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# Biomechanical properties of fixation methods

**Fernando Fonseca, MD PhD**

**António Completo, PhD**



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FHUC FACULDADE DE MEDICINA  
UNIVERSIDADE DE COIMBRA

**Conflict of interest: None**



# ACL biomechanics

- Biomechanical properties of the ACL are determined by:
  - the geometry of the ligament as well as the tensile characteristics of both ligament midsubstance and the ligament-to-bone insertion site
- They can be characterised by the relationship between ligament length and ligament tension, which can be determined when simultaneously measuring load and the corresponding elongation during experimental uniaxial tensile testing
- Biomechanical properties of a ligament are represented by the relation of stress and strain, where:
  - stress is defined as deformation per unit length (%)
  - strain is defined as load per unit cross-sectional area ( $\text{N}/\text{mm}^2$ )

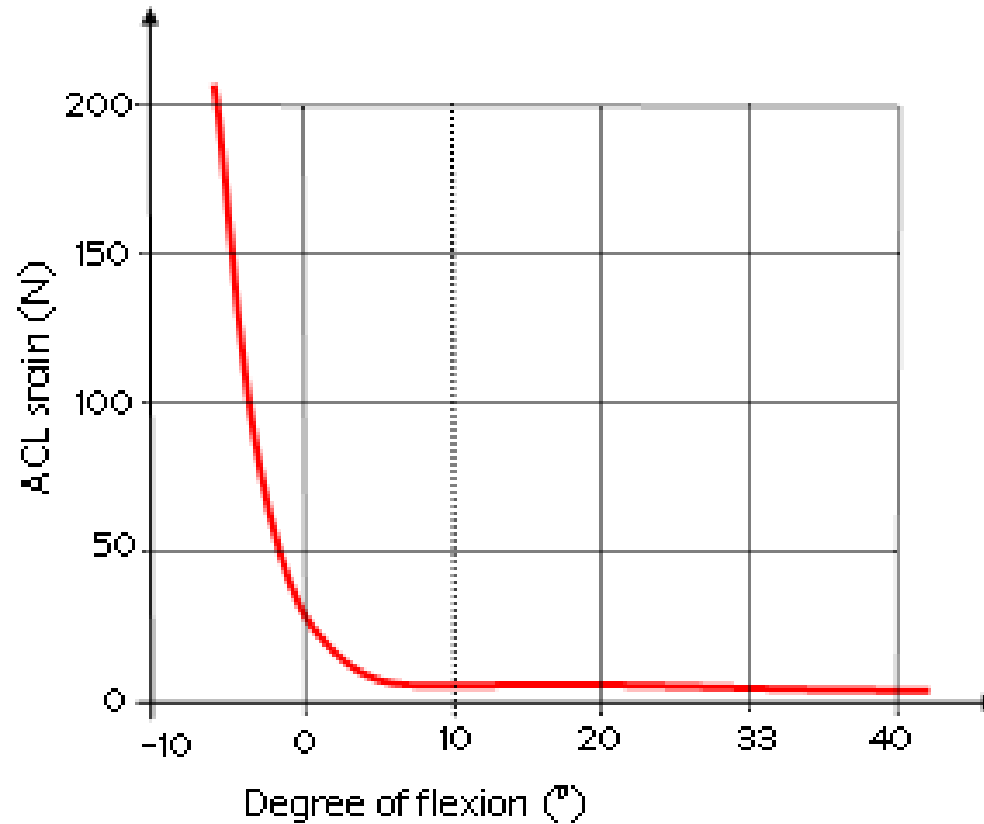


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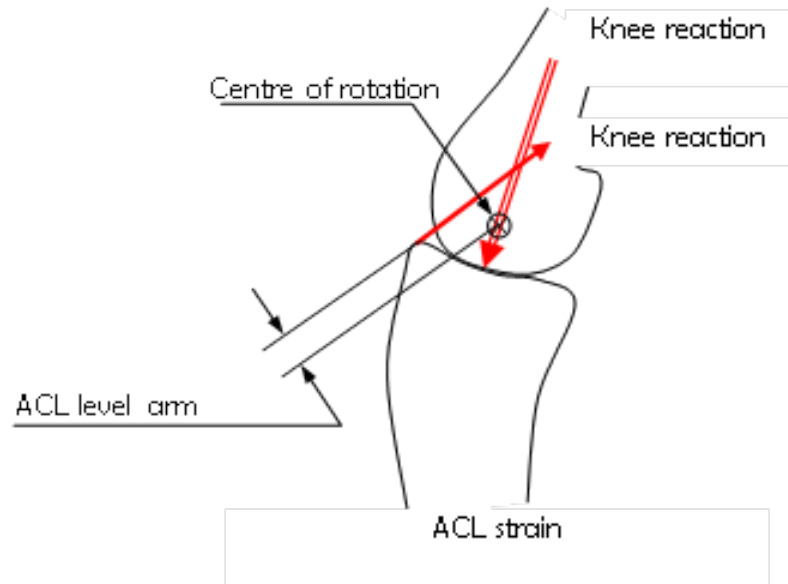
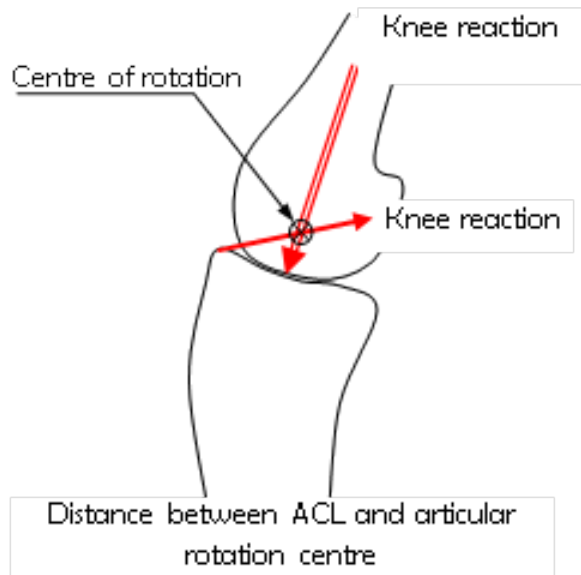


# ACL strain





# ACL biomechanics





# ACL biomechanics

- **Hyper-extension:**

- the posterolateral bundle of the ACL is tight in extension;
- at 5 degrees of hyperextension, ACL forces range between 50 and 240 newtons;
- hyperextension of the knee develops much higher forces in ACL than in the PCL;

- **Flexion:**

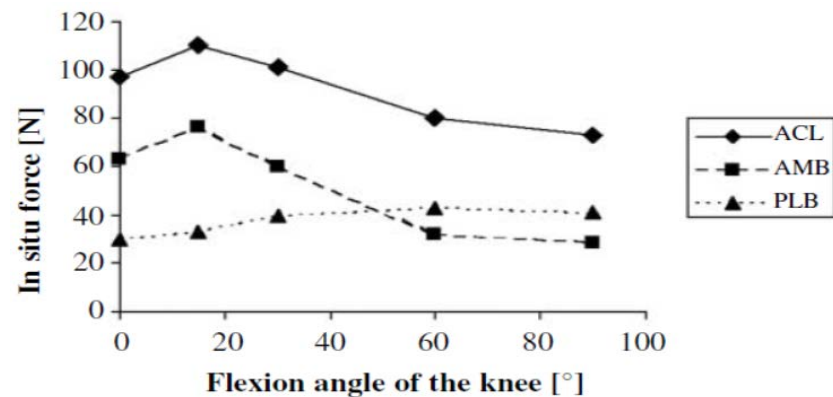
- the anteromedial bundle of the ACL is tight in flexion;
- during isometric quadriceps contraction, ACL strain at 30 deg of knee flexion are significantly higher than at 90 deg where ligament remain unstrained with isometric quadriceps activity;
- active extension of knee between the limits of 50 and 110 degrees does not strain the anterior cruciate;
- at 90 deg of knee flexion:
  - ACL accounts for approx 85% of resistance to anterior drawer test



