Pediatric Anterior Cruciate Ligament Reconstruction

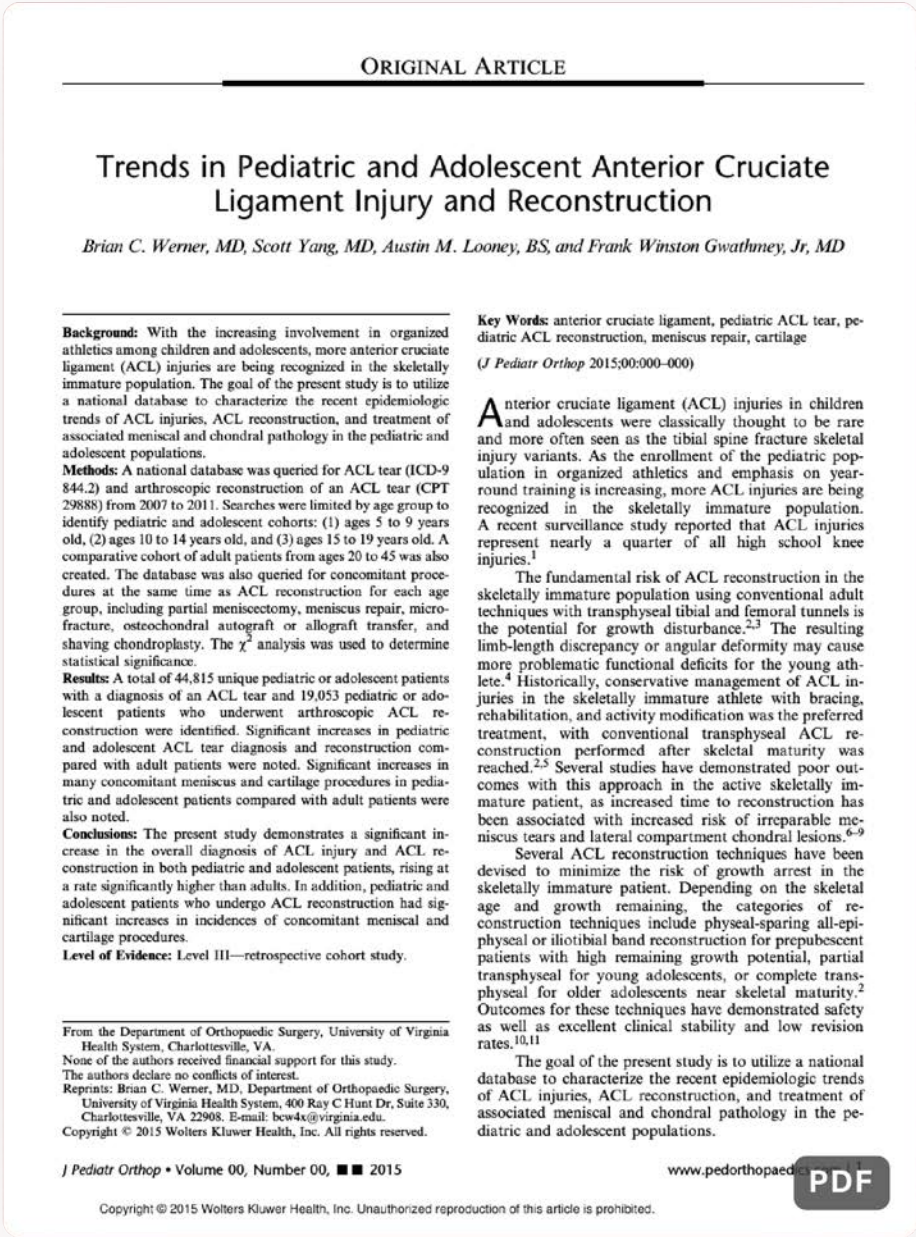
Jonathan C. Riboh, MD

May 22nd 2021

Why I Do What I Do...

Pediatric ACL Injuries Are More and More Common

- PearlDiver database study
- Rate of ACLR growing ~ **25% every 5 years**
- Growth is strongest in **10 - 18 year old group**



ORIGINAL ARTICLE

Trends in Pediatric and Adolescent Anterior Cruciate Ligament Injury and Reconstruction

Brian C. Werner, MD, Scott Yang, MD, Austin M. Looney, BS, and Frank Winston Gwathmey, Jr, MD

Background: With the increasing involvement in organized athletics among children and adolescents, more anterior cruciate ligament (ACL) injuries are being recognized in the skeletally immature population. The goal of the present study is to utilize a national database to characterize the recent epidemiologic trends of ACL injuries, ACL reconstruction, and treatment of associated meniscal and chondral pathology in the pediatric and adolescent populations.

Methods: A national database was queried for ACL tear (ICD-9 844.2) and arthroscopic reconstruction of an ACL tear (CPT 29888) from 2007 to 2011. Searches were limited by age group to identify pediatric and adolescent cohorts: (1) ages 5 to 9 years old, (2) ages 10 to 14 years old, and (3) ages 15 to 19 years old. A comparative cohort of adult patients from ages 20 to 45 was also created. The database was also queried for concomitant procedures at the same time as ACL reconstruction for each age group, including partial meniscectomy, meniscus repair, microfracture, osteochondral autograft or allograft transfer, and shaving chondroplasty. The χ^2 analysis was used to determine statistical significance.

Results: A total of 44,815 unique pediatric or adolescent patients with a diagnosis of an ACL tear and 19,053 pediatric or adolescent patients who underwent arthroscopic ACL reconstruction were identified. Significant increases in pediatric and adolescent ACL tear diagnosis and reconstruction compared with adult patients were noted. Significant increases in many concomitant meniscus and cartilage procedures in pediatric and adolescent patients compared with adult patients were also noted.

Conclusions: The present study demonstrates a significant increase in the overall diagnosis of ACL injury and ACL reconstruction in both pediatric and adolescent patients, rising at a rate significantly higher than adults. In addition, pediatric and adolescent patients who undergo ACL reconstruction had significant increases in incidences of concomitant meniscal and cartilage procedures.

Level of Evidence: Level III—retrospective cohort study.

From the Department of Orthopaedic Surgery, University of Virginia Health System, Charlottesville, VA.

None of the authors received financial support for this study.
The authors declare no conflicts of interest.

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Key Words: anterior cruciate ligament, pediatric ACL tear, pediatric ACL reconstruction, meniscus repair, cartilage

(*J Pediatr Orthop* 2015;00:000–000)

Anterior cruciate ligament (ACL) injuries in children and adolescents were classically thought to be rare and more often seen as the tibial spine fracture skeletal injury variants. As the enrollment of the pediatric population in organized athletics and emphasis on year-round training is increasing, more ACL injuries are being recognized in the skeletally immature population. A recent surveillance study reported that ACL injuries represent nearly a quarter of all high school knee injuries.[1]

The fundamental risk of ACL reconstruction in the skeletally immature population using conventional adult techniques with transphyseal tibial and femoral tunnels is the potential for growth disturbance.[2,3] The resulting limb-length discrepancy or angular deformity may cause more problematic functional deficits for the young athlete.[4] Historically, conservative management of ACL injuries in the skeletally immature athlete with bracing, rehabilitation, and activity modification was the preferred treatment, with conventional transphyseal ACL reconstruction performed after skeletal maturity was reached.[2,5] Several studies have demonstrated poor outcomes with this approach in the active skeletally immature patient, as increased time to reconstruction has been associated with increased risk of irreparable meniscus tears and lateral compartment chondral lesions.[6–9]

Several ACL reconstruction techniques have been devised to minimize the risk of growth arrest in the skeletally immature patient. Depending on the skeletal age and growth remaining, the categories of reconstruction techniques include physeal-sparing all-epiphyseal or iliotibial band reconstruction for prepubescent patients with high remaining growth potential, partial transphyseal for young adolescents, or complete transphyseal for older adolescents near skeletal maturity.[2] Outcomes for these techniques have demonstrated safety as well as excellent clinical stability and low revision rates.[10,11]

The goal of the present study is to utilize a national database to characterize the recent epidemiologic trends of ACL injuries, ACL reconstruction, and treatment of associated meniscal and chondral pathology in the pediatric and adolescent populations.

