Observation in Anterior Cruciate Ligament Reconstruction

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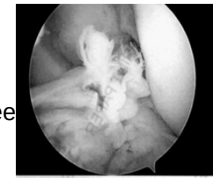
Anterior Cruciate Ligament Injury

The incidence:

- >250,000 / year (USA).
- 20,000 / year (Taiwan ?).

One of the most common knee surgery in sports injury.

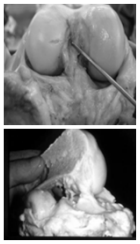


I personally performed 50 to 75 ACL and 30 to 40 PCL reconstructions annually at KCGMH.

Anterior Cruciate Ligament

1. Anteromedial bundle.
2. Posterolateral bundle.
3. Collectively, ACL provides 86% of anterior restraint of the knee.

AM and PL bundles are designated according to the tibia insertion sites.



Biomechanics (1)

The AM bundle is more isometric throughout flexion and extension and reaches the maximum tension between 60^0 and 90^0 of knee flexion.

The PL bundle loosens in flexion and tightens in extension.

The AM bundle restrains anterior translation, and is the primary stabilizer during flexion, whereas the PL bundle restrains rotational load and is the primary stabilizer during extension.

Overall, ACL is the primary restraint to anterior translation and secondary restraint to rotations, and the entire ACL resists hyperextension.

Biomechanics (2)

ACL load:

500 – 700 N on ADL.

600 N in jogging.

67 N in ascending stairs.

Downhill running creates the highest ACL strain.

The failure load – 1700 N.

Mechanism of Injury

- Plant and Pivot; or stop and jump activities.
- Forceful internal rotation of the externally rotated knee - basketball, soccer, rugby.
- Forceful valgus, external rotation of the knee- skiing.
- Forceful quadriceps contracture when falling backward with body weight on feet.

Types of Sports Injury

- Soccer (American football).
- Basketball.
- Skiing.
- Others.

75% occurred in non-contact injuries.
90% occurred during games.
* Basketball is the most common for ACL injury in Taiwan.

Diagnosis of ACL Injury

History of trauma.
Acute pain, popping and swelling within hours.
Soft end point in Lachman test is the key.
Pivot shift test in the late cases.
MRI
Arthroscope

Natural History of ACL Injury

Unknown.
In patients doing cutting and pivot activities – pain, givingway, meniscus tear, articular cartilage damage and osteoarthritis.
Osteoarthritis in untreated ACL injury – 70%.

Non-Operative Treatment

Successful candidates –
< 7 mm in KT-1000.
< 50 hours of cutting, pivoting and jumping sports per year. (one hour per week).

High failure rate in patients –
> 7 mm in KT-1000.
> 200 hours of cutting sports (4 hours per week).
Approximately 30% of ACL injury may do well with conservative treatment especially the recreation athletes.

Indications for Surgery

Life style and activity level are the keys to formulate the treatment plan.
Surgery for high risk/high physical demand patients.
Non-surgical for low risk/low demand patients.
Age and sex are not predictor factors.
Partial ACL tear : >50%, treated as complete tear; <50%, treated conservatively.
Chronic ACL injuries.
Combined ACL and multiple ligament injuries.

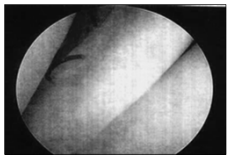
Combined Ligament Injuries

ACL + MCL:
ACL reconstruction only in most cases.
ACL + LCL:
ACL reconstruction + repair of LCL.
ACL + P-L instability:
ACL reconstruction + P-L reconstruction.

Meniscus Repair

Meniscus repair + ACL reconstruction achieve 85-90% healing rate.

However, meniscus repair alone without ACL reconstruction accomplished only 50-60% healing rate.



ACL Surgery

Golden time to do surgery -

When swelling subsided.

ROM returned.

Good muscle control.

Avoid arthrofibrosis.

ACL Surgery

Historically,

Jones (1963) - first patellar tendon used.

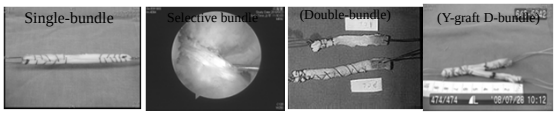
Bruckner (1966) - patellar tendon via bone tunnel.