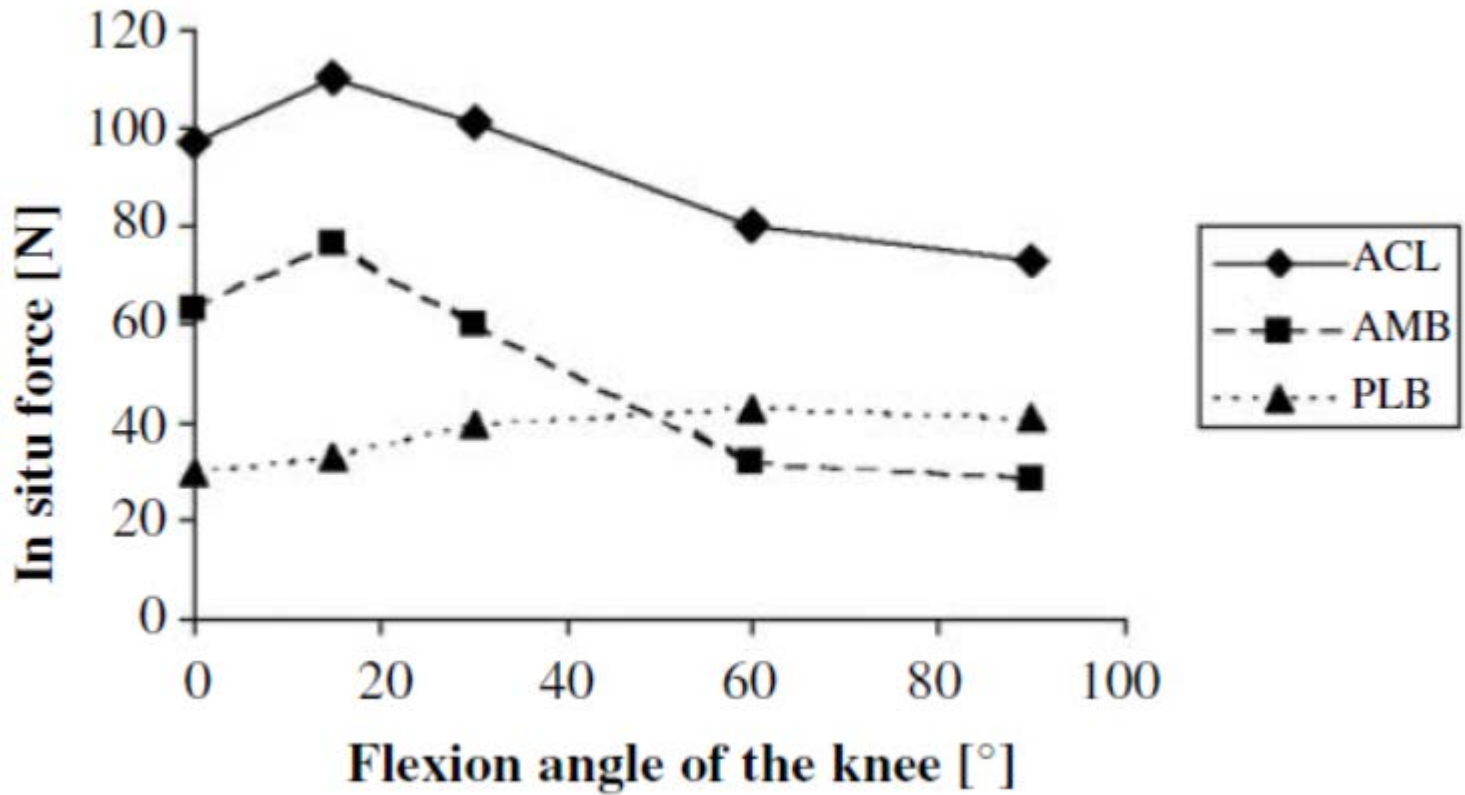
# ACL biomechanics

## Biomechanics:

- ultimate tensile load:  $2160 \pm 157$  N
- stiffness:  $242 \pm 28$  N/mm;
- passive knee extension produces forces along ACL only during last 10 degrees of knee extension;
- normal level walking loads of 169 N
- descending stairs loads of 445 N
- ascending stairs loads of 100 N



Sakane M, Fox RJ, Woo SL, Livesay GA, Li G, Fu FH;J  
Orthop Res. 1997 Mar; 15(2):285-93.



