

Management of ACL injuries in the skeletally immature

www.fisiokinesiterapia.biz

Relevance

- The interest in pediatric ACL injuries has risen dramatically over the past 10 years evident by the increasing numbers of articles published
- Although difficult to prove, there seems to be an increased incidence of ACL injuries in the skeletally immature
- Clanton (JBJS 61(8), 1979) reported a 1% incidence of ACL injuries among the young (most were tibial spine fractures)
- McCarroll (AJSM, 1985) reported that 3.3% of all ACL injuries occurred in skeletally immature patients (of 1722 cases)
- The increase in incidence is likely the result of both improved diagnostic capabilities and increased sports participation (especially among girls)
- Shea (JPO, 2004) found 6.7% ACL injury claims among soccer players 5-18 yrs for 6 million player-years



Why care

- Kocher et al (JPO, 2002) surveyed members of the Herodicus Society and the ACL Study Group and found that on average the respondents saw 5.8 pediatric ACL injuries per year and 78% had performed ACL reconstruction on a skeletally immature patient (139 respondents)
- Although a lot of these injuries end up in the hands of surgeons who have a particular interest in this age group, having some knowledge in this area is important to anyone taking care of sports injuries or children
- These injuries raise challenging questions that often have no single answer
- My goal for this presentation is to shed some light on current knowledge to provide a framework for how to approach this growing population of injured children

What are the questions?

- How are these ACL injuries different?
- What is the role of non-operative treatment?
- What are the reported complications from surgery?
- What are the options?

How are these ACL injuries different?

Presentation

Classification

Incomplete tears

Anatomy

Growth

www.fisiokinesiterapia.biz

- The fundamental difference in the management of ACL injuries in the skeletally immature relates to the growth of the extremity
- Overshadowing goals in the clinical and surgical management of these injuries include the avoidance of surgical complications on one hand and the avoidance of further damage to the joint on the other hand
- The gold standard for an ACL injury in the US is an anatomic reconstruction to restore stability and allow return to pre-injury activity
- For many of us, another long-term goal is avoidance of OA (although this has not been definitely proven)
- In the skeletally immature patient the balance between growth-related complications and knee stability/function must be found

Stability vs. growth

- It comes down to a risk/benefit ratio
- Are we willing to risk a surgical complication in order to provide knee stability and prevent further articular damage?
- It is hard to make a fully informed decision when there is such a lack of data, but what we do know can help point us in the right direction

Presentation

- Stanitski (JPO, 1993) found that 47% of children 7-12 years of age with hemarthrosis had an ACL injury compared with 65% in the 13-18 age group
- Luhman (JPO, 2003) found a 29% incidence of ACL injuries in patients less than 18 years when looking prospectively at 44 consecutive patients with hemarthrosis
- There is a gender difference with females being more prone to ACL injuries (hormonal differences, muscle strength, Q angle, anatomy of notch, ligamentous laxity, jumping mechanics), 2-4 times increased risk in sports like basketball and soccer
- 1/3 of patients feel a pop, this is even less reliable in children
- Most injuries are non-contact, either pivot or hyperextension

Classification

- Classification of pediatric ACL injuries
 - Tibial spine avulsion fractures, types 1 (non-displaced), 2 (hinged), 3 (displaced, A, B)
 - Avulsion of femoral and/or tibial insertion
 - Midsubstance tear, partial or complete
- Kellenberger (1990) found tibial spine avulsion injuries in 80% of children under 12 and midsubstance tears in 90% of children over age 12

Incomplete tears

- The diagnosis of an incomplete tear is somewhat controversial in the adult population, but is felt to be a distinct entity in the skeletally immature
- Most studies favor a higher incidence of partial injuries with younger age
- An incomplete injury only matters if knee stability is maintained and there is healing potential
- In the pediatric population, there is theoretically greater healing potential, and postponing surgery can be important

Incomplete tears

- ACL deficiency rates in adult patients with partial tears treated non-operatively vary from 14-56% in several small series with relatively short follow-up (1-5 yrs), and subsequent reconstruction rates ranges from 11 to 14% (Kocher, 2002)
- Healing potential of partial tears in animal models is variable
- No consensus for treatment in the adult population

Incomplete tears

- Kocher et al, AJSM, 2002
 - Prospective cohort study
 - 45 patients under age 17
 - Partial tears (MRI) confirmed with arthroscopy, Lachman grade A or B on EUA
 - Rehab for 3 months and minimal 2 year follow-up, mean 6.1 year follow-up
 - 31% underwent ACL reconstruction at 13.5 months for instability or reinjury
 - Risk factors for surgery included older age, >50% tear, posterolateral tears, grade B pivot shift exam
 - In the non-operative group 58% were found to have grade B laxity at final follow-up
 - Advocate consideration of non-reconstructive management of children less than 14 with partial tears and normal or near-normal Lachman

MRI findings in recent study

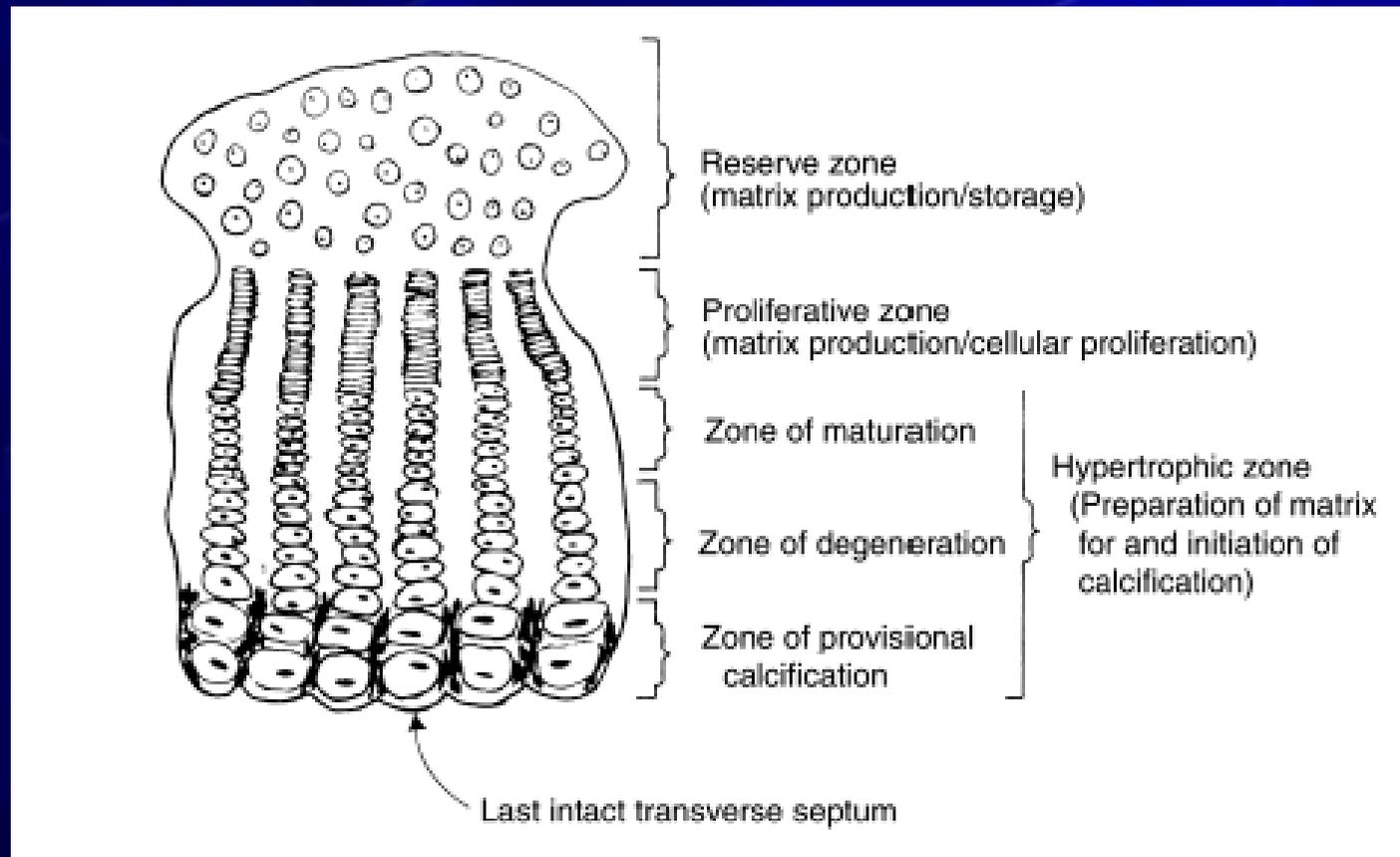
- Prince et al, 2005, AJR
 - 83 consecutive knee MRIs with diagnosis of ACL tears over 4 years
 - Group I - completely open physis
 - Group II - partially open physis
 - Group III - physeal scar
 - As a general trend, the more immature knees had greater numbers of tibial spine fractures and incomplete tears, and less associated injuries (meniscal tears)
 - Partial tears seen in 26% in group I, 15% in group II, 8% in group III
 - Tibial spine fractures seen in 26% in group I, 4% in both groups II and III
 - Overall numbers of complete ACL tears (71%), partial tears (17%), and spine fractures (12%)

www.fisiokinesiterapia.biz

Anatomy

- The ACL fibers in the immature knee are not connected to the underlying bone by Sharpey's fibers, but are rather continuous with the cartilage
- Skak et al (Acta Orthop Scan, 1987) found that midsubstance tears occur with rapid loads at low energy, while tibial spine injuries occur with slower loads and higher energy
- Age seems to have a direct correlation with injury pattern, and as a general trend tibial spine fractures are seen in the younger populations (Kellenberger et al, 62 pts, 1990)