Dandy (1980) - first arthroscopic ACL reconstruction.

Clancy (1980?) - autogenous ACL graft.

Surgical Techniques

- Single-bundle ACL reconstruction.
- Selective-bundle ACL reconstruction.
- Double-bundle ACL reconstruction.
  (Four tunnels two grafts; Three tunnels Y graft.)



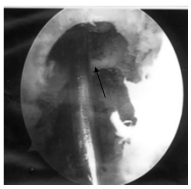
ACL Surgery

Femoral tunnel:

2.0 mm from the over the top position at the junction of the roof and lateral wall.

Anterior graft lengthens in flexion.

Posterior graft lengthens in extension.



*ACL footprint and over the top location are the key landmarks in femoral tunnel placement.

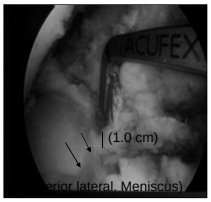
ACL Surgery

Tibia tunnel:

Posterior medial aspect of the ACL footprint, just anterior to the PCL.

Anterior graft will impinge on the roof.

Posterior graft will impinge on the PCL, and lengthen in extension.



*ACL footprint and the posterior margin of lateral meniscus and PCL are the landmarks for tibia tunnel placement.

Postoperative X-ray appearance

ACL Surgery

Sources of graft:
Autogenous grafts.
- Patellar B-T-B
- Hamstrings.

Allogenous grafts.
Synthetic ligament (??)

*Hamstring graft has steadily gained its popularity.

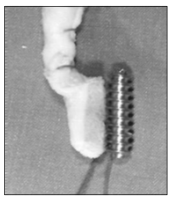
ACL Surgery

Advantages and disadvantages:

Patellar B-T-B	-	the harvest site morbidity. the graft length mismatch.
Hamstrings	-	primary graft fixation. tendon to bone healing.
Allografts	-	availability. quality of tissue bank. disease transmission.
Synthetic ligament	-	foreign body reaction. predicted failure in time. Costly.

ACL Surgery

Graft fixation:
- Interference screw (titanium, bio-absorbable).
- Suture post.
- Staples.
- Endo button.



The use of bio-absorbable interference screw is increasing.

ACL Surgery

Graft position and graft tension:

Ideal graft position	-	near full extension.
Initial graft tension	-	80 N the optimal graft tension is unknown.
Inadequate graft tension	-	incompetent, non-functioning graft.
Over tensioning of graft	-	over constraint knee with delay revascularization, degenerative changes and ultimate failure.

Complications

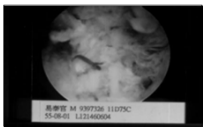
Intra-operative:

Graft site morbidity:

Tibia tunnel too anterior ------ graft impingement.

Femoral tunnel too anterior -- decreased ROM and potential graft failure.

Fixation problems ---------- graft damage, screw divergence, hardware extrusion, posterior wall blowout.

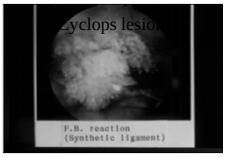


Complications

Postoperative:

Early: hematoma, infection, DVT, PE and N-V complications.

Late : arthrofibrosis, P/F pain, graft failure, painful hardware, and cyclops lesion.



Postoperative Managements

Accelerated rehabilitation program (Shelbourne et al AJSM 1990)

Emphasize full extension.
Immediate early full weight bearing.
Decreased pain, swelling and inflammation in 1-2 weeks.
Closed chain exercises.
Return to sports;
Non-contact activities - 70% thigh muscle strength.
Contact activities - 85% thigh muscle strength.
Sprinting - 89% thigh muscle strength.

Postoperative Management

Functional brace -

Protection of the graft at low load.

No difference with or without brace after ACL reconstruction.

Do not waste money !

Clinical Outcomes (literatures)

- Non-operative treatments in high risk/high demanding patients - 60-70% failure rate.
- Surgical outcomes of ACL reconstruction - 70-100% satisfactory results.
- However, approximately 15 to 25% of the ACL grafts failed.*
- Not changed in the past 20 years.

* *Shelbourne KD et al. Am J Sports Med 1997;25:786-795*

* *Bach BR et al Am J Sports Med 1998;26:20-29.*

Personal Experiences

We performed 50 to 75 ACL, and 30 to 40 PCL reconstructions annually at KCGMH.