Sakane M, Fox RJ, Woo SL, Livesay GA, Li G, Fu FH; J Orthop Res. 1997 Mar; 15(2):285-93.



# ACL reconstruction goals

- Choice of graft material
  - patellar tendon-bone grafts or quadrupled hamstring tendon grafts
- Correct bone tunnel placement
- Adequate graft (pre-)tension
- Graft fixation using graft fixation materials that provide an initial fixation strength exceeding those loads commonly expected during rehabilitation.
  - anatomical graft fixation;
  - sufficient initial graft fixation strength.



# Sufficient graft fixation strength

- The importance of secure graft fixation has dramatically increased as current rehabilitation protocols emphasise early weight bearing after ACL reconstruction and as the fixation site is known to be the weakest link during the early postoperative period
- Graft fixation to bone should furthermore consider that the bone mineral density and the angle of force application significantly differ between the femoral and the tibial bone.
  - Drilling the femoral tunnel with the knee flexed between  $90^\circ$  and  $120^\circ$ , studies on the line of force transmission have shown that the femoral graft fixation strength increases as the angle between the axis of the bone tunnel and the axis of the ligament increases during extension of the knee



# Sufficient graft fixation strength (2)

- On the tibial side, the line of force on the graft is directly in line with the tibial bone tunnel.
  - Tibial graft fixation techniques for patellar tendon-bone grafts showed that interference screw fixation provided superior ultimate strengths of 293–758 N when compared to techniques using sutures and staples
  - Femoral fixation of patellar tendon-bone grafts demonstrated that interference screws, extracortical buttons and transverse fixation systems provided similar fixation strengths ranging from 418 to 640 N



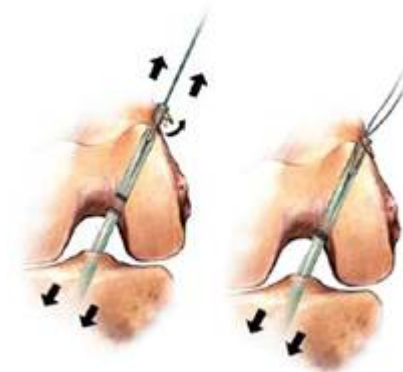
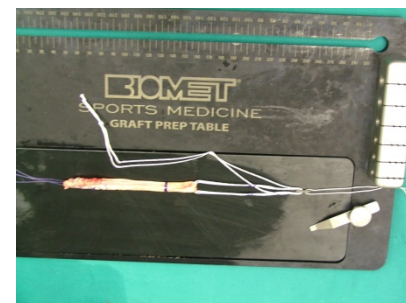
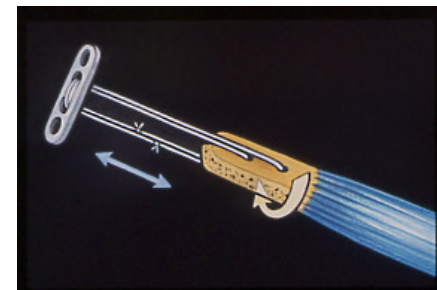
# Current fixation devices

- Femoral
  - Cortical suspensory system
  - Interference screw
  - Cross-pin
- Tibial
  - Interference screw
  - Bio-intrafix



