Graft selection in ACL reconstruction

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Ideal graft for ACL reconstruction

① reproduce complex anatomy of ACL
② provide same biomechanical properties
③ permit strong & secure fixation
④ promote rapid biologic incorporation
⑤ minimize doner site morbidity

Poor results of primary suture repair of cruciate ligaments & LCL
→ other graft sources for reconstruction

* Decision factor for selection of graft
① surgeon and patient
② age
③ activity level of patient
④ cause of ligament disruption
⑤ type of surgery
⑥ surgeon's comfort with graft material
⑦ fixation with respect to technique of reconstruction

Three main categories of graft

1. autograft
2. allograft
3. prosthetic grafts

* Process of graft incorporation (ligamentization)
  ① graft necrosis
  ② cellular repopulation ; 1st 2 month- fibroblast, vascular proliferating cell
  ③ revascularization
  ④ collagen remodelling ; next 10 months
    -maturation stage : over next 2 years
      by 3 years, grafts are ligamentous by histological criteria
    → influenced by graft source, host response,
      biomechanical loading of graft during rehabilitation

* Avascularity of substitute tissue
  perceptible drop in initial strength : 10~15% of initial strength by 3~5th week after implantation
  → proper protection & guided rehabilitation
    graft : revascularized, regain strength 70% of original strength
    revascularization & recollagenization : 1 year ↑

Animal study
  • final tensile strength of graft
    -never greater than its initial tensile strength
  • use graft tissues that have an initial tensile strength greater than that of normal ligament

Biomechanical properties of ACL grafts

	Ultimate strength(N)	Stiffness(N/mm)	Cross sec area(mm^2)
Intact ACL	2160	242	44
P-PT-B (10 mm)	2376	812	35
Quadruple hamstring	4108	776	53
Quad tendon (10 mm)	2352	463	62
Anterior tibialis	3412	344	38
Posterior tibialis	3391	302	48

Reconstruction of ACL : replacement tissue - equal or greater strength to native ACL

1. Autografts

Harvest of tissue - own associated morbidity

Advantage

① no disease transmission

② eliminating an immune reaction to graft tissue

disadvantage

① Harvesting autologous tissue - increased op time, difficult revision

② Knee with multiple ligament injuries - add morbidity by harvesting a graft

1) Ipsilateral patellar tendon(BPTB) autograft

: Gold standard for primary ACL reconstruction

advantage

① high ultimate initial strength (2300~2900 N) & stiffness (620 N/mn)

② maintenance of natural tendon to bone interface

③ microstructure

④ associated bone block

—bone to bone healing, rapid revascularization, strongest initial fixation

⑤ accelerated rehabilitation program

⑥ decreased postsurgical morbidity ; early return to sports participation

disadvantage

① potential doner site morbidity - patellar fracture and tendon rupture

② patellofemoral pain (anterior knee pain)

③ tendinitis ; avoid resistive quadriceps exercise

④ injury to infrapatellar branch of saphenous nerve

⑤ quadriceps weakness ; 5~18% (12~24 months)

⑥ limited graft length limited collagen thickness, inability to use an appropriate sized graft in patients with small patellar tendon.

→ 10 mm patellar tendon autograft (patellar tendon widths of 24~35 mm)

⑦ possibility of physeal injury in skeletally immature patient

Immediate restoration of knee hyperextension following ACL reconstruction

→ eliminate anterior knee problems seen following BPTB ACL reconstruction

Trend towards greater anterior knee pain
: presxistinggrade 3 or 4 chondromalasia

BPTB ACL reconstruction- 4 year follow up (Shelbourne1990)
: 94% no further giving way episode
86% athletes - return to preinjury level of play

*(Indication)
: ① chronic ACL deficient knee,
② acute injury with mod~severe laxity in high level athlete
except older patients, less active patients & preexisting PF problems.
(Avoid) foot ball & sprinting athlete, carpet layer, tilers
bascket ball & tennis player — patellar tendinopathy

2) Contralateral patellar tendon autograft
: less knee surgery involved
separate rehabilitation program
return to full activity and sports earlier

(disadvantage)
① create symptomatic problem in contralateral knee
② quadriceps weakness
: 93% pre op strength at 1 year
95% at 2 year
③ activity related patellar tendinitis during 1st year
→ graft site morbidity : short duration, not long term concern

3) Semitendinosus / Gracilis autograft
: become increasingly popular
—less graft harvest morbidity
improvement in fixation devices
preservation of extensor mechanism

(advantage)

① decreased incidence of anterior knee pain, patellar tendinitis, & quadriceps weakness
② decreased risk for loss of motion
③ longer graft (double/guadruple → strength ↑ : 4000 N)
④ ability to safely harvest graft
⑤ ligament reconstruction in skeletal immature patient
; prevent formation of bone block across the physis & preserve growth potential

(Indication)

① Small patellar tendon
② History of patellofemoral pain
③ Bent knee activity (carpenter, plumbers, painter)
④ ACL revision after failed BPTB
⑤ avoidance of disrupting extensor mechanism