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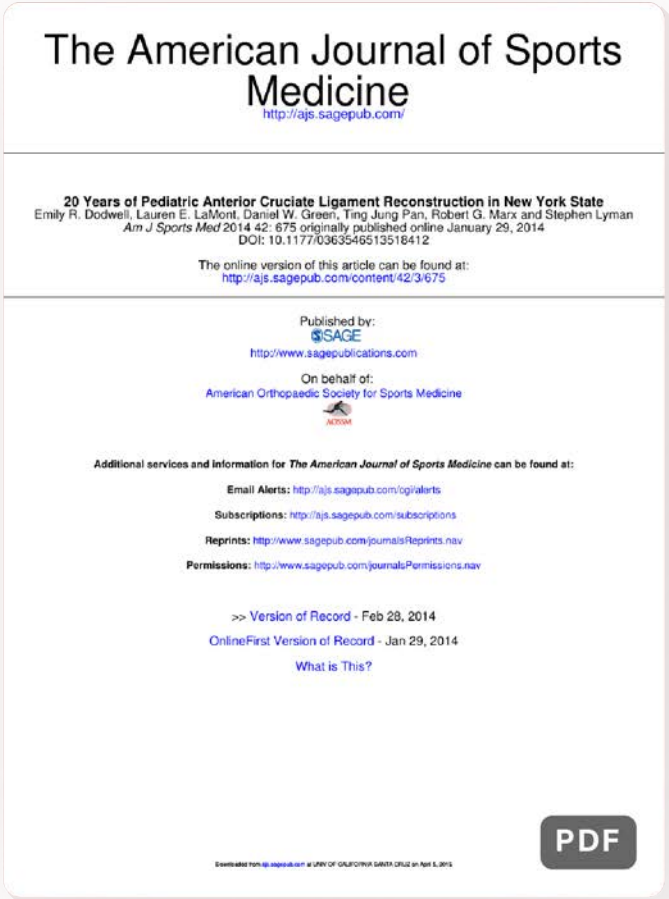

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20 Years of Pediatric Anterior Cruciate Ligament Reconstruction in New York State
Emily R. Dodwell, Lauren E. LaMont, Daniel W. Green, Ting Jung Pan, Robert G. Marx and Stephen Lyman
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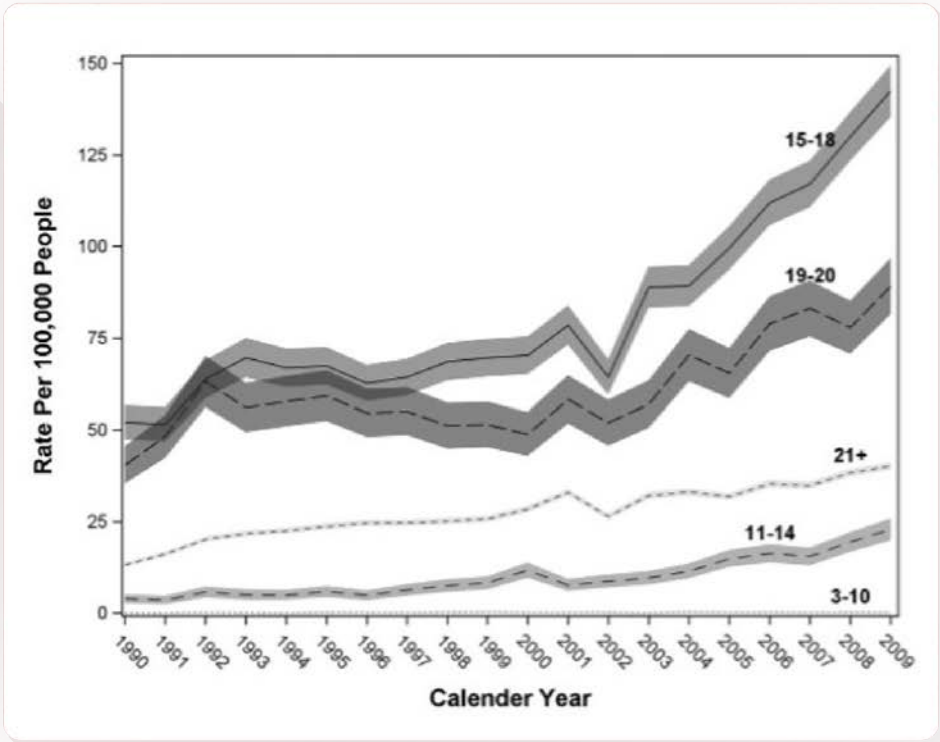
What is This?

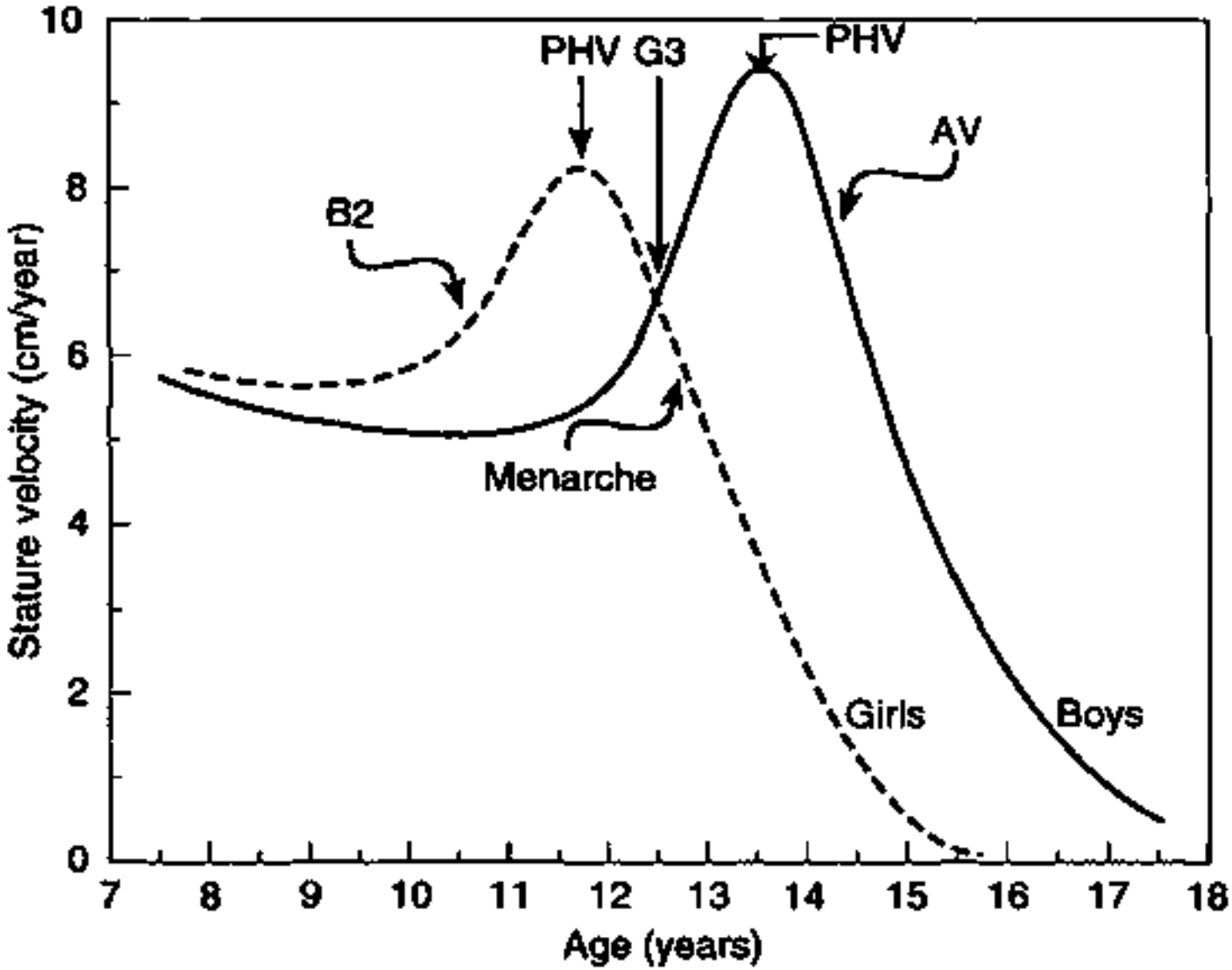
PDF

20 year review of New York State Registry



Growth is primarily in the **late adolescent** group

Assessing Growth Status


10
8
6
4
2
0
Stature velocity (cm/year)
PHV G3
PHV
AV
B2
Menarche
Girls
Boys
7
8
9
10
11
12
13
14
15
16
17
18
Age (years)

Orthopedic Surgeons only about 50% correct in Tanner Staging!

