
Forces Present in the Cruciate Ligaments During Activities of Daily Living

The ACL graft is loaded to approximately 150 to 500 N during normal daily activities.
Conclusion

Zero time fixation strength should be at least 500 N to permit safe post-operative mobilisation.
Tendon to Bone Healing Vs Bone to Bone Healing
During the postoperative period, the maximum loads to the graft substitute construct are provided by rehabilitation.

These loads should be less than or equal to the graft fixation strength achieved in the operating room, at time zero.
In cases where the surgeon is concerned about poor fixation, the rehabilitation program should be customized to the fixation. (low BMD, Tunnel lysis)

These patients must undergo a less aggressive rehabilitation protocol due to inferior fixation.
QHT graft + IFS
Removal of tibial screw 4 weeks pop
No residual laxity
Arthroscopy 2003
Graft Fixation Devices

- Screws (blunted threads)
- Sutures over Post
- Staples ("belt buckle" technique)
- Cross pin designs
- Devices for cortical fixation
- Button
- Washer
- Other
<table>
<thead>
<tr>
<th>Site</th>
<th>Method</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral</td>
<td>Direct</td>
<td>Absorbable</td>
</tr>
<tr>
<td>Tibial</td>
<td>Indirect</td>
<td>Non-absorbable</td>
</tr>
<tr>
<td>Cortical - Cancellous</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Graft Fixation Device Choice

- Familiarity
- Price
- Ease of use
- Efficacy
- Availability
- Other
Direct vs Indirect Fixation

Direct

staples-washer-IFS-cross pins

Indirect

tapes+buttons- suture posts
Direct vs Indirect Fixation

- Direct fixation reduces graft motion.
- Significant in animals.
- Significance in clinical studies not shown
Sutures and post technique

- Postop immobilization
- Slower initial rehabilitation
- Bungee cord effect
- Higher failure rates
Pull out strength is not the only decisive factor in ACL reconstruction.

Shelbourne achieved excellent results using button fixation (UTL 248 N).

Functions of Graft Fixation Devices

1. Provide apposition of the graft with surrounding tissue
2. Resist slippage or migration under repeated loading
3. Resist sudden traumatic loading
4. Restore normal anatomy (close to the joint, Double bundle)
5. Restore the load-displacement response to normal
The Ideal Graft Fixation Technique

- strong, rigid fixation
- anatomic fixation at the articular surface
- no inflammatory response
- ultimate reliance on good biological fixation
- Avoidance of damage or crushing of the graft at the point of fixation
- does not hinder future procedures or investigative techniques
The Ideal Graft Fixation Technique

does not exist yet!
The ultimate strength of the graft – fixation method complex equals the strength of its weakest part.
Endobutton
1000 N

Sutures over Post
150 N
Graft Fixation Methods

✓ Aperture fixation

✓ Semiaperture

✓ Suspended fixation (outside fixation)
- Near anatomic origin adjacent to the articular surface
- Interference Screw
- Anchoring the graft at the entrance into the joint, reduces graft length and elasticity
- Intrafix
- leaves 15 mm
tendon free
Suspended Fixation
(outside fixation)
Outlet fixation

Aperture fixation
Avoidance of:

- suture stretch
- graft-tunnel pistoning
- windshield-wiperening

Aperture fixation vs distal fixation

- delayed incorporation of the graft in the tunnel
- tunnel enlargement
- clinical failure
Disproving the current theory on the effect of location of the fixation within the drill hole, the shorter working length of the apertural methods did not improve the stiffness of the constructs.
Biomechanics Of ACL Graft Fixation
Models of Biomechanical Testing of ACL Graft Fixation

- Test specimen has strong influence on biomechanical data
- Bovine, porcine, young human, and elderly human cadaveric knees
Biomechanics

- Single Cycle Loading (sudden overload)
- Cyclic Loading (Repetitive loading)
- Fatigue Loading
- Stress-Relaxation

All techniques describe graft properties at time zero.
Initial Failure Load is not always the most important factor in fixation method selection.
Caution should be used in extrapolating the results of any study to clinical estimates as we cannot assume that the structural properties of fixation devices determined in animal tissue predict its performance in human knees.
Porcine tissues used for surrogates for human tissues underestimate **graft slippage** past the fixation and overestimate **fixation strength**.
All forms of graft fixation are weaker and less stiff than ACL replacement grafts.