Anatomy of the physis

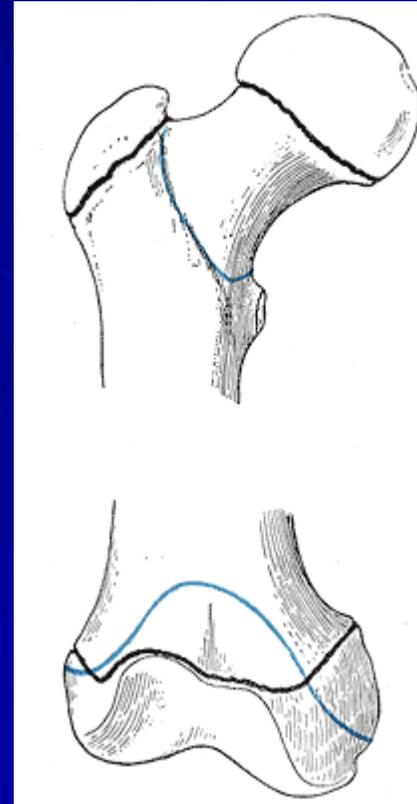
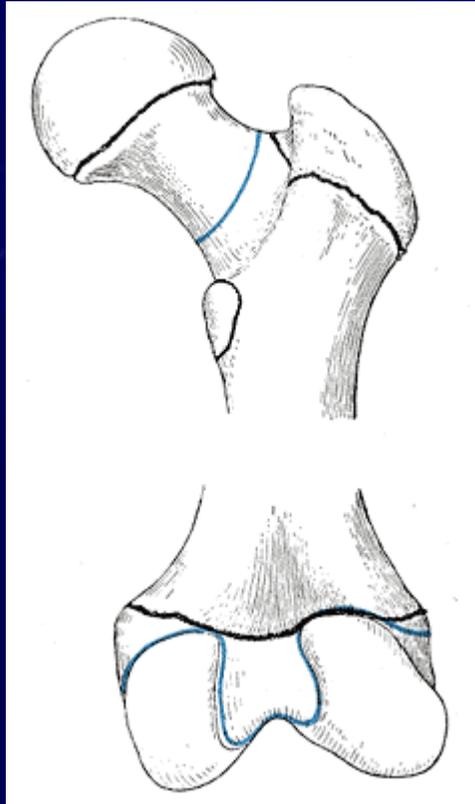


Anatomy of femoral physis

- The distal femoral physis is responsible for the greatest portion of the growth of the lower extremity
- The physis has a unique anatomy with four mammillary processes and an undulating contour, responsible for high risk of growth arrest associated with injury

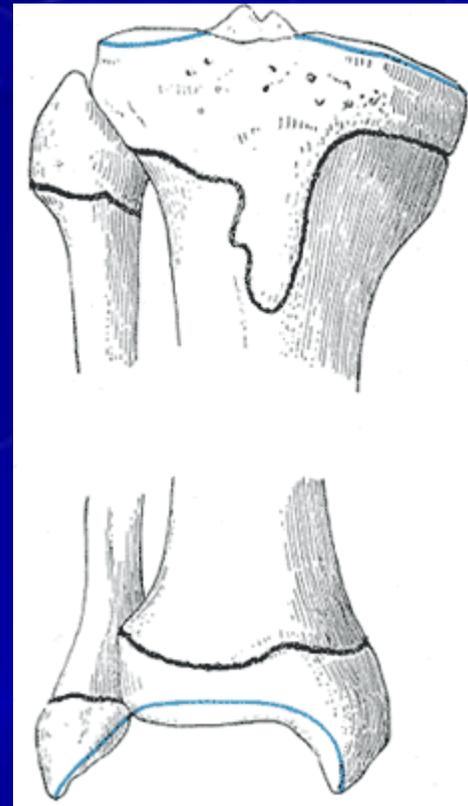


Relationship of capsule and physis



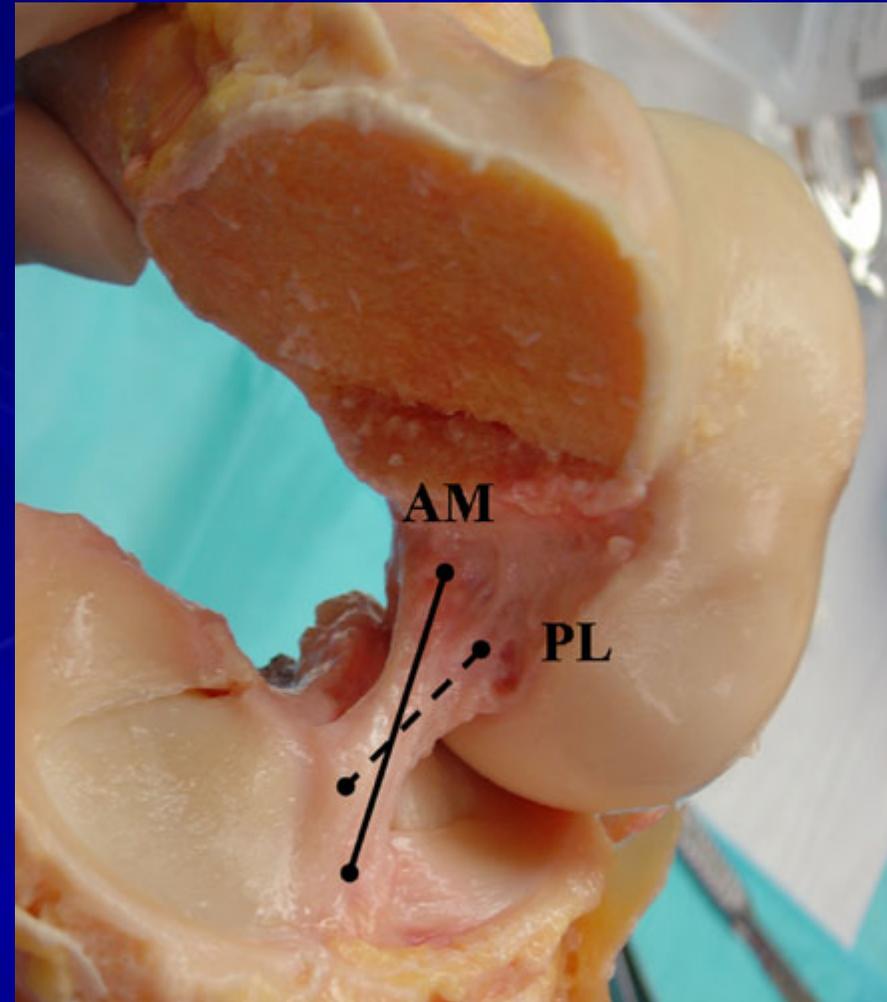
Anatomy of tibial physis

- Less complex with the addition of the tibial tubercle apophysis
- Location of apophysis becomes important in choosing a starting point for the tibial tunnel



ACL

- ACL originates between the resident's ridge and the over-the-top position, inserts anterior to and between the intercondylar prominences
- 33mm long and 11mm in diameter
- Two bundles, AM tight in flexion, PL tight in extension
- Blood supply via middle geniculate and fat pad, the immature ACL receives blood supply thru synovial sheath and the femur and tibia
- Extrasynovial



www.ejbs.org/rrgraphics/1141_87-1_suppl_1-51_fig2.jpg

ACL anatomy

- The ACL fibers in the immature knee are not connected to the underlying bone by Sharpey's fibers, but are rather continuous with the cartilage and attach via a perichondral cuff
- Behr et al (AJSM, 2001) found that there was an average of 2.6 mm distance between ACL origin to the physis in fetal specimens, and 2.9 mm distance in adolescent specimens with no statistically significant difference in the distance
- All specimens regardless of age had a very close relationship between the distal femoral physis (perichondral ring) and the over-the-top position

Intercondylar notch study

- Lui et al (JPO, 2008) published an anatomical study of the pediatric intercondylar notch
 - 54 skeletons aged 3-20 from a museum collection
 - Divided into 5 subgroups based on age
 - Wanted to determine prevalence of resident's ridge and its consistency as a surgical landmark
 - Prior rabbit data suggested that curetting the lateral portion of the epiphysis in rabbits lead to angular deformities (Key, JBJS, 1958)
 - Measurements of distances between resident's ridge and OTP were obtained, as well as angular measurements of the physis to femoral surface

Intercondylar notch study

- In conclusion
 - Space between resident's ridge and OTP in 10-12 year old group was greater than 7 mm, and in 13-15 year old group greater than 8 mm in 9/10/11 o'clock positions, so femoral tunnel can safely be drilled behind resident's ridge without causing damage to the physis
 - The resident's ridge was present only 50% of the time in the younger specimens (3-12 yo) as opposed to 88% in older specimens
 - Drilling the hole more anterior and **medial** with respect to the shaft minimizes chances of crossing the physis obliquely

Growth

- Peak height velocity around 11 in girls and 13 in boys
- The lower extremity physis are responsible for approximately 21 mm longitudinal growth a year (Tachdjian), these are average numbers that are easy to remember but do not tell the whole story
 - Proximal femur - 2
 - Distal femur - 9
 - Proximal tibia - 6
 - Distal tibia - 4

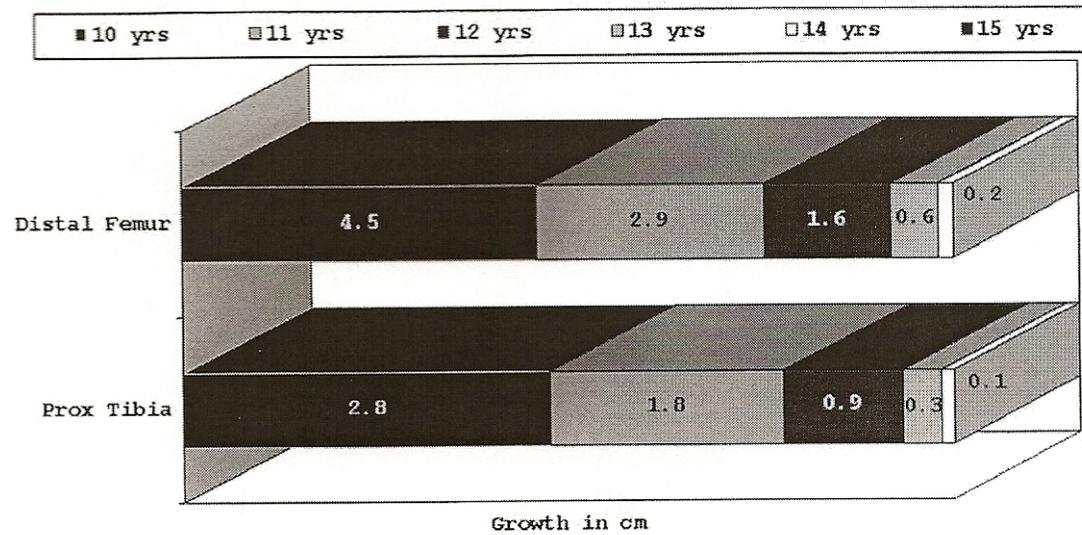


Fig. 1. Physeal growth in girls [9]. (Adapted from Dimeglio A, Bonnel F. Growth and development of the knee. In: DiPablos J, editor. The Immature Knee. Barcelona: Bibliostm Masson, S.A.; 1998; used with permission.)