# Cortical suspensory system

- Non-anatomical
  - Potential space
  - Windshield piston
  - Tunnel widening
- Posterior wall without function
- Great elasticity
- Mechanical failures
  - 1 to 3 mm at load 100/300 N  
FHFu, Am J Sports 1999
- Trade Mark
  - Endobutton (S&N)
  - ToggleLoc (Biomet)
  - EZLoc (Arthrotek)





# Controversies

**Femoral cortical suspension devices for soft tissue anterior cruciate ligament reconstruction: a comparative biomechanical study.**

**Petre BM et al**

**The American Journal of Sports Medicine, Vol. 41, No. 2 - 2013**

**RESULTS:** There were significant differences in the ultimate failure loads among the devices. The highest ultimate failure loads when tested as a construct were observed for the XO Button (1748 N), followed by the Endobutton CL (1456 N), ToggleLoc with ZipLoop (1334 N), and TightRope RT (859 N). Cyclic displacement after 1000 cycles during isolated device testing was less than 1 mm for all devices. Cyclic displacements after 1000 cycles in the porcine construct were 1.88 mm, 2.74 mm, 3.34 mm, and 1.82 mm for the Endobutton, TightRope, ToggleLoc, and XO Button, respectively; all were significantly different from each other except when the Endobutton was compared with the XO Button. The ToggleLoc exceeded the 3.0-mm displacement threshold defined as a clinical failure. The most displacement occurred during the first cycle, especially for the adjustable-length loop devices. Stiffness reapproximated the native ACL stiffness for all constructs.

**CONCLUSION:** The Endobutton, TightRope, and XO Button have the necessary biomechanical properties with regard to ultimate failure strength, displacement, and stiffness for initial fixation of soft tissue grafts in the femoral tunnel for ACL reconstruction. The ToggleLoc had sufficient ultimate failure strength but crossed our 3.0-mm clinical failure threshold for cyclic displacement. Although this study was not designed to compare fixed and adjustable-length loop devices, it was noted that both fixed-loop devices allowed less cyclic displacement and initial displacement.

**CLINICAL RELEVANCE:** Adjustable-length loop devices may need to be retensioned after cycling the knee and fixing the tibial side to account for the increased initial displacement seen with these devices



# Controversies

**Femoral suspension devices for anterior cruciate ligament reconstruction: do adjustable loops lengthen?**

**Barrow AE et al**

**The American Journal of Sports Medicine, Vol. 42, No. 2 - 2014**

**RESULTS:** Total displacement after 4500 cycles of tensioning at variable loads (expressed as mean  $\pm$  SD) was 42.45 mm ( $\pm$ 7.01 mm) for the Arthrex TightRope RT, 5.76 mm ( $\pm$ 0.35 mm) for the Biomet ToggleLoc, and 1.34 mm ( $\pm$ 0.03 mm) for the Smith & Nephew EndoButton CL Ultra ( $P < .001$ ). The Arthrex TightRope reached clinical failure of 3 mm lengthening after fewer cycles ( $1349 \pm 316$ ) than the Biomet ToggleLoc ( $2576 \pm 73$ ) ( $P < .001$ ). The Smith & Nephew EndoButton did not reach clinical failure during cyclic testing. With the free suture ends tied, after 4500 cycles, the Arthrex TightRope had a significant decrease in lengthening to  $13.36 \pm 1.86$  mm ( $P < .037$ ) There was also a significant difference in ultimate load between the TightRope ( $809.11 \pm 52.94$  N) and the other 2 constructs ( $P < .001$ ).

**CONCLUSION:** The ultimate load of all graft-fixation devices exceeded the forces likely to be experienced in a patient's knee during the early postoperative rehabilitation period. However, the adjustable-length fixation devices experienced a clinically significant increase in loop lengthening during cyclic testing. This lengthening is partially caused by suture slippage into the adjustable-length loop.

**CLINICAL RELEVANCE:** Adjustable-length ACL graft cortical suspension devices lengthen under cyclic loads because free suture ends are pulled into the adjustable loop. This may allow for graft-fixation device lengthening during the acute postoperative period.