- It's awkward
- We're not good at it
- **Rather can use your "gestalt"**
  - Onset of **menses** is late in puberty, usually **6 months after PHV**
  - Can get a sense of who is pre-pubertal vs. pubertal
  - Non-invasive assessment:
    - Facial hair, leg hair, breast tissue, voice change, etc.

CLINICAL SCIENCES

Reliability of Tanner Staging Performed by Orthopedic Sports Medicine Surgeons

JENNIFER M. SLOUGH[1], WILLIAM HENNRIKUS[2], and YING CHANG[3]

[1]College of Medicine, Pennsylvania State University, Hershey, PA; [2]Bone and Joint Institute, Pennsylvania State University, Hershey, PA; and [3]Pediatric Endocrinology, College of Medicine, Pennsylvania State University, Hershey, PA

ABSTRACT

SLOUGH, J. M., W. HENNRIKUS, and Y. CHANG. Reliability of Tanner Staging Performed by Orthopedic Sports Medicine Surgeons. *Med. Sci. Sports Exerc.*, Vol. 45, No. 7, pp. 1229–1234, 2013. **Purpose**: The treatment of anterior cruciate ligament (ACL) tears in children is controversial because of the potential injury to the growth plate resulting from traditional transphyseal surgery. Some authors recommend Tanner staging as a method to determine the patient's maturity to decide between physeal-sparing or transphyseal surgery. This study examines the accuracy and interobserver and intraobserver reliabilities of Tanner staging performed by orthopedic surgeons. **Methods**: Twenty-eight photographs representing Tanner stages 1–5 were obtained from a pediatric endocrinologist. Four sports medicine orthopedic surgeons received a tutorial on Tanner staging and independently graded the photographs twice, with a 1-month interval between grading exams. The endocrinologist's grade was considered correct. Intraobserver and interobserver reliabilities were determined. **Results**: The overall average correct scores were as follows: 53% correct Tanner stages on exam 1 and 59% correct on exam 2. The average results for specific Tanner stages were as follows: Tanner stage 1 = 62% correct on exam 1, 83% on exam 2; Tanner stage 2 = 60%/65%; Tanner stage 3 = 60%/46%; Tanner stage 4 = 45%/55%; and Tanner stage 5 = 50%/45%. Per examiner, correct grading was as follows: examiner 1 = 39% on exam 1 and 35% on exam 2; examiner 2 = 67%/82%; examiner 3 = 50%/42%; and examiner 4 = 67%/75%. When comparing the grading between exams 1 and 2, examiner 1 changed five answers from correct to incorrect; four answers from incorrect to correct; and two answers from incorrect to a different incorrect choice; examiner 2, three/seven/zero; examiner 3, six/four/one; and examiner 4, two/four/zero. **Conclusions**: Preoperative Tanner staging performed by orthopedic surgeons is unreliable with large intraobserver and interobserver variabilities. Therefore, relying on Tanner staging as a method to guide decision making for surgery in skeletally immature patients with ACL tears may lead to inadvertent growth plate injury.

Key Words: PEDIATRIC ACL INJURY, PHYSIS, MATURITY, PEDIATRIC ATHLETE

Pediatric anterior cruciate ligament (ACL) injuries have become more common owing to the increased intensity and duration of childhood athletics, improved physical exam skills, and increased use of magnetic resonance imaging (7,13,15,19,22). The exact incidence (rate of occurrence of new cases) of ACL tears in children has not been established. However, ACL injuries represent 7% of youth soccer injury insurance claims and 31% of youth soccer sport-related injury claims (28). The prevalence (total number of cases in a population) of an ACL tear in a child with a traumatic knee hemarthrosis is about 65% (32).

Treatment of ACL injuries in the skeletally immature patient is controversial because standard ACL reconstructions involve the use of drill holes that cross the open physis, potentially causing growth disturbance such as shortening or angulation of the child's leg (15). In the past, some authors have recommended nonoperative treatment, including a brace, rehabilitation, and sports restriction to delay ACL reconstruction until skeletal maturity (4,31,35). However, pediatric athletes and their parents today are less inclined to restrict the pediatric athletes' activity (3). In such cases, an ACL tear in the pediatric athlete treated conservatively can lead to additional instability episodes, meniscal tears, articular cartilage damage, and arthritis (1,10,17,23,24). Therefore, recent literature supports early surgery for most pediatric athletes with an unstable ACL-deficient knee (1,2,5,16,18).

ACL surgery in pediatric athletes is often performed via a physeal-sparing technique (16,22) or a transphyseal technique (26,29). The physeal-sparing technique avoids injury to the growth plate but is nonanatomic in graft placement. The transphyseal technique is anatomic in graft placement but risks physeal injury and growth abnormality. Sports medicine physicians are often presented with the dilemma of a skeletally immature athlete with an ACL tear: when is the athlete physically mature enough to undergo ACL reconstruction via drill holes—transphyseal technique—without causing iatrogenic growth plate injury? Some authors recommend using Tanner staging as a method to decide between physeal-sparing or transphyseal surgery (14,16,18,26,31). Tanner staging defines the physical measurements of the child's development based on external primary and secondary sex

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PDF

ORIGINAL ARTICLE

The Shorthand Bone Age Assessment: A Simpler Alternative to Current Methods

Benton E. Heyworth, MD, Daniel A. Osei, MD,† Peter D. Fabricant, MD, MPH,‡ Robert Schneider, MD,‡ Shevaun M. Doyle, MD,‡ Daniel W. Green, MD,‡ Roger F. Widmann, MD,‡ Stephen Lyman, PhD,‡ Stephen W. Burke, MD,‡ and David M. Scher, MD‡*

Background: Radiographic assessment of skeletal age in pediatric patients is a common practice among orthopaedic surgeons. Current methods of assessment remain labor intensive and require special resources. This study sought to investigate a novel, abridged method of bone age assessment that may serve as a simpler and more efficient alternative to the current standard.

Methods: A shorthand bone age (SBA) method developed at our institution was compared against the Greulich and Pyle method from which it was derived. Standard left hand bone age radiographs of 140 male and 120 female patients, previously assigned skeletal ages ranging from 12.5 to 16 years in males and 10 to 16 years in females by musculoskeletal radiologists using the Greulich and Pyle radiographic atlas, were read using the shorthand method by 3 attending pediatric orthopaedic surgeons and an orthopaedic surgery resident. The shorthand method utilizes a single, univariable criterion for each age, rather than a multivariable subjective comparison to a radiographic atlas. All reviewers were blinded to the original bone age determination. Interobserver reliability, intraobserver reliability, and agreement with the previous records utilizing the atlas were calculated using weighted κ.

Results: The SBA method readings demonstrated substantial agreement with readings by the Greulich and Pyle atlas, demonstrating weighted κ values ranging from 0.71 to 0.75. The SBA method also demonstrated substantial to almost perfect interobserver and intraobserver reliability, with values ranging from 0.77 to 0.87 and from 0.87 to 0.95, respectively.

Conclusions: These results are comparable or superior to previous reports which investigate the validity and reliability of other skeletal age assessment tools. The SBA assessment tool offers a simple and efficient alternative to current methods.

Level of Evidence: Diagnostic study, level III.

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None of the authors received financial support for this study.
There was no external funding source for the current study.
The authors declare no conflict of interest.