The results of 84 patients (84 knees) with 2 – 6 year follow-up.

Excellent	50.0%
Good	29.8%
Fair	19.0%
Poor	1.2%

Bio-absorbable screws were used in all cases.

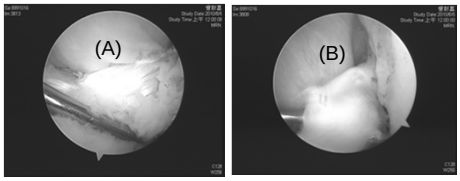
Common causes of ACL failure

1. Surgical technique;
   Mal-position of bone tunnels, misplaced fixation device, inadequate notchplasty (?).
2. Biological;
   Lack of graft incorporation because of avascularity, rejection or stress shielding.
3. Mechanical;
   Re-injury or overt aggressive rehabilitation.

Observation in ACL Graft Failure

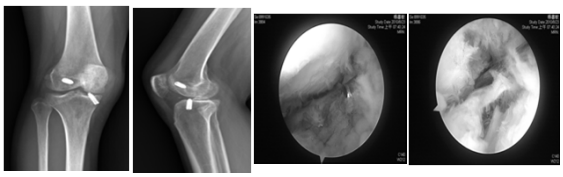
1. Most failures occurred within 3 to 6 months postoperatively.
2. The symptoms due to ACL graft failure varied considerably from individual to individual.
3. Arthroscopic findings revealed “stretched out” or “lax graft”, but intact and viable graft tissues are observed in most cases.
4. ACL failure occurred in both single-bundle and double-bundle reconstructions.

ACL Graft Failure



(A). Good initial graft tension was verified arthroscopically. (B). Lax (loose) ligament and knee instability due to “stretched-out” of the viable graft with bio-screw fixation.

Technical Errors in ACL Reconstruction

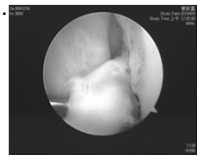


Mal-position of the tunnels, graft impingement and arthrofibrosis are among the most common causes of ACL failure. However, ACL graft failure also occurs in knees with optimal surgical technique.

ACL Graft Failures

Regardless the cause, our observations suggest that ACL graft failure is more likely due to lack of ligamentization between tendon and bone in the bone tunnel. and is attributed to inadequate graft fixation.

The incidence of graft failure further increased as the aggressive rehabilitation program was utilized.



Ligamentization at the tendon-bone interface vs graft fixation

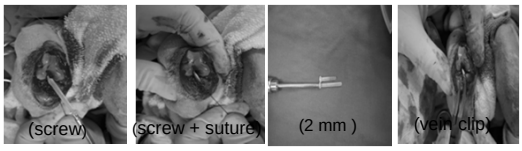
Does it exist?

How long it takes?

Does bio-screw provide adequate fixation?

Graft fixation with bio-screw + suture vs bio-screw only in ACL reconstruction

(Experimental study in rabbits)



Group I: Tibia tunnel was fixed with 2.0 mm bio-screw only.
Group II: Tibia tunnel was fixed with 2.0 mm bio-screw plus suture fixation.
Vein clip secured in ACL graft was used as a marker.

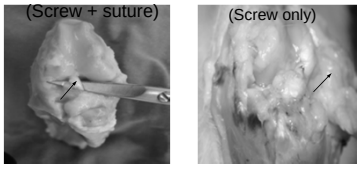
Graft displacements in screw fixation only and screw + suture fixation after ACL reconstruction

(mm)	1wk	4wks	8wks	12wks
Screw only (N=5)	4.38±0.81	5.56±1.77	5.32±0.32	5.43±0.25
Screw+suture (N=5)	2.41±0.4	2.6±0.53	3.55±0.21	4.07±0.46
P-value	0.037	**0.039**	**0.067**	**0.057**

Graft stability between screw plus suture fixation and screw fixation only in rabbits.

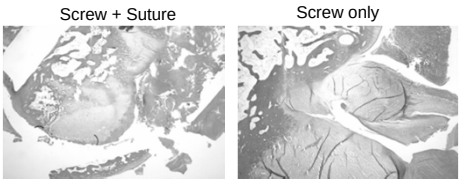
Serial radiographs of the knee showed significantly better graft stability and less graft migration were noted in knees with bio-screw plus suture fixation than screw fixation only.