Doriaz et al, Ortop Clin, 2003

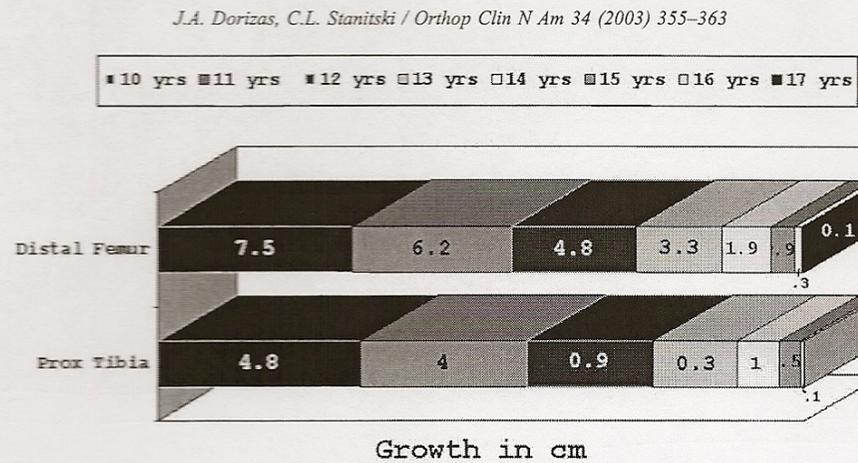


Fig. 2. Physeal growth in boys [9]. (Adapted from Dimeglio A, Bonnel F. Growth and development of the knee. In: DiPablos J, editor. The immature knee. Barcelona: Bibliostm Masson, S.A.; 1998; used with permission.)

Growth arrest

2070 • • • Musculoskeletal Injuries

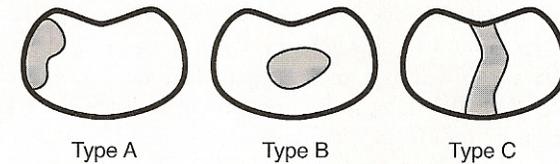
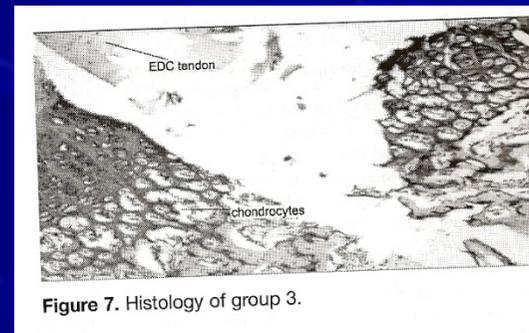


FIGURE 39-16 Classification of partial physeal arrest. Type A—peripheral; type B—central, surrounded by normal physis; type C—central, traversing the physis completely.

- Classification based on location of bar (Tachdjian's Pediatric Orthopedics, 3rd edition)
- Treatment of bars depend on location and percent involvement
- Bars greater than 50% seem to not respond to resection
- The question of how much physis must be injured to arrest the physis is yet to be fully answered
- Rabbit studies (Guzzanti, JBJS 1994) have suggested that 3-4 % of the cross sectional area of the femur and tibia can safely be removed without causing growth disturbance, these defects were filled with soft tissue grafts which seemed to prevent bony bridge formation

Growth arrest



- Stadelmaier et al (AJSM, 1995) showed that drilling the equivalent of a 9mm hole across the femur and tibia in 8 dogs and filling it with soft tissue prevented bony bridge formation, but also failed to show that the non-grafted controls developed any leg length discrepancy as a result of the drilling (attributed to rapid growth)
- More recently, Babb et al (AJSM, 2008) used sponges saturated in mesenchymal stem cells around the soft tissue grafts in rabbits undergoing ACL reconstruction and showed that the addition of these cells provided protection against bony bridges

Growth arrest

- Edwards et al (JBJS, 2001) looked at the effect of placing tensioned grafts across open physis in beagles
 - 12 animals
 - 80 N tension, fixation with screws and washers, 4mm holes (large percentage)
 - No bony bars
 - Significant valgus of femur and varus of tibia
 - Advised against transphyseal fixation



Figure 2. (left) (control) femora of Specimen 12, demonstrating marked valgus angul

Computer model of growth plates

- Guarino et al (Computerized Medical Imaging and Graphics, 2004) developed a virtual and physical 3D model of the pediatric knee to better assess the relationship between drill hole size, position, orientation, and removed growth-plate volume
- CAD was used to create the model of MRI images (8 yo child), and virtual drill holes were placed at various angles and at various locations
- The authors suggested that the data could be utilized for surgical planning and intra-op navigation

Table 1

Volume of growth plate removed corresponding to incorrect and correct drill placement, for various drill diameters

	Volume of physis removed (mm ³)	Percentage of physis removed
<i>Incorrect placement drill hole diameter (mm)</i>		
3	122.21	1.9368
4	194.22	3.0780
5	270.19	4.2819
6	343.92	5.4504
7	418.86	6.6380
8	496.81	7.8734
9	575.69	9.1234
10	643.61	10.1998
11	741.56	11.7521
<i>Correct place drill hole diameter (mm)</i>		
3	31.09	0.4927
4	55.12	0.8735
5	85.91	1.3615
6	123.61	1.9589
7	168.40	2.6688
8	221.02	3.5027
9	282.74	4.4808
10	353.68	5.6051
11	402.48	6.3784

Total volume of physis (mm³) = 6310.02.

Summary

- So far it has been suggested that
 - There is a size threshold beyond which a bony bar overpowers the force of the physis causing growth disturbance, the exact value has not been determined in humans but is somewhere in range of 9-11 %
 - A soft tissue graft across the defect will prevent bony bar formation, but the interface between the graft and the physis will contain a layer of bone probably not sufficiently strong to hold back the growth
 - Mesenchymal stem cells may help prevent the formation of bone at the interface
 - Tension across a grafted physis can lead to angular deformities without the presence of bony bars

What is the role of non-operative treatment?

Non-operative data

- In the adult population, no study has definitively shown that ACL reconstruction prevents the development of OA (Mohtadi et al, 2006)
- ACL reconstruction does allow functional recovery to sports and prevents further intra-articular injury
- A recent interesting study out of Norway by Moksnes in the Scandinavian Journal of Medicine and Science in Sports (2008)
 - 125 pts, non-random, operative vs. rehab for complete ACL tears
 - 18% of non-operative/34% of operative knees had meniscus injuries
 - Average age 27
 - All level I and II sports
 - Evaluation included single leg hop tests, IKDC 2000, KOS-ADLS, KT-1000, VAS, activity level
 - Non-operative group did significantly better on two of the four single leg hop tests, otherwise no difference

Review

- Mohtadi et al, 2006, did a systematic review of the literature pertaining to ACL injuries in the skeletally immature and ended up reviewing 66 articles
 - No level I or II (JBJS criteria)
 - 4 level III, 23 level IV, 35 level V

- Aichroth, 2002
 - 33 kids, cohort, 72 month f/u, 23 non-operative, all with reduced activity levels and Lysholm scores, 10 with degenerative changes
- Janarv, 1996
 - 28 kids, 8 non-operative, similar Lysholm scores
- Graf, 1992
 - 12 kids, 8 non-operative, all with repeat instability and 7/8 with new meniscal tears

- McCarroll, 1994
 - 75 kids, 38 non-operative, all had reconstructive surgery at mean of 29 months, 37 with instability and 27 with meniscus tears
- McCarroll, 1988
 - 40 kids, 16 non-operative, all returned to sports
- Pressman, 1997
 - 66 kids, 13 non-operative, outcomes favored reconstruction
- Woods, 2004
 - 13 kids, all underwent delayed reconstruction, compared with a group of reconstructed knees, comparable results in the two groups but the delayed group had no return to sports until after the reconstruction, more reinjuries in patients with closed physes

- Conclusion
 - There is insufficient evidence from randomized trials to determine whether surgery or conservative management is best for ACL injury
- Ethical dilemma
 - Difficult to counsel parents about surgical options that are non-anatomic
 - Easy to recommend non-operative management when surgery could cause growth disturbance
- Recommendation
 - Future studies, physician acting as a counselor to the patient

- The majority of studies suggest a poor outcome with non-operative treatment, frequent meniscal injuries
- The Woods study suggests that a very strict policy on no return to sports is needed in order to prevent reinjury, and children are in general not the best at compliance with such a program

Non-operative protocol

- Woods, all non-operative patients were given braces and strict excuses from sports, good compliance with rehab and brace wear but possibly difficult to reproduce
- Stanistki described three phases of rehab
 - Phase 1, partial weight bearing until pain subsides
 - Phase 2, strengthening over 6 weeks
 - Phase 3, gradual return to sports

What are the reported complications from surgery?