The tibial fixation site is weaker and fails predominantly.
Bone - Patellar Tendon - Bone Graft
Bone - Patellar Tendon - Bone Graft

- Interference Screw Fixation
- Cross Pin Fixation
- Press Fit Fixation
- Other forms of fixation
Bone-Patellar Tendon-Bone Graft

✅ Gold standard

✅ Equal results with metallic, titanium, absorbable screws
Interference Screw Fixation of the BPTB graft is the gold standard for ACL reconstruction !!!!

- Fixation Strength: 416 N
- Stiffness: 51 N/mm
- Slippage: 3.8 mm at 500 N

Kurosaka, 1988
### Interference Screw Fixation

**Porcine tibia**

<table>
<thead>
<tr>
<th></th>
<th>BPTB</th>
<th>Hamstrings</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTL</td>
<td>658</td>
<td>490</td>
</tr>
<tr>
<td>Stiffness</td>
<td>400</td>
<td>3500</td>
</tr>
<tr>
<td>Slippage</td>
<td>2.5</td>
<td>6.3</td>
</tr>
</tbody>
</table>
Tendon Damage – IF Screw
Femoral fixation of the graft is stronger than the tibial tunnel fixation.

- Greater bone mineral density of the distal femur
- Angle of stress relative to fixation
- The tibial fixation is subjected to more loads

The weak link in the system at time zero, immediately after surgery, is the tibial fixation point.
<table>
<thead>
<tr>
<th>Construct</th>
<th>Failure (N)</th>
<th>Stiffness (N/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EndoButton&lt;sup&gt;b&lt;/sup&gt;</td>
<td>554 (276)</td>
<td>27.0 (13.5)</td>
</tr>
<tr>
<td>Mitek device&lt;sup&gt;b&lt;/sup&gt;</td>
<td>511 (350)</td>
<td>18.3 (8.3)</td>
</tr>
<tr>
<td>Press-fit&lt;sup&gt;b&lt;/sup&gt;</td>
<td>350 (48)</td>
<td>36.8 (16.3)</td>
</tr>
<tr>
<td>Interference screw from outside-in&lt;sup&gt;87&lt;/sup&gt;</td>
<td>423 (175)</td>
<td>46 (24)</td>
</tr>
<tr>
<td>Endoscopic interference screw&lt;sup&gt;87&lt;/sup&gt;</td>
<td>588 (282)</td>
<td>33 (14)</td>
</tr>
<tr>
<td>Interference screw outside-in&lt;sup&gt;14&lt;/sup&gt;</td>
<td>235 (124)</td>
<td>82.8 (30.1)</td>
</tr>
<tr>
<td>Endoscopic interference screw&lt;sup&gt;14&lt;/sup&gt;</td>
<td>256 (130)</td>
<td>70.2 (28.9)</td>
</tr>
<tr>
<td>Metal endoscopic interference screw&lt;sup&gt;19&lt;/sup&gt;</td>
<td>558.3 (67.9)</td>
<td>No stiffness reported</td>
</tr>
<tr>
<td>BioScrew endoscopic interference screw&lt;sup&gt;19&lt;/sup&gt;</td>
<td>552.5 (56.4)</td>
<td>No stiffness reported</td>
</tr>
<tr>
<td>Metal interference screw&lt;sup&gt;70&lt;/sup&gt;</td>
<td>640 N (201)</td>
<td>No stiffness reported</td>
</tr>
<tr>
<td>BioScrew interference screw&lt;sup&gt;70&lt;/sup&gt;</td>
<td>418 N (118)</td>
<td>No stiffness reported</td>
</tr>
<tr>
<td>Metal interference screw&lt;sup&gt;44&lt;/sup&gt;</td>
<td>436 (111–903)</td>
<td>No stiffness reported</td>
</tr>
<tr>
<td>Biodegradable interference screw&lt;sup&gt;44&lt;/sup&gt;</td>
<td>565 (248–987)</td>
<td>No stiffness reported</td>
</tr>
</tbody>
</table>

Brand et al., 2000
Fixation strength and stiffness are increased

- Larger diameter screws (9.0 vs 6.5 mm and 9 vs 7 mm in 10 mm drill holes)
- Compaction Drilling
- Circular bone plugs > cylindrical
Fixation strength and stiffness are increased

**Soft-tissue Grafts**

- Screw diameter should be >1 mm that of the osseous tunnel
- Use of a longer screw (28 mm vs 23 mm)
Screw Divergence
Screw Divergence

Optimal interference fixation occurs when screws are placed parallel to the bone plug or soft-tissue graft, thus allowing **maximal surface area** contact between screw and graft.