Graft stability in screw plus suture fixation and screw fixation only in rabbits



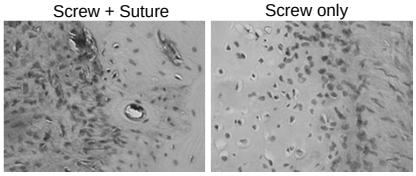
Intact and viable graft with very little graft migration in knees with screw + suture fixation, whereas significant graft migration was noted in knees with screw fixation only.

Tendon and bone integration under H&E stain (Histological examination)



(%)	**12 wks**
Screw only	19.98±5.39
screw+suture	54.3±14.67
P-value	0.05

BMP-2 expressions at tendon-bone junction

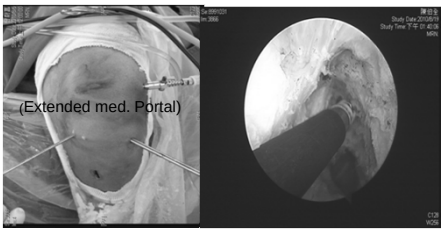


(%)	12wks
Screw only	29.78±1.95
Screw+suture	42.54±3.87
P-value	0.04

Changes in ACL Surgery

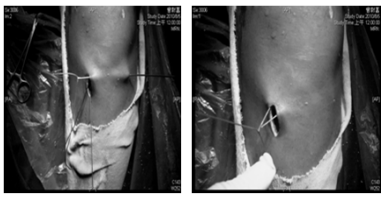
1. Extended medial portal for femoral tunnel placement produces more physiological graft pattern.
2. Bio-absorbable interference screw + suture fixation for tibia tunnel.
3. Double-bundle and selective-bundle ACL reconstructions (?).
4. Enhancement of tendon-bone healing
   (1). Gene therapy (pCMV-BMP-2 gene therapy).
   (2). ESWT.
   (3). periosteum enveloping of tendon graft.
4. Modify postoperative rehabilitation.

Extended medial portal approach



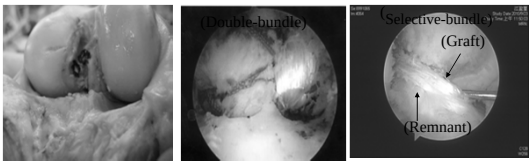
It produced more horizontally oriented graft (duckbill) at the proximal end that avoids graft impingement against the intercondylar notch.

Bio-absorbable screw plus suture fixation in tibia tunnel.



Interference bio-screw plus suture fixation is better than screw fixation only in tibia tunnel..

Double-bundle and selective-bundle ACL reconstructions

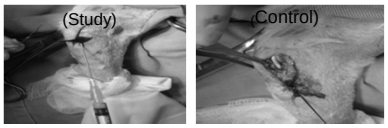


Double-bundle ACL reconstruction theoretically provides stability of A-P translation (AM bundle) and rotational load (PL bundle) of the knee.

Selective-bundle reconstruction augments with the remnants. Functional outcomes of single- vs double-bundle ACL reconstructions?

Gene Therapy (pCMV-BMP-2 gene)

- The pCMV-BMP-2 is synthesized from full-length human BMP-2 cDNA followed by cloning into pCMV Script vector. In the study group, A 3 x 10^7 pCMV-BMP-2-transfected NRK cells encapsulated in 2 ml of the fibrin scaffold were placed at the tendon-bone interface during ACL reconstruction, whereas no gene as used in the control.



(Wang CJ et al, Arthroscopy and related surgery July 2010)

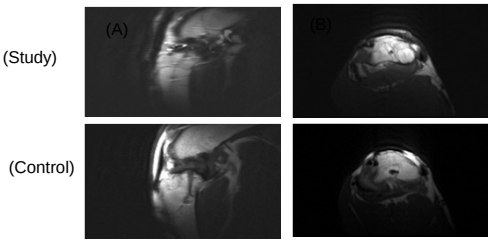
Results of MRI (tendon-bone healing in bone tunnel)

The distance between tendon and bone in mm.