(Disadvantage)

Lack of rigid bony fixation for early aggressive rehabilitation & return to full activity
(protecting healing process at least 8 weeks)

(Biomechanics)

• single strand semitendinosus graft : 70% strength of ACL
single strand gracilis : 49%
→ double, quadruple : increase stiffness and strength
quadruple - stiffness : 807N/mm (ACL 3 times, twice BPTB)
ultimate tensile load : 4108N (ACL 3 times)
larger collagen cross sectional area than BPTB
Cybex : no significant difference in hamstring flexion or extension strength
→ 2 year follow up (Lipscomb, 1984)

(disadvantage)

① fixation : not as good as interference screw fixation of bone plug

② not enough to allow early ROM & weight bearing during incorporation

(Complication of harvesting)

saphenouss N injury(uncommon), tendon transection, altered hamstring function

(Avoid) history of recurrent hamstring tears /tendinitis

gymnastics & wrestling

<BPTB graft vs Hamstring graft>

1) Increased incidence of P-F pain & quadriceps muscle weakness with patellar autograft when compared with hamstring grafts

→ Patellofemoral pain

: BPTB autograft harvest : 16-47%

Hamstring autograft : 3-21%

ACL deficient knee (nonoperative) : 28%

→ not entirely attributed to graft harvest

(Cause of P-F pain)

① preexisting degenerative cartilage

② surgical iatrogenic damage

③ nonisometric graft placement

④ excessive scarring with development of flexion contractures

⑤ patellar entrapment

⑥ quadriceps muscle weakness

2) Doner site morbidity : hamstring - minimal

Hamstring grafts : normal quadriceps strength sooner (by 3~6 month)

no difference in quadriceps strength at 1 year post-surgery

Hamstring graft vs BPTB graft in chronic ACL reconstruction

—no difference in functional and clinical results (Marder 1991. Aglietti 1994)

* 4 studies with at least 2 year follow up

(Cooper 1993, Aglietti 1994; Paulos 1987, O' Neil 1996)

① Return to preinjury play

BPTB - 75%, Hamstring - 64%

② 20 lbs KT testing : 〉3mm laxity

BPTB - 17%, Hamstring - 29%

③ Equal results to functional outcome & patient' s satisfaction

3) Hamstring tendon autograft

: better in acutely reconstructed knee

Moderate P-F crepitus : 17% in BPTB reconstruction

3% in Hamstring reconstruction

Extension loss(〈3°) : 40% in BPTB group

3% in Hamstring group

Driving after reconstructionof ACL

: 4~6 weeks after operation

4) Quadriceps tendon bone autograft

length : 87±9.7 mm, stiffer than BPTB & most knee ligament

bulky (cross scetconal area ↑ ; 1.86 thicker),

ultimate tensile failure load : 2173 N (1.36 times that of BPTB)

bone to bone fixation on one end.

(advantage)

① avoids damaging infrapatellar branch of saphenous nerve

② decrease anterior knee pain

(disadvantage)

① weakness of quadriceps

② unsightly scar, technically difficult

No difference between BPTB &Quadriceps tendon ACL reconstruction at 1 year

(Griffith, Arthroscopy, 1998)

After 1 year : Q-strength - 80% of normal knee

(Indication) Revision ACL surgery

multiple ligament injury

5) Fascia lata autograft
alternative of additional graft material
weaker & least stiff grafts
advocated for proximal tibiofibular joint ligament reconstruction

6) Achilles tendon autograft
biggest strongest tendon in body with large cross sectional area of collagenous tissue
: one half of Achieles tendon with calcaneal insertion

(advantage)
① length (upto 15㎝) : elastic strain modulus
② maintanance of natural tendon to bone insertion
→ posterolateral corner reconstruction
PCL reconstruction
③ Bone to bone fixation on one end

(disadvantage)
① soft tissue fixation on one end
② lack of familiarity in harvesting tendon
③ risk of harvest morbidity
→ Achilles tendon rupture

7) Iliotibial tract
: IKDC normal or near normal : 77%
Same level of activity : 16%

2. Allografts

(advantages)
1) readily available
2) no doner site morbidity

3) flexibility in size and amount of tissue
4) smaller incision & improved cosmesis
5) reduced operative time.
6) placement of large, strong graft without removing other supporting structures or risking injury of harvest site

(disadvantage)
① disease transmission (hepatitis, HIV) -(incidence 1/1600000 - 1/8000000)
: radiation - collagen structure change, tensile strength ↓
② remodelling & effects on mechanical properties
③ immunogenicity ; slower biologic incorporation
④ preservation & 2ndary sterilization of grafts

Graft remodelling & mechanical properties
① healing pattern of allografts & autografts - similar
proceed at different rate
② frozen patellar tendon allograft - benign, comparable to autogenous tendon
freezing - immune response is blunted
freeze drying - superior to deep freezing of tissue for reducing immunogenecity of tissue
- alter graft mechanical properties
③ Rate controlled deep freezing, gamma radiation of less than 2.5 Mrad (1.5-2.5 Mrad)
→ diminish immune response without dramatically altering graft's mechanical properties
inactivate HIV → kill HIV (3Mrad) : structure change(+)
④ Ethylene oxide sterilization
-intraarticular reaction(+), synovitis, graft destruction
cystic change around graft channels
→ should be avoided