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Key Words: bone age, skeletal age, radiography, shorthand method, interobserver reliability, intraobserver reliability, pediatric, adolescent

(*J Pediatr Orthop* 2013;33:569–574)

Radiographic assessment of skeletal age in pediatric and adolescent patients is a common practice in pediatric orthopaedics and other pediatric subspecialties. The assessment of bone age in the peripubertal period, when there is peak growth velocity, is a well-established, yet still evolving, science. Accuracy is critical to the timing and nature of management decisions for scoliosis, leg length discrepancy, limb deformity, as well as medical and surgical interventions that may disrupt normal physeal growth. The optimal method or combination of methods for assessment of skeletal maturity remains an area of considerable controversy.

Introduced by Greulich and Pyle[1] in 1959, use of the *Radiographic Atlas of the Hand and Wrist* has emerged as the single most common method of bone age evaluation in the fields of radiology and orthopaedic surgery, and is considered the gold standard by many practitioners in the United States. However, the Greulich and Pyle method (GPM) has significant drawbacks that limit its use. First, the technique relies on the use of a voluminous atlas in hard copy form. Furthermore, adequate training in the technique, which involves an exhaustive comparison of the appearance of a variety of morphologic features in a left hand and wrist radiograph to a corresponding image in the atlas, is uncommon in subspecialty training programs other than radiology. Orthopaedic surgeons and other caregivers investigating patients' skeletal age, such as general pediatricians, pediatric endocrinologists, and pediatric metabolic bone specialists often are reliant upon radiologists to provide bone age readings because copies of the atlas are not always available in multiple sites at treatment centers.

To address these limitations, several methods of bone age estimation using hand radiographs have been proposed as alternatives to that of Greulich and Pyle.[2–4] In addition, a variety of authors have contended that radiographic analysis of other body parts may be superior to those of the

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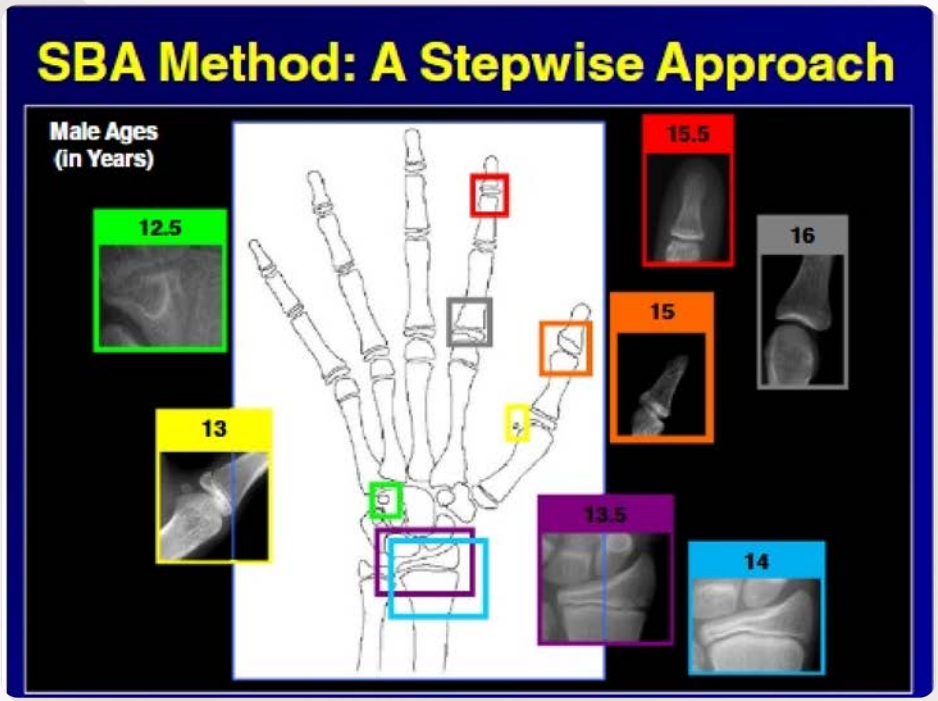
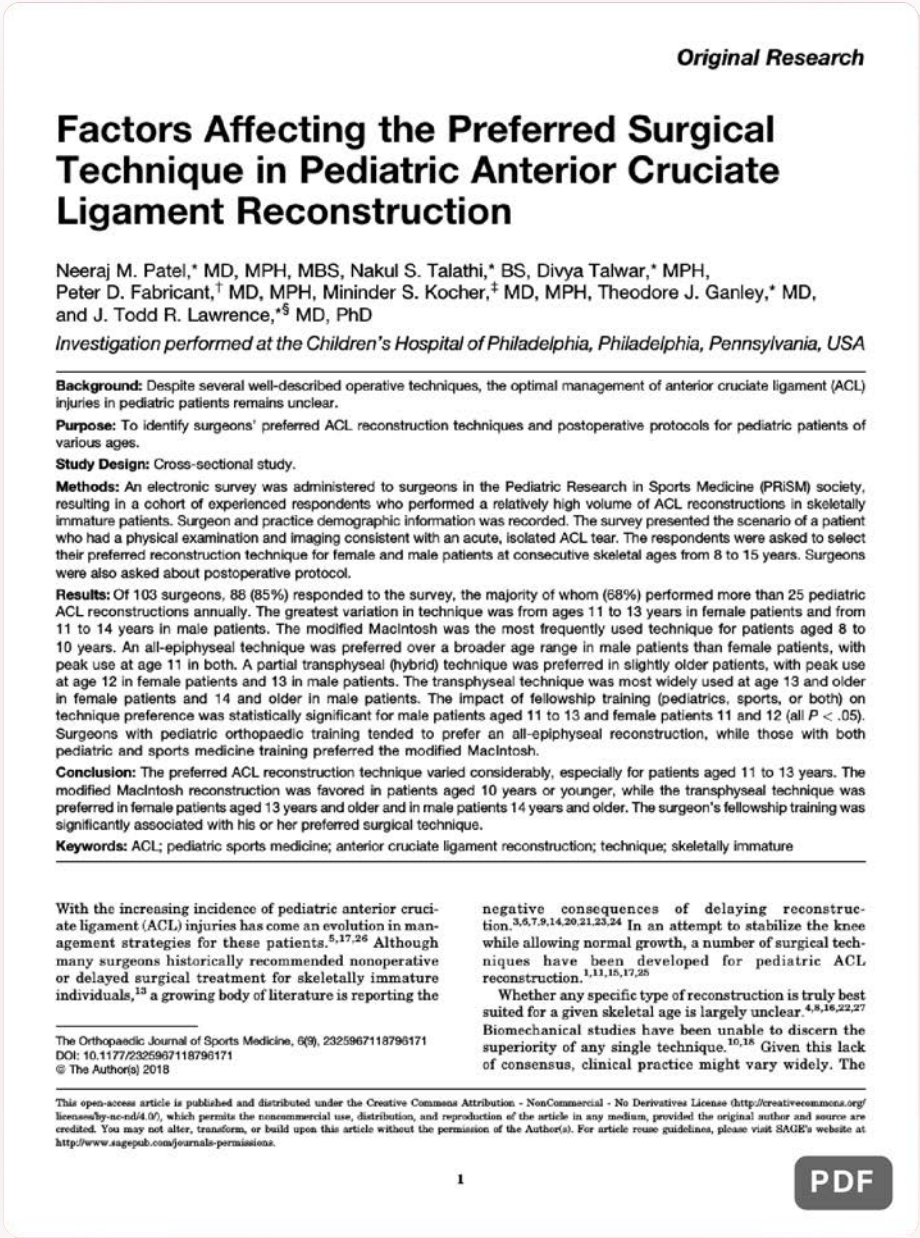


How Do PRISM Members Stratify Based on Skeletal Age?

- Strong consensus for complete growth sparing technique ages **10 and under** (ITB or AE)
- Strong consensus on using transphyseal technique **age 13 and older in females, age 14 and older in males**
- Lots of variability in treatment in ages **11 - 13**



Original Research

Factors Affecting the Preferred Surgical Technique in Pediatric Anterior Cruciate Ligament Reconstruction

Neeraj M. Patel,* MD, MPH, MBS, Nakul S. Talathi,* BS, Divya Talwar,* MPH, Peter D. Fabricant,† MD, MPH, Mininder S. Kocher,‡ MD, MPH, Theodore J. Ganley,* MD, and J. Todd R. Lawrence,*§ MD, PhD

Investigation performed at the Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, USA

Background: Despite several well-described operative techniques, the optimal management of anterior cruciate ligament (ACL) injuries in pediatric patients remains unclear.