# Controversies

- Windshield piston
- Tunnel widening



ToggleLoc™ Device w/ZipLoop™



Smith & Nephew EndoButton® CL



# Controversies

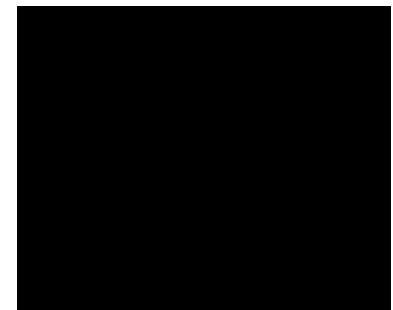
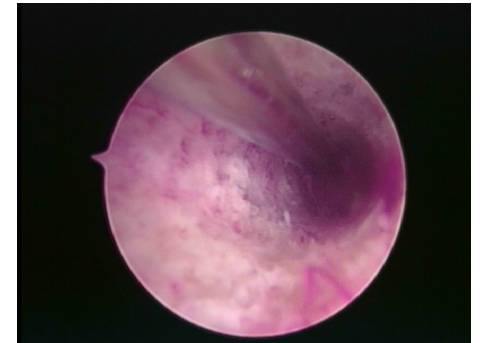
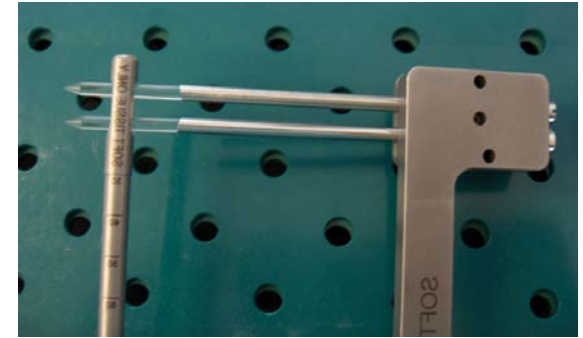
## Results – ANOVA

Variable	Endobutton	Retrobutton	ToggleLoc with Ziploop	ACL Tightrope	ANOVA
Displacement (mm)	0.154 ± .017	0.159 ± .017	0.718 ± .116	0.336 ± .067	< 0.001
Load to Failure (N)	1253 ± 62	1074 ± 172	1120 ± 184	814 ± 76	< 0.001
Displacement at failure (mm)	2.89 ± .16	2.58 ± 1.02	2.94 ± .64	1.47 ± .14	< 0.001



# Cross-pin

- Wire guidance
- Metallic or resorbable
- Material require intra-articular device
- Does not require intact posterior wall
- Trade Mark
  - RigidFix (Depuy-Mitek)
  - PINN-ACL Cross Pin (CondMed Linvatec)





# Controversies

**Biomechanical comparison of Cross-pin and Endobutton-CL femoral fixation of a flexor tendon graft for anterior cruciate ligament reconstruction--a porcine femur-graft-tibia complex study**

Shen HC et al

J Surg Res, Vol. 161 (2) 2010

## **RESULTS:**

The amount of total femur-graft-tibia complex graft displacement was significantly lower in the Cross-pin fixation group (5.37 +/- 0.28 mm) than in Endobutton-CL fixation group (6.08 +/- 0.61 mm:  $P < 0.05$ ). There were no significant differences in the maximal failure load, yield load, and stiffness between the Cross-pin and Endobutton-CL fixation groups.

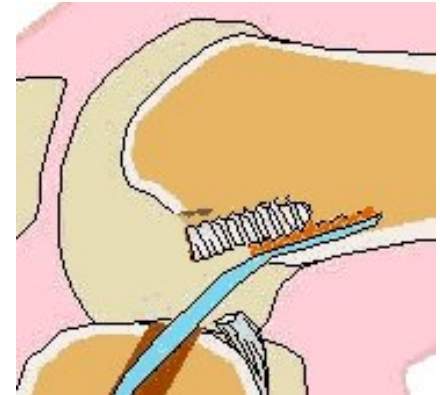
## **CONCLUSIONS:**

This biomechanical study reveals that the Endobutton-CL and Cross-pin femoral fixation devices have an equally strong and safe fixation for ACL reconstruction. However, the Cross-pin fixation has significantly less displacement of femur-graft-tibia complex than that of Endobutton-CL fixation in response to the cyclic loading test. It indicates that the Cross-pin fixation is more suitable for early aggressive rehabilitation following ACL reconstruction.