- Only 2 of all these studies reported on complications
 - Kocher's survey of Herodicus/ACL Study Group, self reported
 - 8 cases femoral valgus due to arrest
 - 3 cases tibial recurvatum
 - 2 cases genu valgum without arrest
 - 2 cases of leg length discrepancy
 - Koman et al, 1999
 - Valgus deformity case report due to transfixation pin across lateral physis

- In addition there have been two more reports of complications (Utukuri et al, 2006)
 - Barber et al, 2000, isolated case of distal femoral physeal arrest with ST graft
 - Lipscomb and Anderson, 1986, 2 cm LLD due to stapling of both physis

Interesting study

- Bollen et al, JBJS Br, 2008
 - 5 patients, ages 12-14 at time of surgery
 - All had transphyseal hamstring reconstructions (endobutton, pins, screws)
 - Average f/u 34.6 months
 - Average growth 17.3 cm (14-24)
 - No growth arrest or leg length discrepancy
 - Grafts grew in length by 33-57%
 - Graft diameter did not change
 - Redistribution of graft tissue vs. growth

Table II. Changes in graft/tunnel dimensions over time/growth

Case	1	2	3	4	5
Period of follow-up (mths)	38	37	58	18	22
Age (yrs, mths)					
At surgery	12, 3	13, 10	12, 6	14, 3	14, 2
At follow-up	15, 5	16, 11	17, 4	15, 9	15, 11
Height gain (cm)	18.5	15	15	14	24
Femoral tunnel diameter (mm)					
Start to finish	6 to 6	7.5 to 7.5	7 to 7	6.5 to 6.5	6.5 to 6.5
Change	0	0	0	0	0
Tibial tunnel diameter (mm)					
Start to finish	6 to 6	7.5 to 7.5	7 to 7.5	6.5 to 6.5	6.5 to 6.5
Increase	0	0	0.5 (metaphysis) 2 (epiphysis)	0	0
Tibial tunnel length (mm)					
Start to finish	40 to 52	42 to 50	39 to 50	56 to 71	50 to 70
Increase	12	8	11	15	20
Percentage increase	30	19	28	27	40
Femoral tunnel length (mm)					
Start to finish	40 to 80	37 to 60	34 to 54	35 to 60	40 to 75
Increase	40	23	20	25	35
Percentage increase	100	62	59	71	88
Length of intra-articular portion of graft (mm)					
Start to finish	20 to 25	23 to 26	33 to 37	25 to 27	25 to 30
Increase	5	3	4	2	5
Percentage increase	25	13	12	8	20
Length of whole graft (mm)					
Start to finish	100 to 157	102 to 136	106 to 141	116 to 158	115 to 175
Increase	57	34	35	42	60
Percentage increase	57	33	33	36	52

Algorithm

- Closed physis – adult reconstruction
- Adolescent with growth remaining (boys 13-16, girls 12-14) – transphyseal hamstring
- Prepubescent – rehab and brace if no meniscus tear with limited sports participation, OTP transtibial IT band for reconstruction

Operative options

- Direct repair
- Anatomic vs. non-anatomic
- Physeal sparing vs. transphyseal
- Extra- vs. intra- articular

Choice of procedure

- Choice of surgical procedure influenced by multiple factors
 - Physiologic age
 - Peak height velocity coincides with menarche in girls and presence of curly axillary hair in boys
 - Chronologic age often does not correlate, so obtain hand film for bone age

Primary repair

- Not recommended
- A few case reports have shown poor results with continued instability
 - Engebretsen, failure in 8/8

Reconstructive options

- To cross or not to cross, that is the question
- Usually avoiding the physis means compromising isometry and accepting a non-anatomic reconstruction
- Non-anatomic reconstructions are generally thought of as temporary solutions until an anatomic reconstruction can be performed

If physis must be crossed

- Away from perichondral ring
- Perpendicular to physis
- Relatively small in diameter
- Filled with soft tissue
- No hardware or bone crossing physis

Alternative

- Only way to obtain an anatomic physal sparing reconstruction is to drill holes across the epiphysis as Allen Anderson described

www.fisiokinesiterapia.biz

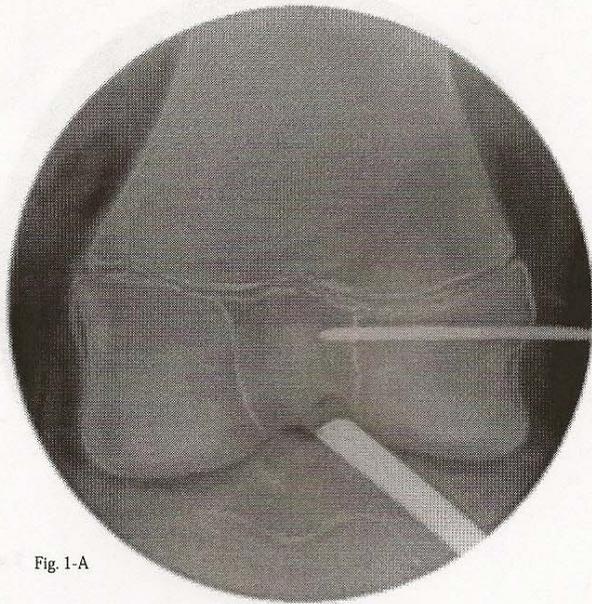


Fig. 1-A

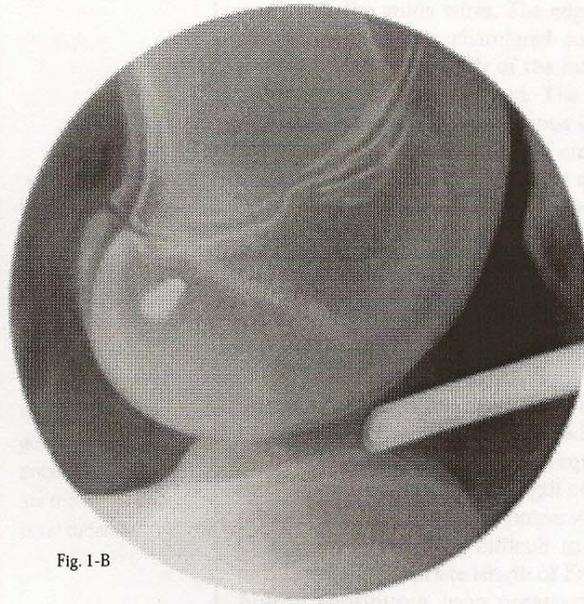


Fig. 1-B

Anteroposterior (Fig. 1-A) and lateral (Fig. 1-B) views shown on a fluoroscopic monitor, demonstrating the position of the guide wire in the femoral epiphysis.

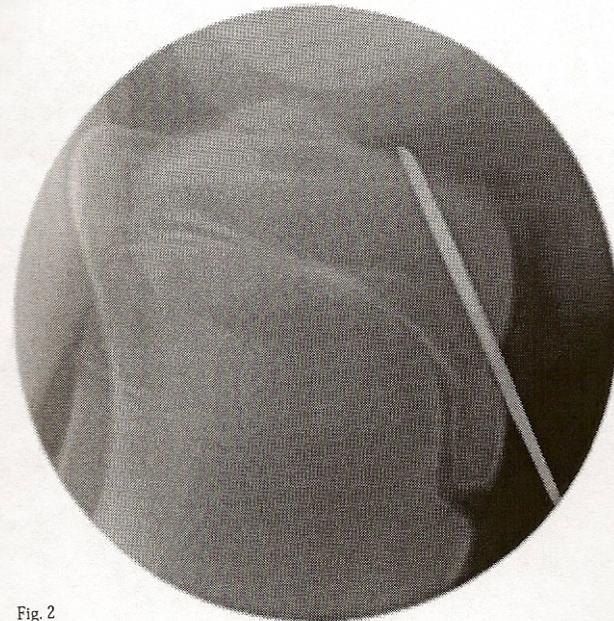


Fig. 2

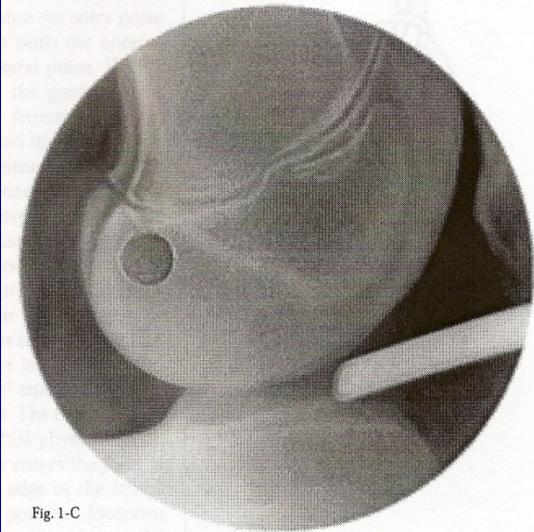


Fig. 1-C

Graphically enhanced lateral view from the fluoroscopic monitor after drilling of the femoral hole.