Purpose: To identify surgeons' preferred ACL reconstruction techniques and postoperative protocols for pediatric patients of various ages.

Study Design: Cross-sectional study.

Methods: An electronic survey was administered to surgeons in the Pediatric Research in Sports Medicine (PRiSM) society, resulting in a cohort of experienced respondents who performed a relatively high volume of ACL reconstructions in skeletally immature patients. Surgeon and practice demographic information was recorded. The survey presented the scenario of a patient who had a physical examination and imaging consistent with an acute, isolated ACL tear. The respondents were asked to select their preferred reconstruction technique for female and male patients at consecutive skeletal ages from 8 to 15 years. Surgeons were also asked about postoperative protocol.

Results: Of 103 surgeons, 88 (85%) responded to the survey, the majority of whom (68%) performed more than 25 pediatric ACL reconstructions annually. The greatest variation in technique was from ages 11 to 13 years in female patients and from 11 to 14 years in male patients. The modified MacIntosh was the most frequently used technique for patients aged 8 to 10 years. An all-epiphyseal technique was preferred over a broader age range in male patients than female patients, with peak use at age 11 in both. A partial transphyseal (hybrid) technique was preferred in slightly older patients, with peak use at age 12 in female patients and 13 in male patients. The transphyseal technique was most widely used at age 13 and older in female patients and 14 and older in male patients. The impact of fellowship training (pediatrics, sports, or both) on technique preference was statistically significant for male patients aged 11 to 13 and female patients 11 and 12 (all $P < .05$). Surgeons with pediatric orthopaedic training tended to prefer an all-epiphyseal reconstruction, while those with both pediatric and sports medicine training preferred the modified MacIntosh.

Conclusion: The preferred ACL reconstruction technique varied considerably, especially for patients aged 11 to 13 years. The modified MacIntosh reconstruction was favored in patients aged 10 years or younger, while the transphyseal technique was preferred in female patients aged 13 years and older and in male patients 14 years and older. The surgeon's fellowship training was significantly associated with his or her preferred surgical technique.

Keywords: ACL; pediatric sports medicine; anterior cruciate ligament reconstruction; technique; skeletally immature

With the increasing incidence of pediatric anterior cruciate ligament (ACL) injuries has come an evolution in management strategies for these patients.[5,17,26] Although many surgeons historically recommended nonoperative or delayed surgical treatment for skeletally immature individuals,[13] a growing body of literature is reporting the negative consequences of delaying reconstruction.[3,6,7,9,14,20,21,23,24] In an attempt to stabilize the knee while allowing normal growth, a number of surgical techniques have been developed for pediatric ACL reconstruction.[1,11,15,17,25]

Whether any specific type of reconstruction is truly best suited for a given skeletal age is largely unclear.[4,8,16,22,27] Biomechanical studies have been unable to discern the superiority of any single technique.[10,18] Given this lack of consensus, clinical practice might vary widely. The

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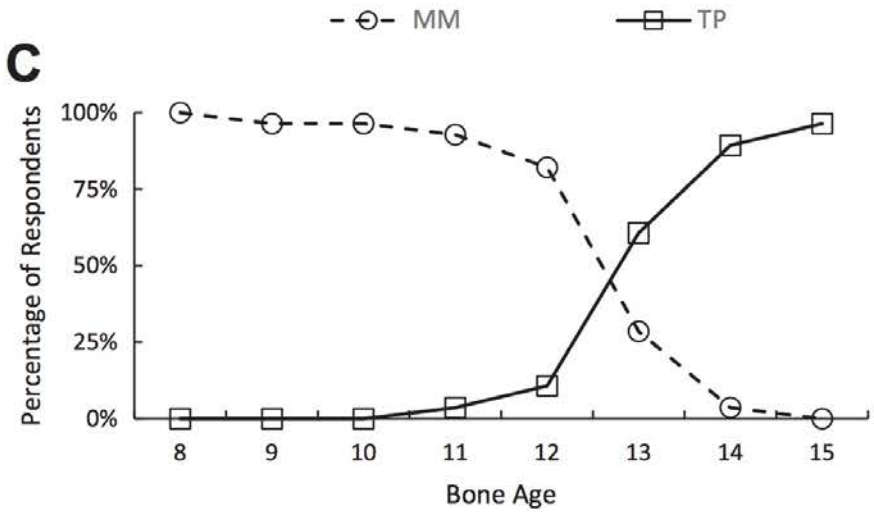
Pediatric ACLs Come in Three "Flavors"

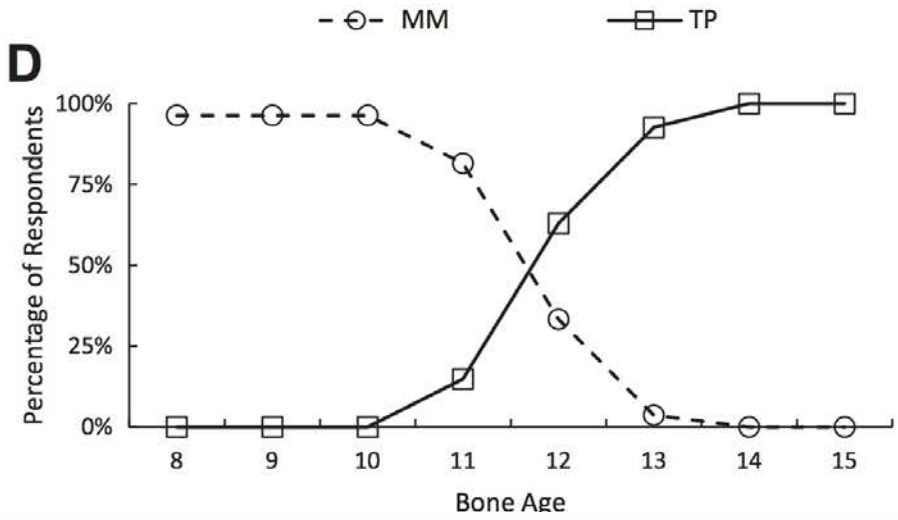
1. **Pre-pubescent (almost always males)**
   - 12 and under boys
   - 11 and under girls

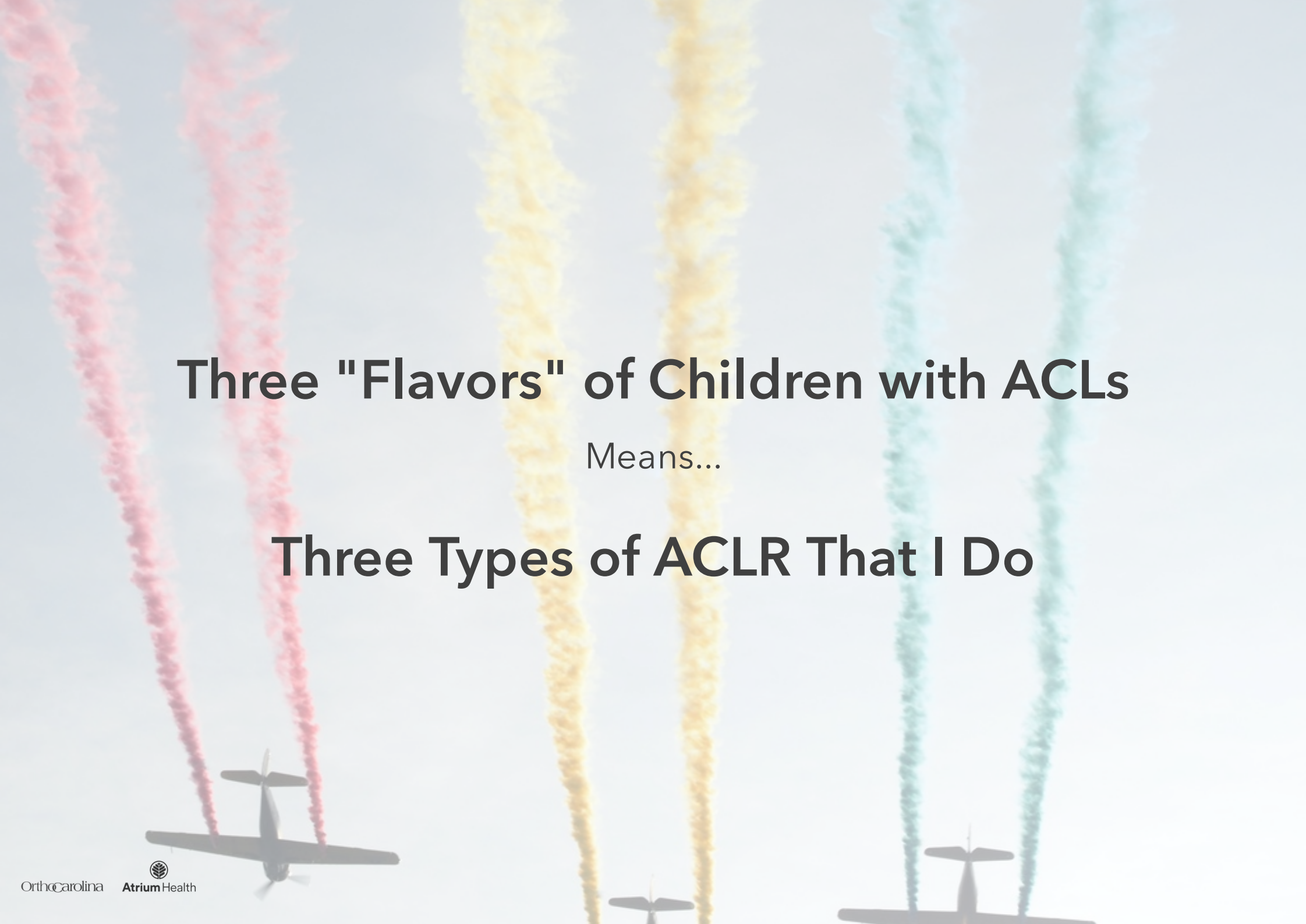
2. **"Tweeners"**
   - 13 - 15 yo boys
   - 12 - 13 yo girls