<Allograft vs Autograft>

① Allograft : weaker mechanically
less robust biologic response
less stable than autograft (Jackson 1993. 1991)

② Allograft - similar pattern of change in strength as autograft
(slow return of strength) (Jackson 1992)
revascularization & collagen orientation
→ *resembling normal ACL*

Allograft : similar both histologically & biomechanically (shino 1984)
(1 year post surgery)

③ Durability of allograft

Noyes (1993) - abnormal AP displacement as length of time from reconstruction increased
(1/3 of allograft)

Barber - Westin & Noyes (1995)
: no significant deterioration for AP displacement, P-F crepitus, pain, overall score graft failure : 3%

(Relative indication of Allograft)

① no autograft alternative
② multiple eijament reconstruction (to reduce morbidity)
③ chronic patellar tendon disruption
④ patents older than 40 years
⑤ revision ligament reconstruction

1) Patellar tendon allograft

results - favorable
no difference between allograft & autograft at 3 -5 yr post surgery (Johnson 1994)

(Indication)

① revision ACL reconstruction
② ACL reconstruction in multiple ligament injuried knee

③ PCL reconstruction

2) Achilles tendon allograft ; long soft tissue graft

(advantages)

① natural tendinous insertion to bone - bone to bone fixation at one end

② calcaneal bone plug - used for grafting of associated bony deficits (revision ligament surgery)

③ large cross sectional area of collagenous tissue for added biomechanical strength

(disadvantage)

; one end - tendon to bone healing (soft tissue fixation)

Achilles allograft ACL reconstruction

; vascularized completely by 1 year (biopsy)
linear orientation of collagen bundles
longitudinally arranged fibroblast - 18~24 month
no change in objective laxity measurement after 1st year
−87% - side to side difference of 〈 5 mm

(Indication)

① PCL reconstruction

② chronic, isolated lateral collateral ligament

③ combined LCL/posterolateral corner injuries

④ chronic patellar ligament & quadriceps tendon disruption

3) Fascia lata allograft

; ACL reconstruction
−67% normal strength by 6month, 82-95%(good, excellent)
Noyes (1990) - Knee stability : Fascia lata 78%, BPTB 82%
Failure : fascia lata 17%, BPTb 8%
(disadvantage) ;need for soft tissue tendon to bone fixation at both end

4) other allograft tissues
: Anterior or posterior tibial tendon
—equal or better strength & stiffness than hamstring tendons
; greater cross sectional area than flat tendon(BPTB, Achilles)
better fill in bone tunnel
—ACL reconstruction

3. Prosthetic grafts

ACL prosthetic ligaments

1) Permanent prosthesis: (Gore Tex, Stryker Dacron)
→ high ultimate tensile strength
limited potential for ingrowth
2) Scaffolds (Leeds - Keio, Carbon fiber ligament)
: allow ingrowth of autogenous tissue over time
→increase graft strength
3) Augumentation devices (LAD)
: act as a stent to supplement autogenous tissue and to protect the graft as it matures
→ helpful during revascularization & remodelling phase
→ but not proven to be benefit

(advantage)
; eliminate graft harvest morbidity
readily available
no risk of disease transmission
return to activity - not be limited
strength - exceed any biological tissue

(disadvantage)
; not very durable
high rates of early rupture in clinical practice
increased rate of infection
frequent effusion synovitis

tunnel osteolysis due to particulate debris
→ restrict to special cases

High failure rate as a result of fatigue, abrasion, particulate debris

4) Xenograft, tissue engineering grafts, growth factors & gene therapy

① Xenograft : limited vascular invasion, no growth of fibrous tissue, severe synovitis
- removal of alpha-Gal epitopes from xenograft
→ greatly reduced immune response

② Tissue engineering ligament graft
-biodegradable polymer scaffolds seeded with cell
include growth factors(TGF, PDGF, EGF, BFGF, BMP) promote healing of soft tissue & bone
→ future ACL reconstruction

③ Gene theraphy
Growth factor - hampered by short half life
To prolong GF delivery, required GF can be encoded into denatured viral or nonviral vector
→ invade target cell allowing sustained release of growth factor

Summary

1) Choice of graft selection
: depends on surgeon's philosophy & experience,
tissue availability(anatomical anomalies, prior surgery or injury)
& patient activity level & desiers.
patients - educated as to potential advantage & disadvantages of each choice available to them.
No one graft has been shown to be overwhelmingly superior to another.

2) High demand individual (cutting, pivoting, jumping sports, skiing)
- BPTB graft choice

Lower demand or older individuals - hamstring reconstruction
Allograft : older individuals(45 years old)
sign of arthritis(compelling evidence of instability)
individual who do not want their own tissue
Prosthetic ligaments - long term results : disappointing

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