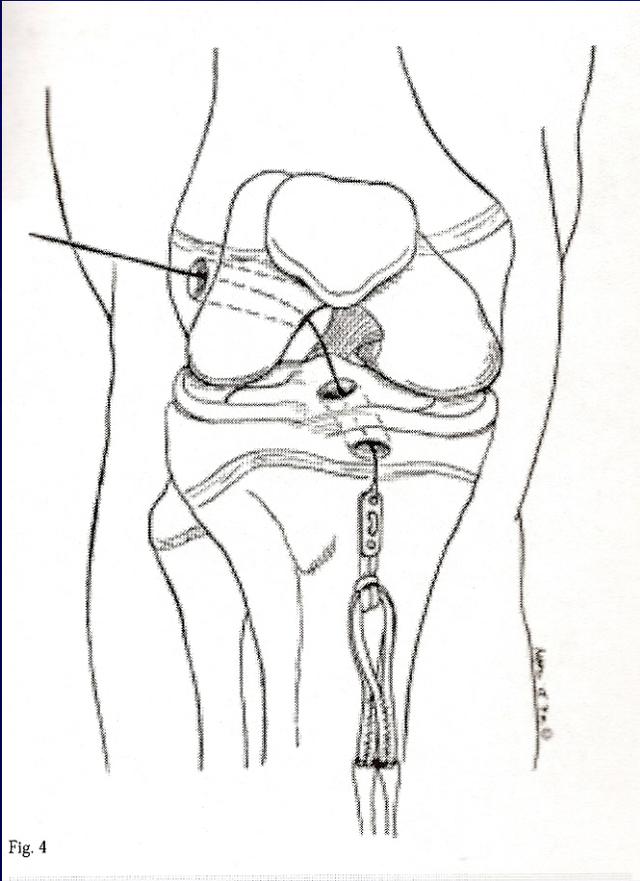


Fig. 4

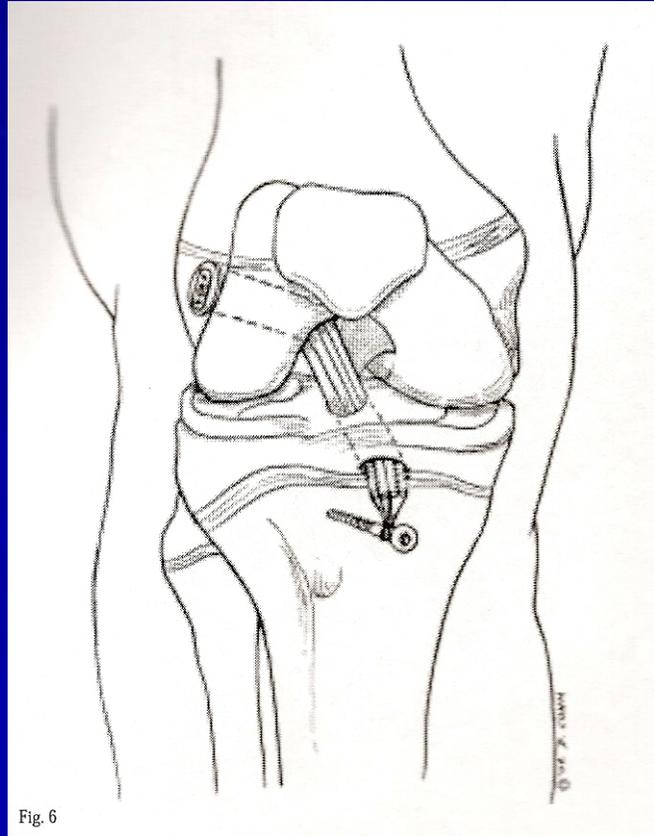
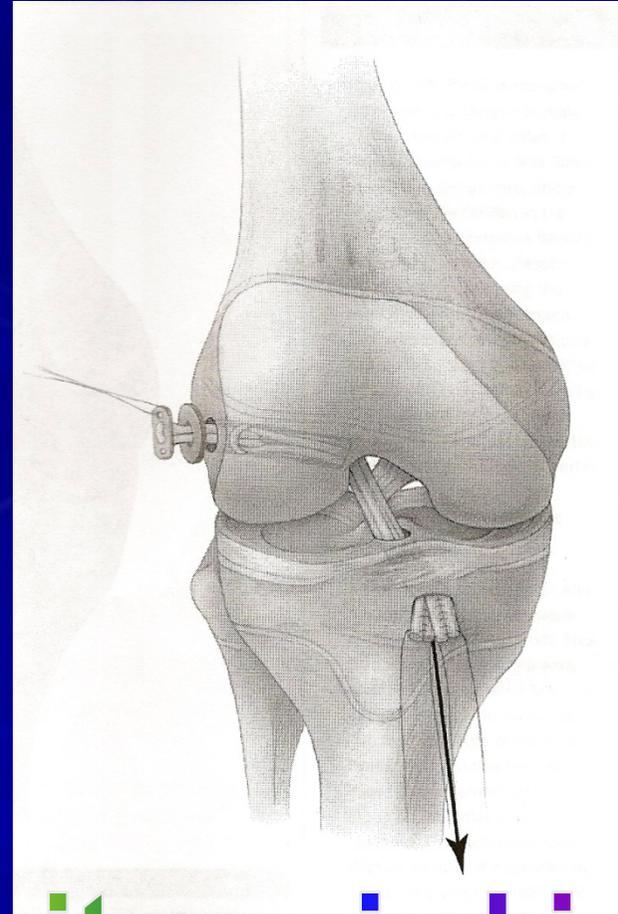
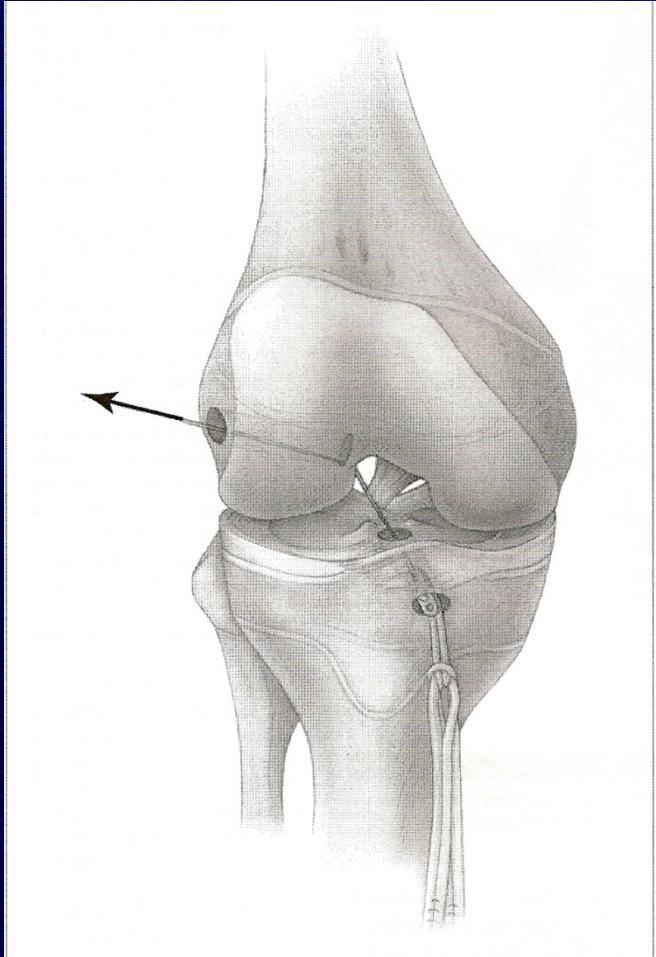


Fig. 6



www.fisiokinesiterapia.biz

- 12 pts, 16 cm growth at f/u, no complications
- Technically very challenging
- Pearls