Screw divergence of $>15^\circ$ dramatically decreases the fixation strength of the construct.
Divergence Prevention

✓ Notching the anterior edge of the femoral tunnel prior to screw insertion

✓ Flexing the knee 100°-120°

✓ Placing the screwdriver through the tibial tunnel
Divergence Prevention

The in-line direction of pull in the tibial tunnel compared to the wedge effect in the femoral tunnel makes avoidance of screw divergence more critical on the tibial side than the femoral side.
Although laboratory significance has been demonstrated, screw divergence has not been correlated with laxity clinically.
Bioabsorbable Screws

- Biocompatible, non-immunogenic, non-toxic
- Polyglycolic acid (PGA)
- Poly-L-lactic acid (PLLA)
- Co-Polymers (PGA/PLLA, PGA/TMC, PGA/PDS)
Interference Screw: Ideal Material?

- Retain sufficient strength over time
- Versatile processing
- Reproducible synthesis for consistency
- No inflammatory response
- Completely resorb without residual
- After resorption, body should “forget” that the implant was there
- The sharp threads of metallic interference screws used for bone plug fixation are blunted
Elimination via the Krebs cycle and excreted in the urine

Little difference in the rate of degradation from the different locations in the body

Depends on MW, area, crystallinity, porous vs non-porous

PLLA takes from 2-5 years to be completely absorbed
Bioabsorbable Screws

- High initial tensile strength@ crystallinity
- High crystallinity increases EtoF (less brittle)
- High modulus
- Low elongation to failure
- PLA maintains up to 75% of its initial mechanical strength 20 weeks in vivo
Clinically, bioabsorbable screws have provided good results.

The literature is mixed regarding complete dissolution of the bioabsorbable implant.
Potential disadvantages are:

- screw breakage during insertion
- inflammatory response
- inadequate fixation after partial degradation prior to biologic incorporation.
However,

- more bone plug fractures have been seen with metal interference screws
- similar cysts have been seen with metallic fixation as those reported with bioabsorbable screws
Hamstring Tendon Graft
Hamstring Graft Fixation

Fixation has evolved from staples to endobutton to interference screws and ultimately to cross pins.
Hamstring Reconstruction Techniques

- fixation devices
- fixation level
- fixation method (direct vs indirect)
- graft configuration
Free tendon grafts rely on establishing bone to tendon incorporation over time, thus requiring direct apposition of tendon to bone without detrimental reduction of initial fixation.
Quadrupled Hamstring Graft Fixation Prerequisites

- Tight fit
- Sufficient Tendon Length
- Preservation of tendon integrity
- Postoperative Protection
- Outlet fixation
Brand et al., 2000
Early fixation techniques for soft-tissue grafts were limited to distal, indirect fixation techniques (suspensory fixation) which are hindered by:

- inferior stiffness
- windshield-wiper effect (anterior/posterior)
- bungee cord effects (superior/inferior)

which may lead to delayed biological incorporation and tunnel enlargement.
Disadvantages of Hamstring Graft Fixation

- Less secure initial and long term fixation
- Increased knee laxity after reconstruction
- Lack of regrowth or regeneration

Recently there has been a surge of interest in the use of hamstring tendon grafts due in part to improvements in graft fixation techniques.
Femoral Fixation of a QHT Graft