3. **Skeletally mature**
   - 16 and older boys
   - 14 and older girls

Crowd Psychology...







Three "Flavors" of Children with ACLs

Means...

Three Types of ACLR That I Do

OrthoCarolina Atrium Health

Extraphyseal

All-Epiphyseal

Partial Transphyseal

Transphyseal

Adult type

Original Research

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The Really Young Ones

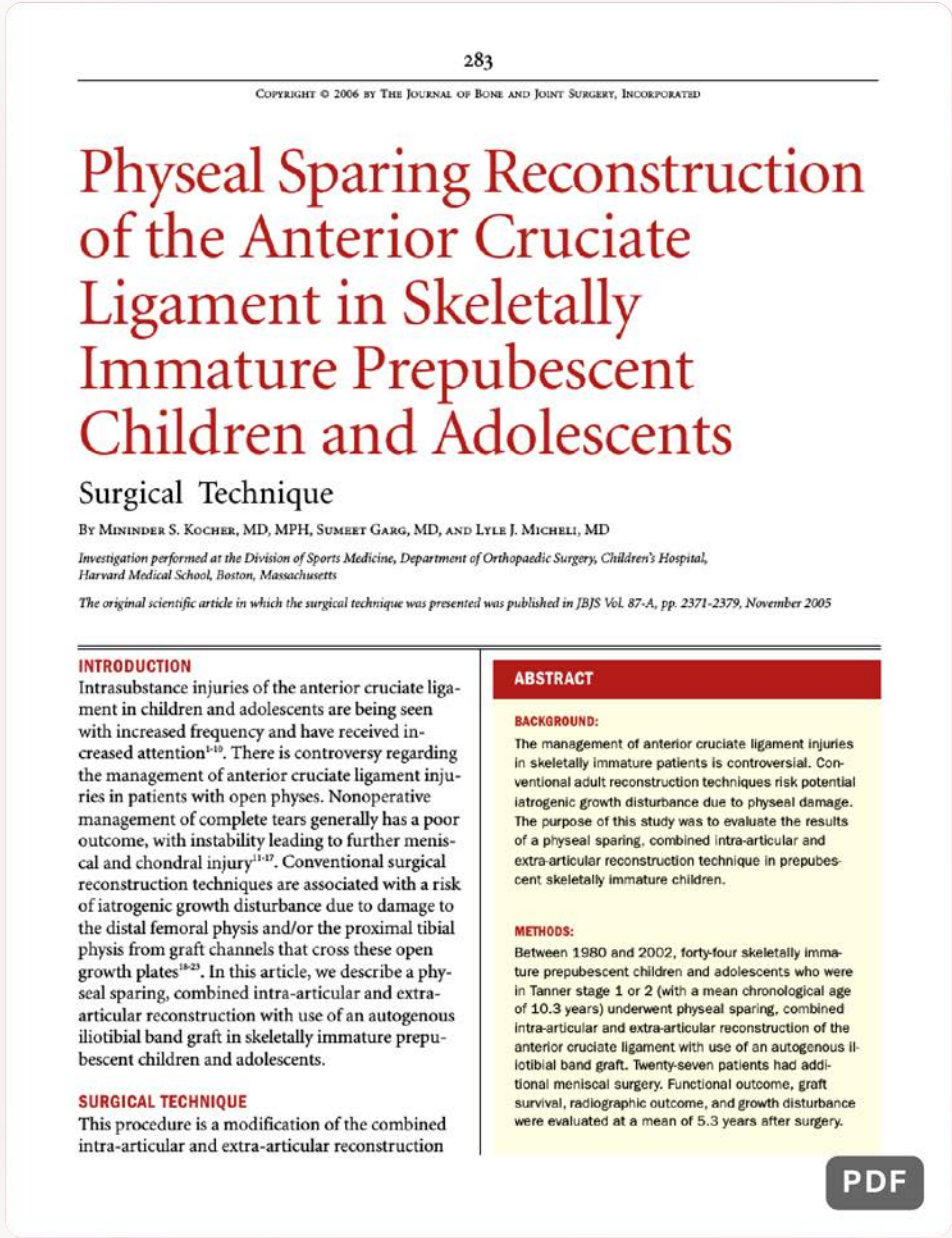
Pre-Pubescent ACLR

OrthoCarolina Atrium Health

Original Technique Description

A MUST READ!

Modification of the McIntosh Procedure



Physeal Sparing Reconstruction of the Anterior Cruciate Ligament in Skeletally Immature Prepubescent Children and Adolescents

Surgical Technique

BY MININDER S. KOCHER, MD, MPH, SUMEET GARG, MD, AND LYLE J. MICHELI, MD

Investigation performed at the Division of Sports Medicine, Department of Orthopaedic Surgery, Children's Hospital, Harvard Medical School, Boston, Massachusetts

The original scientific article in which the surgical technique was presented was published in JBJS Vol. 87-A, pp. 2371-2379, November 2005

INTRODUCTION

Intrasubstance injuries of the anterior cruciate ligament in children and adolescents are being seen with increased frequency and have received increased attention[1-10]. There is controversy regarding the management of anterior cruciate ligament injuries in patients with open physes. Nonoperative management of complete tears generally has a poor outcome, with instability leading to further meniscal and chondral injury[11-17]. Conventional surgical reconstruction techniques are associated with a risk of iatrogenic growth disturbance due to damage to the distal femoral physis and/or the proximal tibial physis from graft channels that cross these open growth plates[18-23]. In this article, we describe a physeal sparing, combined intra-articular and extra-articular reconstruction with use of an autogenous iliotibial band graft in skeletally immature prepubescent children and adolescents.

SURGICAL TECHNIQUE

This procedure is a modification of the combined intra-articular and extra-articular reconstruction

ABSTRACT

BACKGROUND:

The management of anterior cruciate ligament injuries in skeletally immature patients is controversial. Conventional adult reconstruction techniques risk potential iatrogenic growth disturbance due to physeal damage. The purpose of this study was to evaluate the results of a physeal sparing, combined intra-articular and extra-articular reconstruction technique in prepubescent skeletally immature children.