IT band

- Originally described by MacIntosh and Darby, modified by Micheli

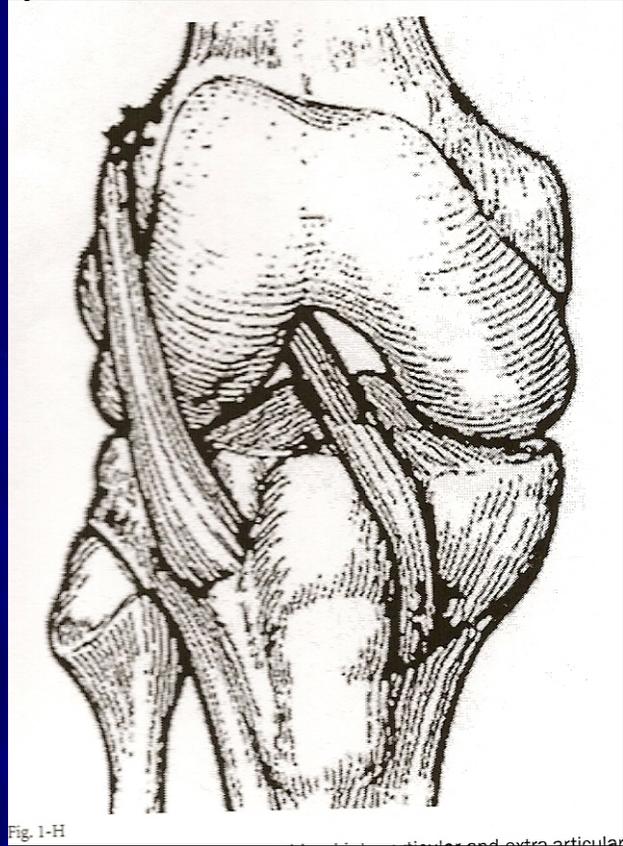
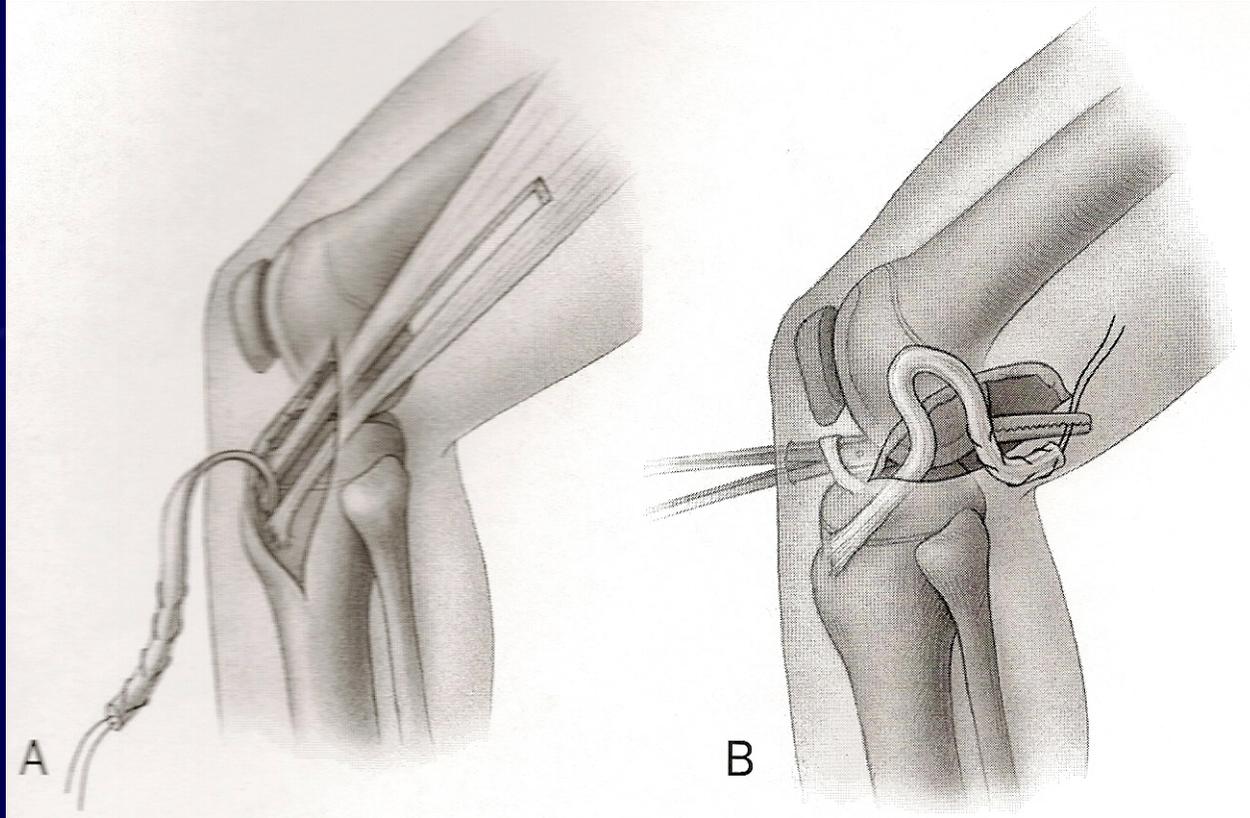
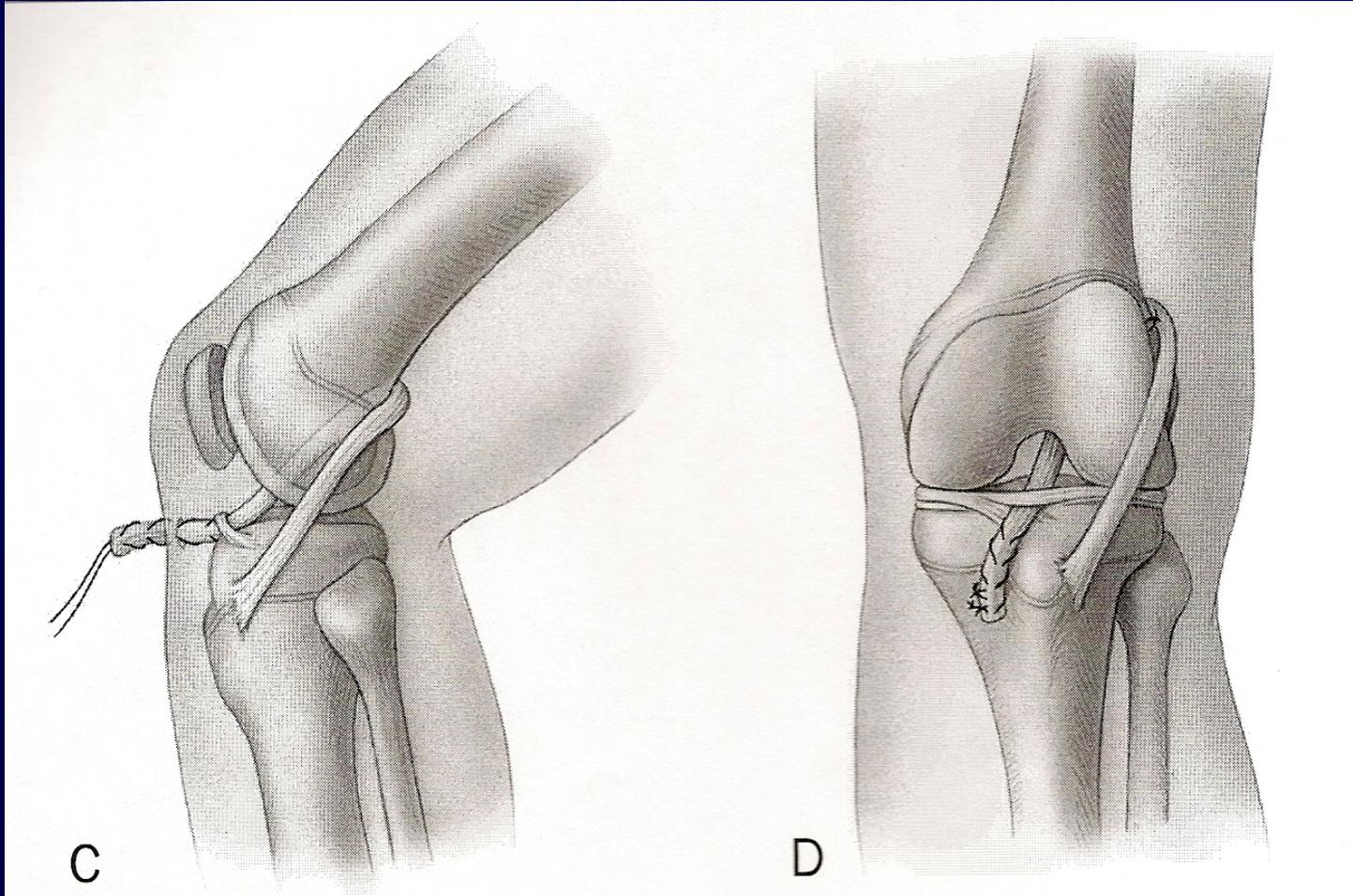