	Study (N=18)	Control (N=18)	P-value
Proximal	**1.19±0.57**	**1.2±0.51**	**0.779**
Middle	**0.76±0.14**	**1.3±0.51**	**0.056**
Distal	**0.32±0.14**	**1.0±0.27**	**<0.0001**

The study group showed significantly better contact and a smaller gap between tendon and bone as compared with the control group, especially at the distal 1/3 of the bone tunnel. The changes in the proximal and middle 1/3 were not as dramatic probably due to gravity shifting of the cells in the scaffold.

Results (MRI)

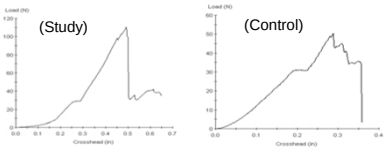


MRI in longitudinal (A) and transverse plane (B) showed better contact and a smaller gap between tendon and bone in the study group, and less contact and a larger gap in the control group.

Results (Biomechanical study)

The Results of Biomechanical Testing on MTS

	Study (N=9)	Control (N=9)	P-value
Tensile strength			
Mean±SD (N)	**69.93±6.98**	**51.768±4.14**	**0.034**
Tensile stiffness			
Mean±SD (N/mm²)	**10.6±1.04**	**10.33±2.57**	**0.47**
Mode of graft failure			**0.018**
Intra substance tear	**7 (78%)**	**2 (22%)**	
Pull-out from tunnel	**2 (22%)**	**7 (78%)**	



Results (Biomechanical study)

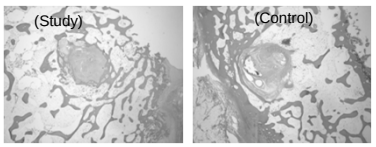
The study group showed significantly higher maximal tensile strength of the graft than the control, however, no difference is peak tension stiffness. Graft failure because of rupture of the tendon proper occurred in 78% of specimens in the study group and 22% in the control group. Failure occurred because of graft pullout from the bone tunnel for the remainder of specimens: 22% in the study group and 78% in the control group.

Results (Histological examination)

Contact between tendon and bone within a bone tunnel.

Contact (%)*	Study (N=9)	Control (N=9)	P-value
Mean ± SD	**85.3%±2.2%**	**47.7%±0.5%**	**0.0004**
Tissue distribution			
Bone	**69.5%±7.4%**	**49.3%±3.6%**	**0.0471**
Cartilage	**5.8%±0.5%**	**4.5%±0.3%**	**0.065**
Fibrous tissue	**24.7%±7.0%**	**46.1%±3.9%**	**0.0481**

***The percentage area showed contact between tendon and bone in 360° around the tendon graft.**



Results (Histological examination)

- The study group showed significantly more intimate contact and smaller gap between tendon and bone within the bone tunnel than the control.
- There was significantly more bone tissue and less fibrous tissue around the tendon graft in the study group as compared to the control group.

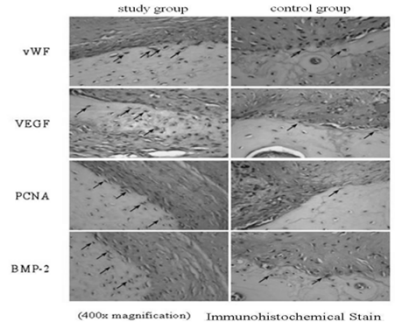
Results (Immunohistochemical analysis)

	(Mean±SD)		
	Study (N=9)	Control (N=9)	P-value
vWF	**77.0%±2.4%**	**25.6%±8.1%**	**0.0025**
VEGF	**49.5%±2.1%**	**21.7%±4.2%**	**0.0011**
PCNA	**80.9%±2.4%**	**64.9%±1.4%**	**0.0045**
BMP-2	**71.2%±4.2%**	**34.5%±5.6%**	**0.0006**

The values refer to the percentage of positive stained cells for the specific reagent.

The study group showed significant increases in vWF, VEGF, PCNA and BMP-2 compared with the control group. These findings suggest that pCMV-BMP-2 gene therapy significantly enhanced new vessel formation, cell activity, and remodeling between tendon and bone within the bone tunnel.

Results (Immunohistochemical analysis



The microscopic features in immunohistochemical stain showed significantly higher values of vWF, VEGF, PCNA and BMP-2 in the study group than the control group (400x magnification).