<table>
<thead>
<tr>
<th>Construct</th>
<th>Failure (N)</th>
<th>Stiffness (N/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QHT with Trans-Fix&lt;sup&gt;c&lt;/sup&gt;</td>
<td>523 (263)</td>
<td>34.2 (14.3)</td>
</tr>
<tr>
<td>QHT with Bone Mulch&lt;sup&gt;c&lt;/sup&gt;</td>
<td>583 (108)</td>
<td>24.4 (4.17)</td>
</tr>
<tr>
<td>QHT with an EndoButton, mersilene tape&lt;sup&gt;c&lt;/sup&gt;</td>
<td>520 (50)</td>
<td>34.8 (22.3)</td>
</tr>
<tr>
<td>QHT with EndoButton and Endotape&lt;sup&gt;c&lt;/sup&gt;</td>
<td>618 (242)</td>
<td>22.4 (6.9)</td>
</tr>
<tr>
<td>QHT with EndoButton and three #5 suture&lt;sup&gt;c&lt;/sup&gt;</td>
<td>663 (211)</td>
<td>18.1 (6.9)</td>
</tr>
<tr>
<td>QHT with EndoButton and 2 loops of Endotape&lt;sup&gt;c&lt;/sup&gt;</td>
<td>678 (179)</td>
<td>20.6 (7.8)</td>
</tr>
<tr>
<td>QHT with Mitek&lt;sup&gt;c&lt;/sup&gt;</td>
<td>699 (210)</td>
<td>30.2 (8.5)</td>
</tr>
<tr>
<td>Semitendinosus fixed with the EndoButton and tibial post&lt;sup&gt;74&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QHT with the RCI titanium screw&lt;sup&gt;18&lt;/sup&gt;</td>
<td>628 (359)</td>
<td>21.2 (5.5)</td>
</tr>
<tr>
<td>QHT with BioScrew&lt;sup&gt;18&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QHT BioScrew, 0.5 mm graft sleeves&lt;sup&gt;86&lt;/sup&gt;</td>
<td></td>
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</tr>
</tbody>
</table>

Brand et al., 2000
Femoral Fixation

Endobutton, Bone Mulch Screw, Rigid Fix, Bio-Screw, Rigid Fix Bioscrew, RCI screw, Smartscrew ACL

Fresh Hamstring Tendons

<table>
<thead>
<tr>
<th>Fixation</th>
<th>$N$</th>
<th>Yield load (N) (mean ± SD)</th>
<th>Stiffness (N/mm) (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EndoButton CL</td>
<td>10</td>
<td>1086 ± 185</td>
<td>79 ± 7.2&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Bone Mulch Screw</td>
<td>10</td>
<td>1112 ± 295</td>
<td>115 ± 28</td>
</tr>
<tr>
<td>RigidFix</td>
<td>10</td>
<td>868 ± 171</td>
<td>77 ± 17&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>BioScrew</td>
<td>10</td>
<td>589 ± 204&lt;sup&gt;a,c,e&lt;/sup&gt;</td>
<td>66 ± 28&lt;sup&gt;a,f&lt;/sup&gt;</td>
</tr>
<tr>
<td>RCI screw</td>
<td>10</td>
<td>546 ± 174&lt;sup&gt;a,c,e&lt;/sup&gt;</td>
<td>68 ± 15&lt;sup&gt;a,f&lt;/sup&gt;</td>
</tr>
<tr>
<td>SmartScrew ACL</td>
<td>10</td>
<td>794 ± 152&lt;sup&gt;b,d&lt;/sup&gt;</td>
<td>96 ± 20</td>
</tr>
</tbody>
</table>
1500 Loading Cycles 50-150 N

<table>
<thead>
<tr>
<th>Fixation</th>
<th>N</th>
<th>Yield load (N) (mean ± SD)</th>
<th>Stiffness (N/mm) (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EndoButton CL</td>
<td>10</td>
<td>781 ± 252</td>
<td>105 ± 13&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Bone Mulch Screw</td>
<td>10</td>
<td>925 ± 280</td>
<td>189 ± 38</td>
</tr>
<tr>
<td>RigidFix</td>
<td>10</td>
<td>768 ± 253</td>
<td>136 ± 13&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>BioScrew</td>
<td>9</td>
<td>565 ± 137&lt;sup&gt;d&lt;/sup&gt;</td>
<td>113 ± 15&lt;sup&gt;a,e&lt;/sup&gt;</td>
</tr>
<tr>
<td>RCI screw</td>
<td>9</td>
<td>534 ± 129&lt;sup&gt;d,f&lt;/sup&gt;</td>
<td>134 ± 23&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>SmartScrew ACL</td>
<td>10</td>
<td>842 ± 201</td>
<td>162 ± 28</td>
</tr>
</tbody>
</table>

Only Screws failed during the cyclic loading

Considerable differences are shown between static and cyclic loading.
The structural properties of a fixation method may not be the same in animal and human tissue.