METHODS:

Between 1980 and 2002, forty-four skeletally immature prepubescent children and adolescents who were in Tanner stage 1 or 2 (with a mean chronological age of 10.3 years) underwent physeal sparing, combined intra-articular and extra-articular reconstruction of the anterior cruciate ligament with use of an autogenous iliotibial band graft. Twenty-seven patients had additional meniscal surgery. Functional outcome, graft survival, radiographic outcome, and growth disturbance were evaluated at a mean of 5.3 years after surgery.

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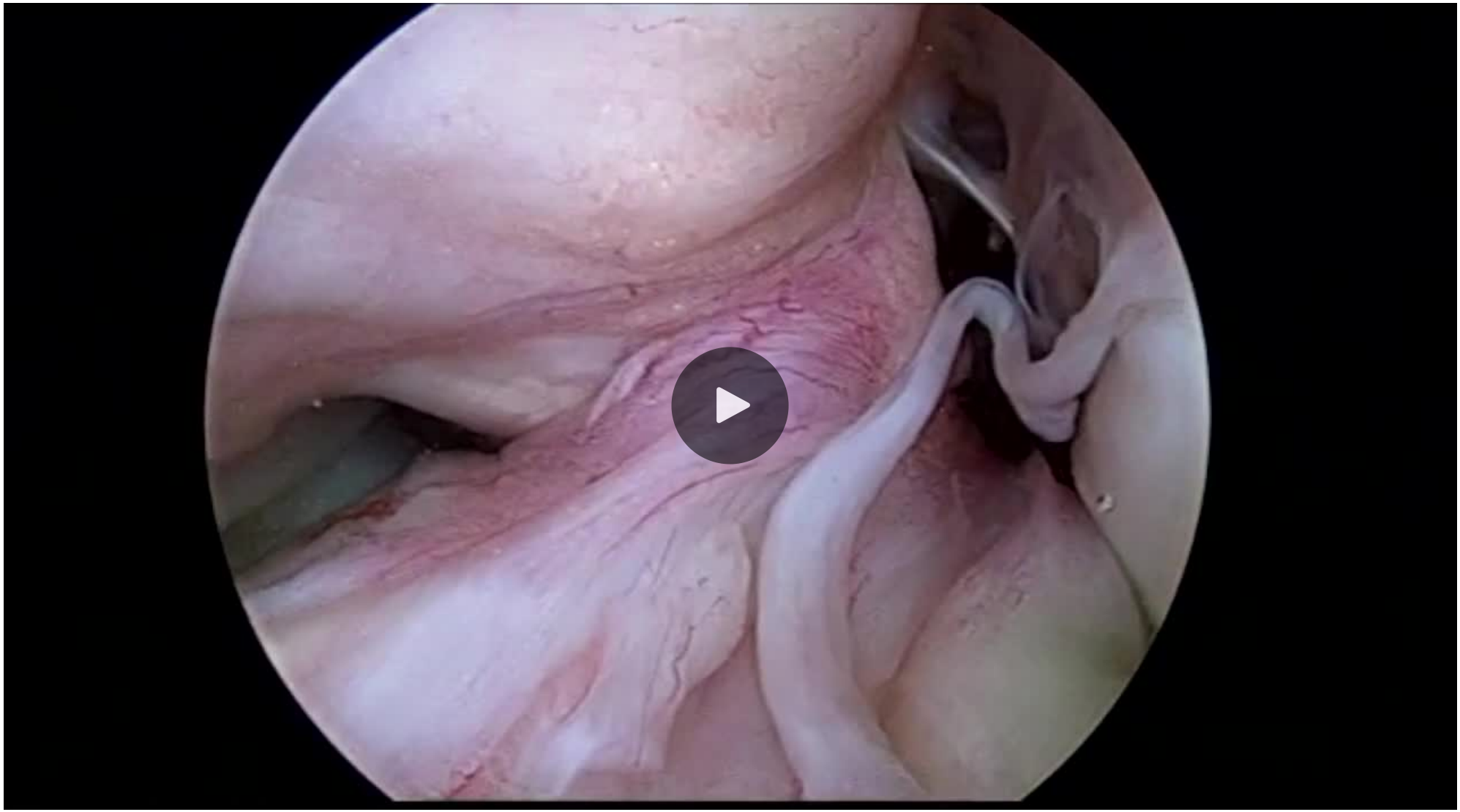

Outcomes of Micheli Technique

Largest series in literature
Boston Children's group

240 knees
Mean 6 year follow-up

6.6% graft rupture
0% growth abnormality
50% cosmetic lateral thigh changes

Outcomes of Physeal-Sparing ACL Reconstruction with Iliotibial Band Autograft in Skeletally Immature Prepubescent Children

Mininder S. Kocher, MD, MPH, Benton E. Heyworth, MD, Peter D. Fabricant, MD, MPH, Frances A. Tepolt, MD, and Lyle J. Micheli, MD

Investigation performed at Boston Children's Hospital, Boston, Massachusetts

Background: Anterior cruciate ligament (ACL) tears are occurring in youth athletes with increasing frequency. Many ACL reconstruction procedures designed to allow for continued growth in patients with open physes have been described, but large series with mid- to long-term outcomes data are lacking. The purpose of the current study was to assess the clinical outcomes of a large cohort of prepubescent children who underwent a physeal-sparing, combined intra- and extra-articular ACL reconstruction with iliotibial (IT) band autograft over a 23-year period.

Methods: Included in our analysis were 237 patients (240 knees) who underwent ACL reconstruction using IT band autograft at Tanner stage 1 or 2 (mean age of 11.2 ± 1.7 years). Physical examination data were analyzed for 225 of the 240 knees (mean follow-up, 25.8 months), and 137 (57%) of the knees had corresponding patient-reported clinical outcomes (patient-reported graft rupture and Pediatric International Knee Documentation Committee [Pedi-IKDC], Tegner activity scale, and Lysholm scores; mean follow-up, 6.2 years). Rates of growth arrest, IT band graft-harvest morbidity, and return to sports were analyzed.

Results: Physical examination revealed that 96.8% of the knees were grade A on the Lachman test and 98.8% were grade A on the pivot-shift test. Graft rupture occurred in 9 (6.6%) of 137 knees, at an average of 33.5 months (range, 8.2 months to 8.0 years) postoperatively. For patients who did not sustain a graft rupture, the mean Pedi-IKDC score was 93.3 ± 11.0, the mean Lysholm score was 93.4 ± 9.9, and the mean score on the Tegner activity scale was 7.8 (mode, 7). While lateral thigh asymmetry at the IT band harvest site was noted by 48% of the subjects, only 1.6% reported associated pain. No cases of limb-length discrepancy or angular deformity were observed.

Conclusions: This procedure was associated with excellent functional outcomes, minimal risk of growth disturbance, and a low graft-rupture rate in skeletally immature prepubescent children. These results appear durable at mid- to long-term follow-up, at an average of >6 years postoperatively.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Anterior cruciate ligament (ACL) tears were once considered a rare injury in children. However, a dramatic rise in youth sports participation, year-round training and competition[1], early sport specialization[2], and increased ACL injury awareness have contributed to the increase in the frequency of ACL tears in skeletally immature athletes. A recent epidemiologic analysis in New York State revealed that the rate of ACL reconstruction among patients <20 years of age had increased nearly 3-fold over 20 years and indicated that youth athletes represented the largest per capita demographic of ACL reconstructions[3].

Historically, nonoperative management strategies, such as the use of a brace, physical therapy, and activity modification, were often recommended as a temporizing approach to ACL deficiency until skeletal maturity, when a traditional adult-type ACL reconstruction could be performed. However, enhanced understanding of the pitfalls of nonoperative treatment and surgical delay in this population[4-8] has more recently supported

Disclosure: No external funding was received for this study. On the **Disclosure of Potential Conflicts of Interest** forms, *which are provided with the online version of the article*, one or more of the authors checked "yes" to indicate that the author had a relevant financial relationship in the biomedical arena outside the submitted work (http://links.lww.com/JBJS/E783).