Conclusion

pCMV-BMP-2 gene therapy significantly enhances the healing of tendon to bone and promotes angiogenesis and osteogenesis at the tendon-bone interface after ACL reconstruction in rabbits.

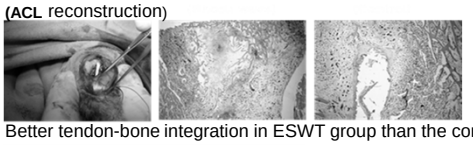
The tendon-bone interface treated with pCMV-BMP-2 gene therapy shows better integration between tendon and bone and provides better graft stability after surgery.

Application of pCMV-BMP-2 gene therapy may be an effective adjunct therapy to provide therapeutic benefits to enhance biological integration of tendon to bone after ACL reconstruction.

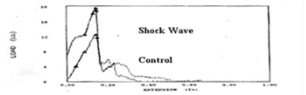
Extracorporeal shockwave therapy enhances the healing of tendon to bone in bone tunnel after ACL reconstruction in rabbits.

CJ Wang, M.D. et al. J Orthopaedic Research 2005: 23: 274-80.

(ACL reconstruction)

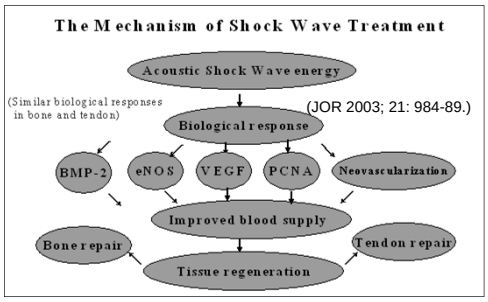


Better tendon-bone integration in ESWT group than the control.



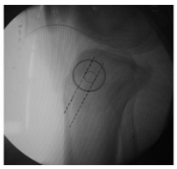
Better graft tension and failure load in ESWT group than the control.

Biological Mechanism of Shockwave



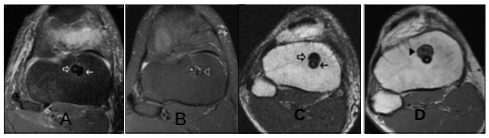
這個震波的作用機轉很受國際專家學者的肯定與共識，被採納為金科玉律，多次在國際性學術研討一再被引用，在全世界豎立一個圭臬，提高台灣在世界的學術知名度。

ESWT enhances tendon-bone interface healing after ACL reconstruction in human subjects.



The study group included 17 patients with 17 knees who received 1500 impulses of ESWT at 14 Kv to mid-tibia tunnel after ACL surgery. The control group consisted of 17 patients with 17 knees that did not receive ESWT.

ESWT on Tendon-Bone Healing after ACL Reconstruction



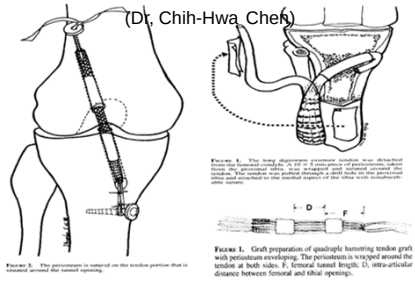
MRI of the ESWT group showed hypointense graft and screw immediately after surgery (A), and integration of graft with surrounding bone marrow 6 months after surgery + ESWT (B).

MRI of the control group depicts ACL graft and screw in tibia tunnel immediately after surgery (C). and enlargement of the tunnel 6 months postoperatively.

ESWT significantly enhanced the early tendon-bone healing and decreased the tibia tunnel enlargement after ACL reconstruction.

Periosteum enveloping of the ACL graft.

(Dr. Chih-Hwa Chen)



Periosteum enveloping enhances graft fixation to bone.

Summary

ACL reconstruction is one of the most successful procedure for knee injury in sports.

The success in ACL surgery relies on patient selection, surgical skill and postoperative rehabilitation.

Despite the improvement in surgical technique, approximately 15 to 25% of ACL grafts failed.

The cause of graft failure is multi-factorial, but in part is due to inadequate graft fixation and lack of ligamentization. Several innovative methods are shown effective in the improvement of graft fixation.

Modified postoperative rehabilitation with longer protection for the graft may be beneficial to the healing of ACL graft.