Interference screws perform better in animal tissue.
WasherLoc, Tandem spiked washer, Intrafix, Bioscrew, Softsilk IFS, Smartscrew ACL

<table>
<thead>
<tr>
<th>Fixation</th>
<th>N</th>
<th>Yield load (N) (mean ± SD)</th>
<th>Stiffness (N/mm) (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WasherLoc</td>
<td>10</td>
<td>975 ± 232&lt;sup&gt;a&lt;/sup&gt;</td>
<td>87 ± 23&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tandem spiked washers</td>
<td>10</td>
<td>769 ± 141&lt;sup&gt;b&lt;/sup&gt;</td>
<td>69 ± 14&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Intrafix</td>
<td>10</td>
<td>1332 ± 304</td>
<td>223 ± 62</td>
</tr>
<tr>
<td>BioScrew</td>
<td>10</td>
<td>612 ± 176&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>91 ± 34&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>SoftSilk</td>
<td>10</td>
<td>471 ± 107&lt;sup&gt;b,d,e&lt;/sup&gt;</td>
<td>61 ± 12&lt;sup&gt;a,f&lt;/sup&gt;</td>
</tr>
<tr>
<td>SmartScrew ACL</td>
<td>10</td>
<td>665 ± 201&lt;sup&gt;b,g&lt;/sup&gt;</td>
<td>115 ± 34&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
Direct soft-tissue fixation with interference screws still allows considerable graft slippage, which can be limited by using a bone block or application of a backup or hybrid fixation, especially on the tibial fixation site.
Augmentation with sutures tied to an intraarticular anchor (ball-disc) or external post, staple or button improves initial fixation strength.

IFS demonstrate the tendency for the tendon to slip past the screw.
Combined Fixation

- Screw + Outlet fixation
- Cross pin + Screw
Graft Pretensioning
Preconditioning
Initial Tensioning

Have been recommended for elimination of viscoelastic tendon creep and prevention of postoperative knee laxity
Initial Graft Tension for ACL Reconstruction

- 10N?
- 20N?
- 30N?
- 80N?
- 100N?
- 120N?
- ???

Enough load should be applied:

- ✓ To prevent slippage
- ✓ To eliminate pathological anterior laxity
- ✓ To maintain physiologic laxity and kinematics
Preconditioning of the Graft

- Static
- Cyclic

- Pre-implantation
- Intraoperative
Graft Preconditioning
Clinically applicable preconditioning protocols do not fully eliminate the intrinsic tendon creep.

The initially set tension decreases considerably postoperatively due to the remaining tendon creep.
Initial Graft Tension for ACL Reconstruction

Graft tension affects remodeling of the autograft in ACL reconstruction.

Not only stress-deprivation but also stress-enhancement significantly affect the mechanical properties of tendon autografts.

High initial tension reduces the postoperative anterior laxity of the knee joint after ACL reconstruction using the doubled hamstring tendons.
Increase of initial tension from 20 to 80 N significantly increases the initial stiffness of the fixation.
Additional increase of initial graft tension above 80 N does not increase the stiffness of the FT graft using an interference-screw-fixation for ACL reconstruction after cyclic loading.
Pathological changes in the graft such as increased central necrosis rate or cartilage damage due to 'overconstraining' of the knee may occur.
Graft Tensioning
Most surgeons do not tension the graft maximally. Cunningham, 2002

There is a range of tensions at which ACL grafts can be fixed.
Inadequate Tension results in

- continued instability

Excessive graft tension

- restriction of ROM

- arthrosis acceleration
Alternative Fixation Methods
Over The Top Femoral Fixation

- Primary and Revision Surgery
- Avoids problems associated with drilling a femoral tunnel
- Clinically successful
- Biomechanically sound
- Reproducible
Over The Top Femoral Fixation

Indications

- Posterior wall perforation
- Adolescent ACL reconstruction
- Revision surgery
- Surgeon’s preference
Press Fit Femoral and Tibial Fixation
Press Fit Femoral and Tibial Fixation
Cyclic Elongation - Creep

Press fit fixation, Musahl 2000
Advantages - Disadvantages

✔ No hardware
✔ Bone to bone healing
✔ No intraarticular defects
✔ Easier revision surgery
✔ Mini-Arthrotomy
ACL PROSTHESES
ACL PROSTHESSES

- Permanent Prostheses
- Non Degradable Scaffolds designed for tissue ingrowth
- Graft Augmentation Devices
- Resorbable Synthetics and Tissue-Derived Biomaterials
- Fibroblast Seeded Scaffolds
Synthetic Ligaments

- Scarcity of literature
- Not relying on permanent bone-polyester fixation
- The strength of the fixation is static and declines with time
- The ligament material fails progressively with time
- Ultimate rupture and failure is inevitable
- Foreign Body Reaction - Synovitis
- Not recommended for ACL reconstruction
Augmentation

- Stress shielding (28-45%)
- Unknown biological impact
- Clinically not necessary
- Probably useful in insufficient graft material
Conclusion

- Intraoperatively achieved fixation strength guides the postoperative regimen.