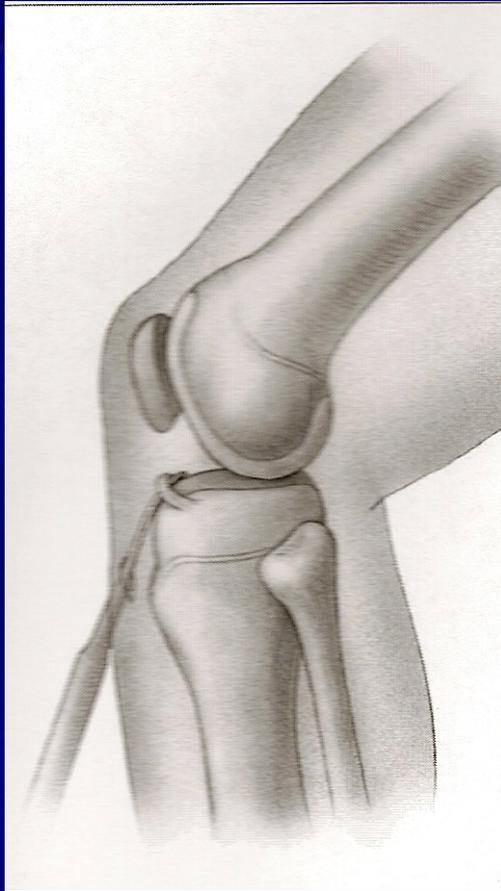
Fig. 1-H

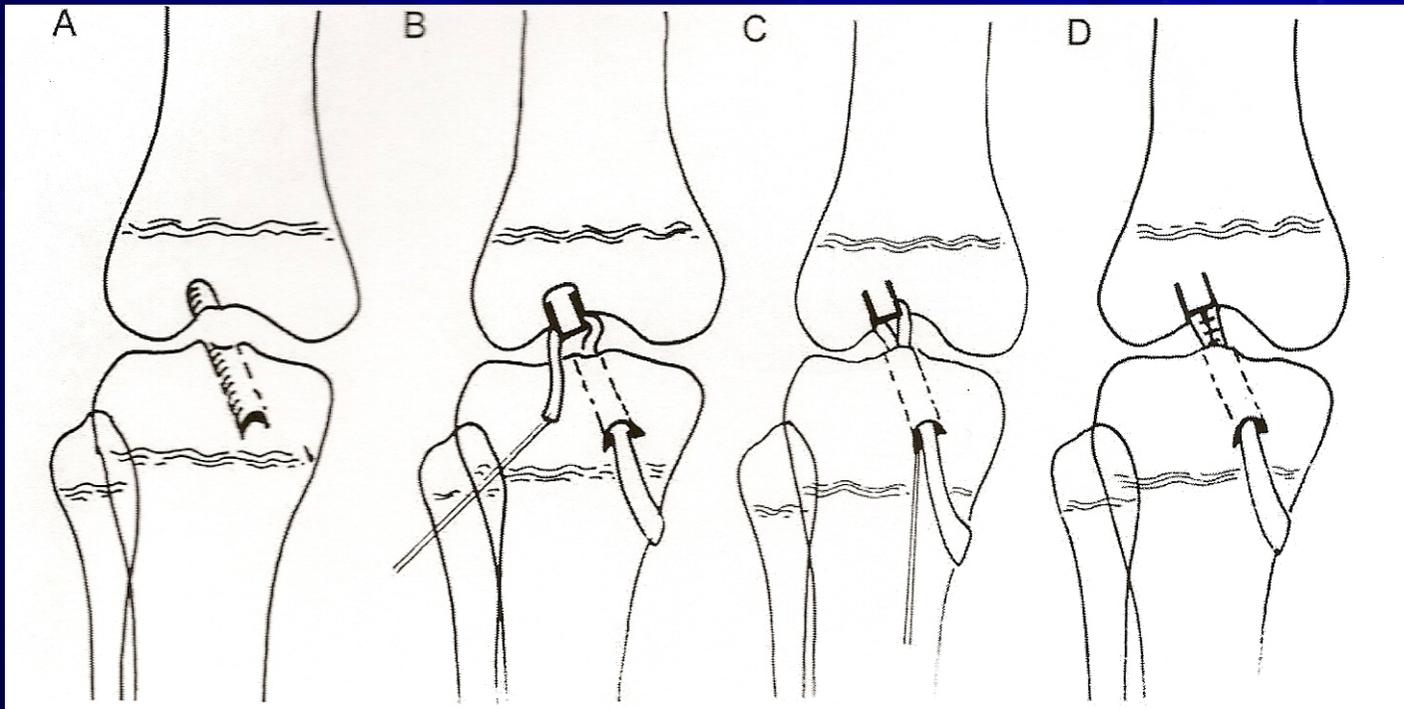
...tissue and extra-articular

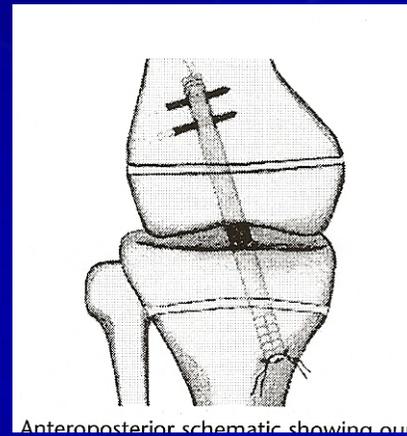
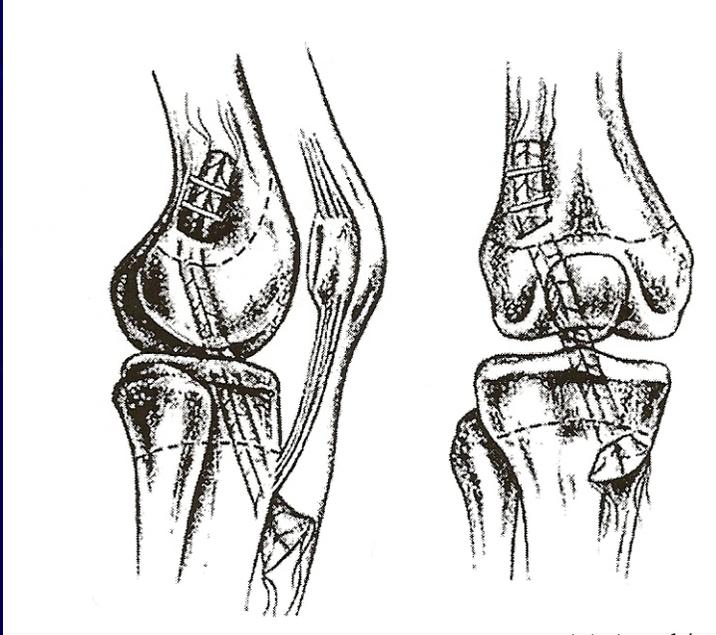


www.fisiokinesiterapia.biz



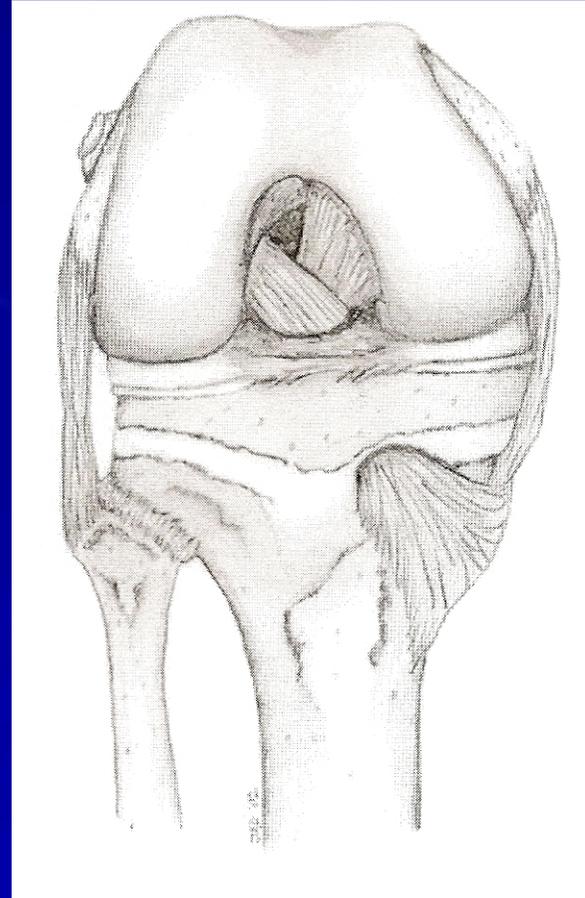
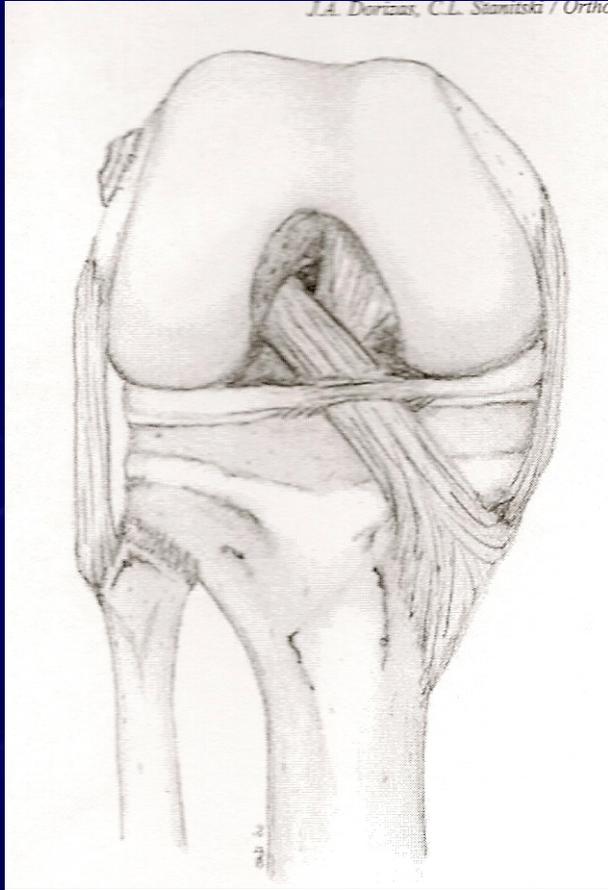






Anteroposterior schematic showing our

J.A. Dorizas, C.L. Stanitski / Ortho



- ZR
- 8 yo at presentation
- Pivot injury, football
- Weakly positive Lachman and pivot

www.fisiokinesiterapia.biz

ru1
Ex:
Se: 1001/2
Im: 1001/1
LOW_EXM

CHKD-Oyster Point
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: 00RA07046322
2007 Aug 30
Acq Tm: 14:37:41.921



Lin:DCM / Lin:DCM / Id:ID
W:2450 L:1415

SIZES ARE APPROXIMATE

ru1
Ex:

Se: 1002/2
Im: 1002/1

LOW_EXM

CHKD-Oyster Point
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: 00RA07046322
2007 Aug 30
Acq Tm: 14:37:45.328



Lin:DCM / Lin:DCM / Id:ID
W:2439 L:1420

SIZES ARE APPROXIMATE

1.5T MRC14308
Ex: MRI-KNLWO
T2 TSE Sag FS LEFT
Se: 879
Im: 10/23
Seq: L83.1 (COI)

Children's Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: 00MR07003129
2007 Sep 11
Acq Tm: 09:03:45.382483

256 x 230

A

P

ET: 13
TR: 4260.0
TE: 71.0

4.0mm/0.4mm
14:DCM / Lin:DCM / 14:ID
W:3000 L:1177

I

DFOV: 15.0 x 15.0 cm

1.5T MRC14308
Ex: MRI-KNLWO
T2 TSE Sag FS LEFT
Se: 879
Im: 11/23
Seq: L78.9 (COI)

Children's Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: 00MR07003129
2007 Sep 11
Acq Tm: 09:03:43.160005

256 x 230

A

P

ET: 13
TR: 4260.0
TE: 71.0

4.0mm/0.4mm
14:DCM / Lin:DCM / 14:ID
W:3000 L:1177

I

DFOV: 15.0 x 15.0 cm

1.5T MRC14308
Ex: MRI-KNLWO
T2 TSE Sag FS LEFT
Se: 879
Im: 12/23
Seq: L74.7 (COI)

Children's Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: 00MR07003129
2007 Sep 11
Acq Tm: 09:03:45.197491

256 x 230

A

P

ET: 13
TR: 4260.0
TE: 71.0

4.0mm/0.4mm
14:DCM / Lin:DCM / 14:ID
W:3000 L:1177

I

DFOV: 15.0 x 15.0 cm

1.5T MRC14308
Ex: MRI-KNLWO
T2 TSE Sag FS LEFT
Se: 879
Im: 13/23
Seq: L70.5 (COI)

Children's Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: 00MR07003129
2007 Sep 11
Acq Tm: 09:03:42.975013

256 x 230

A

P

ET: 13
TR: 4260.0
TE: 71.0

4.0mm/0.4mm
14:DCM / Lin:DCM / 14:ID
W:3000 L:1177

I

DFOV: 15.0 x 15.0 cm

1.5T MRC14308
Ex: 4083540
SE PD Sag FS LEFT
Se: 6/8
Im: 4/22
Sag: L106.6 (COI)
Chidrer Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: MR20080012039
2008 Apr 23
Acq Tm: 20:25:47.657481



1.5T MRC14308
Ex: 4083540
SE PD Sag FS LEFT
Se: 6/8
Im: 5/22
Sag: L102.5 (COI)
Chidrer Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: MR20080012039
2008 Apr 23
Acq Tm: 20:25:46.567485



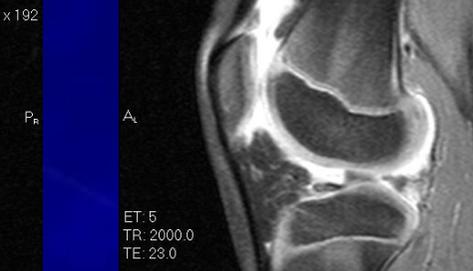
1.5T MRC14308
Ex: 4083540
SE PD Sag FS LEFT
Se: 6/8
Im: 6/22
Sag: L98.4 (COI)
Chidrer Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: MR20080012039
2008 Apr 23
Acq Tm: 20:25:47.567520