# Interference screw

- Anterior (superficial) to the graft
- Material does not require intra-articular device
- Does not require intact posterior wall
- Impingement with graft if screw inferior to the graft
- Beware of the femoral screw insertion hole



# Tibial fixation

- Usually screw interposition
- Bone is "very tolerant"
  - The largest possible diameter for STRI
- Interference screw
- Screw and Sheath





## **Biomechanical Comparison of Interference Screws and Combination Screw and Sheath Devices for Soft Tissue Anterior Cruciate Ligament Reconstruction on the Tibial Side**

**Cathrine Aga et al**

**The American Journal of Sports Medicine, Vol. 41, No. 4**

The ultimate failure loads were highest for the GraftBolt ( $1136 \pm 115.6$  N), followed by the INTRAFIX ( $1127 \pm 155.0$  N), AperFix II ( $1122 \pm 182.9$  N), BIOSURE PK ( $990.8 \pm 182.1$  N), Bio-Interference Screw ( $973.3 \pm 95.82$  N), BIOSURE SYNC ( $829.5 \pm 172.4$  N), RCI Screw ( $817.7 \pm 113.9$  N), and ExoShape ( $814.7 \pm 178.8$  N). The AperFix II, GraftBolt, and INTRAFIX devices were significantly stronger than the BIOSURE SYNC, RCI Screw, and ExoShape. Although the 3 strongest devices were combination screw and sheath devices, no significant differences were observed between the ultimate failure strengths of the screw and combination devices when compared as groups. The least amount of cyclic displacement after 1000 cycles was observed for the GraftBolt ( $1.38 \pm 0.27$  mm), followed by the AperFix II ( $1.58 \pm 0.21$  mm), Bio-Interference Screw ( $1.61 \pm 0.22$  mm), INTRAFIX ( $1.63 \pm 0.15$  mm), ExoShape ( $1.68 \pm 0.30$  mm), BIOSURE PK ( $1.72 \pm 0.29$  mm), BIOSURE SYNC ( $1.92 \pm 0.59$  mm), and RCI Screw ( $1.97 \pm 0.39$  mm). The GraftBolt allowed significantly less displacement than did the BIOSURE SYNC and RCI Screw. Similarly, no significant differences were observed between the cyclic displacements of the screws and combination devices when compared as groups.



# Graft fixation strength

	Fixation technique	Ultimate failure load [N]	Stiffness [N/mm]
Intact ACL		2160±157	242±28
Quadrupled hamstring tendon graft		4140±n.n.	807±n.n.
Tibial	Interference screw	776±155	226±56
	Suture/post	830±187	60±14
	Washer (20 mm)	930±323	126±28
Femoral	Interference screw (b)	507±93	58±14
	Interference screw (b)	621±139	76±20
	Interference screw (t)	419±77	40±11
	Interference screw (t)	774±154	80±15
	Cross-pin	737±140	
	Endobutton	864±164	
	Transfix	746±119	
Patellar tendon-bone graft		2376±151	
Tibial	Interference screw (b)	718±219	46±5
Femoral	Interference screw (b)	707±169	115±26
	Interference screw (b)	702±168	190±78
	Interference screw (t)	681±146	107±25
	Press-fit	571±109	125±29
	Cross-pin	639±156	226±63

J. Dargel et al.; Strat Traum Limb Recon (2007)



# Conclusion

- All fixation devices have good resistance qualities
- Using Taglock be sure that device is well fastened
- Don't forget the other rules of a good ACL reconstruction
  - Correct bone tunnel placement
  - Adequate graft (pre-)tension