- Rehabilitation and reintroduction of activities should correlate with fixation strength achieved in the operating room.

- Clinical results are good with most fixation techniques
Conclusion

Improvement of biological incorporation of replacement grafts will lead to better insertion site healing and faster ingrowth of the graft.
Gene therapy

Cell therapy

Tissue Engineering

Growth Factors
Ευχαριστώ
Conclusion

If the surgeon performs < 30 ACL reconstructions/year he should use 1 technique

If he performs > 50 ACL reconstructions/year

he should be familiar with more techniques
Over-tensioning of the graft increases the forces in the graft at all angles of flexion causing:

- Posterior tibial subluxation
- Tensioning of the PCL
- Decreased range of AP laxity

It is not possible to find levels of graft tension that restored AP laxities at all flexion positions and restored forces in both grafts to those of their native cruciate counterparts during passive motion.
Goals of ACL reconstruction

- Sufficient initial strength to avoid fixation failure
- Sufficient stiffness to restore stability of the knee
- Anatomic fixation to minimize graft movement within the tunnel
- Sufficient resistance against slippage under cyclic loading
454 N is the critical graft substitute strength required to endure daily activities, which are recreated during rehabilitation.

Tension Pattern of the Intact ACL

Force, N

Flexion Angle, Degrees

20

120

140
Rehabilitation

Surgical Technique

Fixation

Graft

Patient

Injury
Subluxation followed by Reduction

the effect of reconstruction on the anterior translation characteristics of the centre of the tibia during the pivot-shift test
Graft Options

- Autograft – BPTB, QHT, Quadriceps
- Allograft – BPTB, Achilles Tendon
- Xenograft – Bovine
- Synthetic Grafts – Prosthetic Ligament, Ligament Augmentation Device, Scaffold
- Tissue Engineering – Future of ACL reconstruction
Hamstrings vs BPTB

- 7 prospective studies BPTB and QHT grafts

- 4 have found similar laxity values and functional results between the two types of graft tissues

- 3 found statistically tighter instrument measured values with the BPTB graft that did not correlate with functional outcome
The ideal fixation for hamstring graft should have the following features:

- Minimum length of free graft to reduce the bungee cord effect
- Ultimate reliance on good biological fixation
- Zero time fixation strength should be at least 500N
Brand et al., 2000
Screw & Washer System
Longitudinal Motion between Graft and Tunnel

Tensile Loading on Graft
Intrafix

Pullout data: Intrafix Vs. 9x28mm Abs. Screw
(foam bone w/tendons)

<table>
<thead>
<tr>
<th></th>
<th>Newtons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrafix w/6-8mm Screw Avg. in 9mm Tunnel (N=6)</td>
<td>937</td>
</tr>
<tr>
<td>9x28mm Abs. Screw Avg. in 9mm Tunnel (N=3)</td>
<td>442</td>
</tr>
</tbody>
</table>
Cross pin fixation

slingshot
In tension most ligament reconstructions fail at or near the fixation to bone

Modes of Failure
Suture knot
Cracking of bone block
Slipping of sutures through soft tissue
Slipping of graft past an IFS
Rigid Fix

Soft-Tissue (ST)

Bone-Tendon-Bone (BTB)
Braiding of the Hamstring Tendons

- Reduction in Strength and Stiffness
- Failure at the midsubstance
- Braiding is not advisable
No histologic evidence of foreign-body reaction or inflammatory response was seen in the area surrounding the femoral screw.
The challenge by Gareth Gorman which has almost certainly ended Pascal Vaudreuil's season.

(Photo: Paddy Gallagher)
“There are many choices of device to use for femoral fixation of a hamstring tendon graft, but none of the currently used soft tissue fixation devices has been proven to be biomechanically superior to the others.”
Graft load can be as high as 560 N with a 1500 N quadriceps contraction.

Extension exercises can induce loads in ACL greater than the strength of most fixation methods.
Most devices appear to achieve this
Graft-tunnel motion 2.4 vs 0.5 mm
Elongation of tendon 0.4 mm vs 0.1 mm

The elongation of the tendon accounts for only a small amount of graft-tunnel motion.
BPTB graft has slightly higher initial strength than intact ACL.

In multiple studies conducted to characterize strength of different screws, failure always occurred at fixation site.

Fixation rigidly depends on screw design.