4.0thk/0.4sp
Id:DCM / W:2252
1.5T MRC14308
Ex: 4083540
SE PD Sag FS LEFT
Se: 6/8
Im: 7/22
Sag: L94.3 (COI)
Chidrer Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: MR20080012039
2008 Apr 23
Acq Tm: 20:25:46.474989



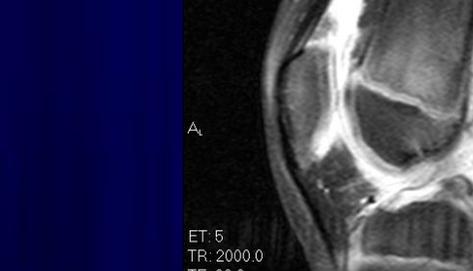
4.0thk/0.4sp
CM / Lin:DC L1033
1.5T MRC14308
Ex: 4083540
SE PD Sag FS LEFT
Se: 6/8
Im: 8/22
Sag: L90.1 (COI)
Chidrer Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: MR20080012039
2008 Apr 23
Acq Tm: 20:25:47.474983



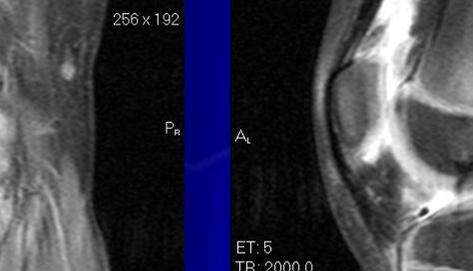
4.0thk/0.4sp
1.5T MRC14308
Ex: 4083540
SE PD Sag FS LEFT
Se: 6/8
Im: 9/22
Sag: L86.0 (COI)
Chidrer Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: MR20080012039
2008 Apr 23
Acq Tm: 20:25:46.384987



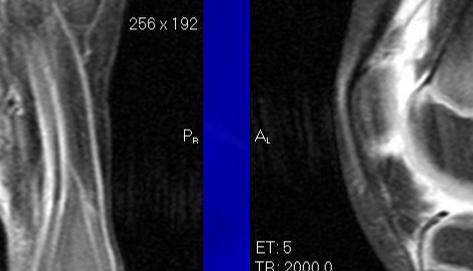
4.0thk/0.4sp
Id:DCM / Lin:DCM / W:2008 L:989
1.5T MRC14308
Ex: 4083540
SE PD Sag FS LEFT
Se: 6/8
Im: 10/22
Sag: L81.9 (COI)
Chidrer Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: MR20080012039
2008 Apr 23
Acq Tm: 20:25:47.384982



4.0thk/0.4sp
Id:DCM / Lin:DCM / W:1923 L:949
1.5T MRC14308
Ex: 4083540
SE PD Sag FS LEFT
Se: 6/8
Im: 11/22
Sag: L77.8 (COI)
Chidrer Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: MR20080012039
2008 Apr 23
Acq Tm: 20:25:46.294986



4.0thk/0.4sp
Id:DCM / Lin:DCM / W:1938 L:964
1.5T MRC14308
Ex: 4083540
SE PD Sag FS LEFT
Se: 6/8
Im: 12/22
Sag: L73.7 (COI)
Chidrer Hospital of the King's Daughter's
RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Acc: MR20080012039
2008 Apr 23
Acq Tm: 20:25:47.294980

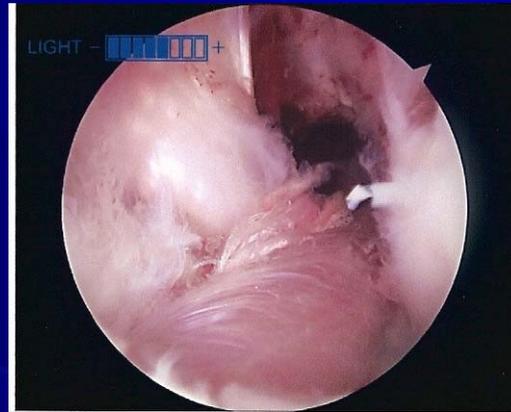
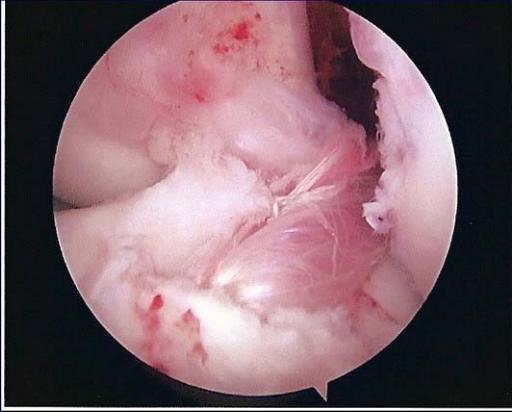


4.0thk/0.4sp
Id:DCM / Lin:DCM / W:1923 L:949
DFOV: 15.0 x 15.0cm

4.0thk/0.4sp
Id:DCM / Lin:DCM / W:1871 L:929
DFOV: 15.0 x 15.0cm

4.0thk/0.4sp
Id:DCM / Lin:DCM / W:1938 L:964
DFOV: 15.0 x 15.0cm

4.0thk/0.4sp
Id:DCM / Lin:DCM / W:1938 L:964
DFOV: 15.0 x 15.0cm



ru1 Children's Hospital of the King's Daughters
Ex: RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Se: 1001/2 Acc: CR20080035410
Im: 1001/1 2008 Jun 04
Acq Tm: 10:24:28.906

LOW_EXM

LT



**AP SUPINE
@1025**

Lin:DCM / Lin:DCM / Id:ID
W:2354 L:1460

SIZES ARE APPROXIMATE

ru1 Children's Hospital of the King's Daughters
Ex: RICHARDS ZACKARY MILES
1998 Jul 20 M 000447775
Se: 1002/2 Acc: CR20080035410
Im: 1002/1 2008 Jun 04
Acq Tm: 10:24:35.765
LOW_EXM



LT

CTL SUPINE
@1025

Lin:DCM / Lin:DCM / Id:ID
W:2444 L:1418

SIZES ARE APPROXIMATE

References

- AAOS/POSNA Surgical Techniques Course, Rosemont, IL, 2008
- POSNA One-Day Course, 2008
- Anderson, A. Transepiphyseal Replacement of the Anterior Cruciate Ligament Using Quadruple Hamstring Grafts in Skeletally Immature Patients. *JBJS*. 2004; 86: 201-209.
- Anderson, A. Transepiphyseal Replacement of the Anterior Cruciate Ligament in Skeletally Immature Patients: A Preliminary Report. *JBJS*. 2003; 85: 1255-1263.
- Babb, J. et al. Transphyseal Anterior Cruciate Ligament Reconstruction Using Mesenchymal Stem Cells. *AJSM*. 2008; 36: 1164-1170.
- Bollen, S. et al. Changes in the Four-strand Hamstring Graft in Anterior Cruciate Ligament Reconstruction in the Skeletally-immature Knee. *JBJS Br*. 2008; 90B(4): 455-459.
- Dorizas, J. et al. Anterior Cruciate Ligament Injury in the Skeletally Immature. *Orthop Clinics N Am*. 2003; 34: 355-363.
- Edwards, T. et al. The Effect of Placing a Tensioned Graft Across Open Growth Plates. *JBJS*. 2001; 83A(5): 725-734.
- Guarino, J. et al. Modeling the Growth Plates in the Pediatric Knee: Implications for Anterior Cruciate Ligament Reconstruction. *Comp Med Im Graphics*. 2004; 28: 419-44.
- Guzzanti, V. et al. Physeal Sparing Intraarticular Anterior Cruciate Ligament Reconstruction in Preadolescents. *AJSM*. 2003; 31: 949-953.
- Guzzanti, V. et al. The Effect of Intraarticular ACL Reconstruction on the Growth Plates of Rabbits. *JBJS Br*. 1994; 76B(6): 960-963.
- Kocher, M. et al. Physeal Sparing Reconstruction of the Anterior Cruciate Ligament in Skeletally Immature Prepubescent Children and Adolescents. *JBJS*. 2005; 87: 2371-2379.
- Kocher, M. et al. Physeal Sparing Reconstruction of the Anterior Cruciate Ligament in Skeletally Immature Prepubescent Children and Adolescents. *Surgical Technique*. *JBJS*. 2006; 88: 283-293.
- Kocher, M. et al. Partial Tears of the Anterior Cruciate Ligament in Children and Adolescents. *AJSM*. 2002; 30: 697-703.
- Liu, R. et al. An Anatomic Study of the Pediatric Intercondylar Notch. *JPO*. 2008; 28(2): 177-183.
- Mohtadi, N. et al. Managing Anterior Cruciate Ligament Deficiency in the Skeletally Immature Individual: A Systematic Review of the Literature. *Clin J Sports Med*. 2006; 16(6): 457-464.
- Mosknes, H. et al. Performance-based Functional Evaluation of Non-operative and Operative Treatment after Anterior Cruciate Ligament Injury. *Scan J Med Sci Sports*. 2008; 1-11.
- Prince, J. et al. MRI of Anterior Cruciate Ligament Injuries and Associated Findings in the Pediatric Knee: Changes with Skeletal Maturation. *AJR*. 2005; 185: 756-762.
- Sankar, W. et al. Combined Anterior Cruciate Ligament and Medial Collateral Ligament Injuries in Adolescents. *JPO*. 2006; 26(6): 733-736.
- Stadelmaier, D. et al. The Effect of Drilling and Soft Tissue Grafting Across Open Growth Plates. *AJSM*. 1995; 23(4): 431-435.
- Utukuri, M. et al. Update on Paediatric ACL Injuries. *The Knee*. 2006; 13: 345-352.