J Bone Joint Surg Am. 2018;100:1087-94 • http://dx.doi.org/10.2106/JBJS.17.01327

PDF

Outcomes of Micheli Technique

Only cohort other than Boston group

22 knee
Mean 3 year follow-up

14% graft rupture
0% growth abnormality

The American Journal of Sports Medicine
http://ajs.sagepub.com/

Micheli Anterior Cruciate Ligament Reconstruction in Skeletally Immature Youths: A Retrospective Case Series With a Mean 3-Year Follow-up
S. Clifton Willimon, Christopher R. Jones, Mackenzie M. Herzog, Keith H. May, Melissa J. Leake and Michael T. Busch
Am J Sports Med published online October 23, 2015
DOI: 10.1177/0363546515608477

The online version of this article can be found at:
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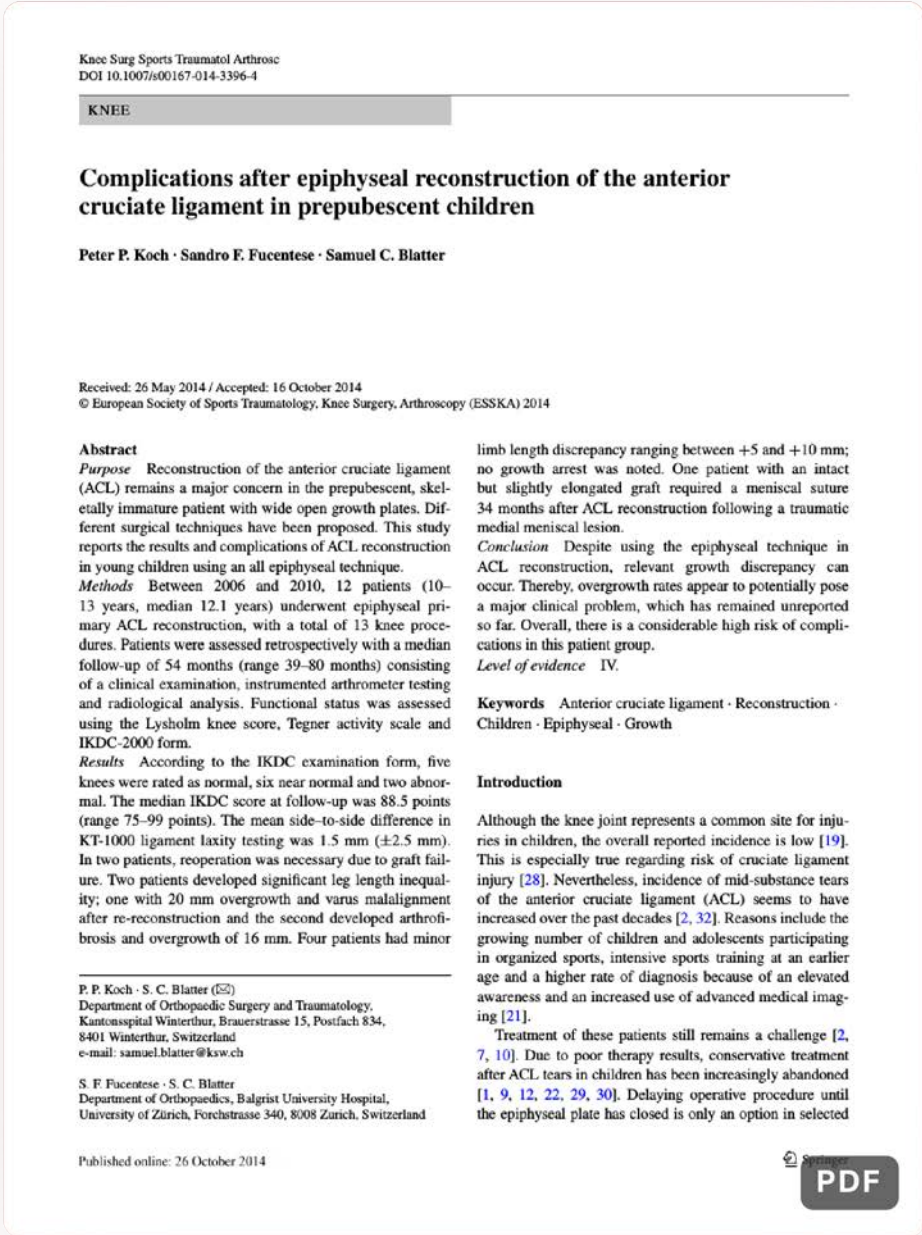
PDF

High Incidence of Growth Abnormalities with All-Epiphyseal Technique

- 50% measurable growth abnormality
- 16% severe (> 2 cm)
- 33% mild/moderate (5 - 10mm)
- Always **OVERGROWTH**



Knee Surg Sports Traumatol Arthrosc
DOI 10.1007/s00167-014-3396-4

KNEE

Complications after epiphyseal reconstruction of the anterior cruciate ligament in prepubescent children

Peter P. Koch · Sandro F. Fucentese · Samuel C. Blatter

Received: 26 May 2014 / Accepted: 16 October 2014

Abstract
Purpose Reconstruction of the anterior cruciate ligament (ACL) remains a major concern in the prepubescent, skeletally immature patient with wide open growth plates. Different surgical techniques have been proposed. This study reports the results and complications of ACL reconstruction in young children using an all epiphyseal technique.
Methods Between 2006 and 2010, 12 patients (10–13 years, median 12.1 years) underwent epiphyseal primary ACL reconstruction, with a total of 13 knee procedures. Patients were assessed retrospectively with a median follow-up of 54 months (range 39–80 months) consisting of a clinical examination, instrumented arthrometer testing and radiological analysis. Functional status was assessed using the Lysholm knee score, Tegner activity scale and IKDC-2000 form.
Results According to the IKDC examination form, five knees were rated as normal, six near normal and two abnormal. The median IKDC score at follow-up was 88.5 points (range 75–99 points). The mean side-to-side difference in KT-1000 ligament laxity testing was 1.5 mm (±2.5 mm). In two patients, reoperation was necessary due to graft failure. Two patients developed significant leg length inequality; one with 20 mm overgrowth and varus malalignment after re-reconstruction and the second developed arthrofibrosis and overgrowth of 16 mm. Four patients had minor limb length discrepancy ranging between +5 and +10 mm; no growth arrest was noted. One patient with an intact but slightly elongated graft required a meniscal suture 34 months after ACL reconstruction following a traumatic medial meniscal lesion.
Conclusion Despite using the epiphyseal technique in ACL reconstruction, relevant growth discrepancy can occur. Thereby, overgrowth rates appear to potentially pose a major clinical problem, which has remained unreported so far. Overall, there is a considerable high risk of complications in this patient group.
Level of evidence IV.

Keywords Anterior cruciate ligament · Reconstruction · Children · Epiphyseal · Growth

Introduction

Although the knee joint represents a common site for injuries in children, the overall reported incidence is low [19]. This is especially true regarding risk of cruciate ligament injury [28]. Nevertheless, incidence of mid-substance tears of the anterior cruciate ligament (ACL) seems to have increased over the past decades [2, 32]. Reasons include the growing number of children and adolescents participating in organized sports, intensive sports training at an earlier age and a higher rate of diagnosis because of an elevated awareness and an increased use of advanced medical imaging [21].

Treatment of these patients still remains a challenge [2, 7, 10]. Due to poor therapy results, conservative treatment after ACL tears in children has been increasingly abandoned [1, 9, 12, 22, 29, 30]. Delaying operative procedure until the epiphyseal plate has closed is only an option in selected

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Published online: 26 October 2014

PDF

All Epiphyseal ACLR is Inferior to Micheli Technique in Meta-Analysis

- All-epiphyseal has higher failure rate
- All epiphyseal has higher incidence of significant growth abnormality
- All epiphyseal has lower return to sports rates

Why I Don't Do All Epiphyseal ACLR

1. Higher failure rates
2. Higher incidence of growth abnormality
3. Technically challenging
4. Requires significant radiation to child
5. More expensive than Micheli (cost of implants, OR time)
6. Lower return to sport rates
7. Harder revision
8. Do I need an 8th reason?

The "Tweeners"

Quadriceps Autograft using Hybrid Transtibial Transphyseal Technique

OrthoCarolina Atrium Health

13 year old female

- Dancer
- Tore ACL dancing
- Goals to dance and play lacrosse
- Skeletal age 13.5 years
- Parents highly educated and concerned about growth disturbance

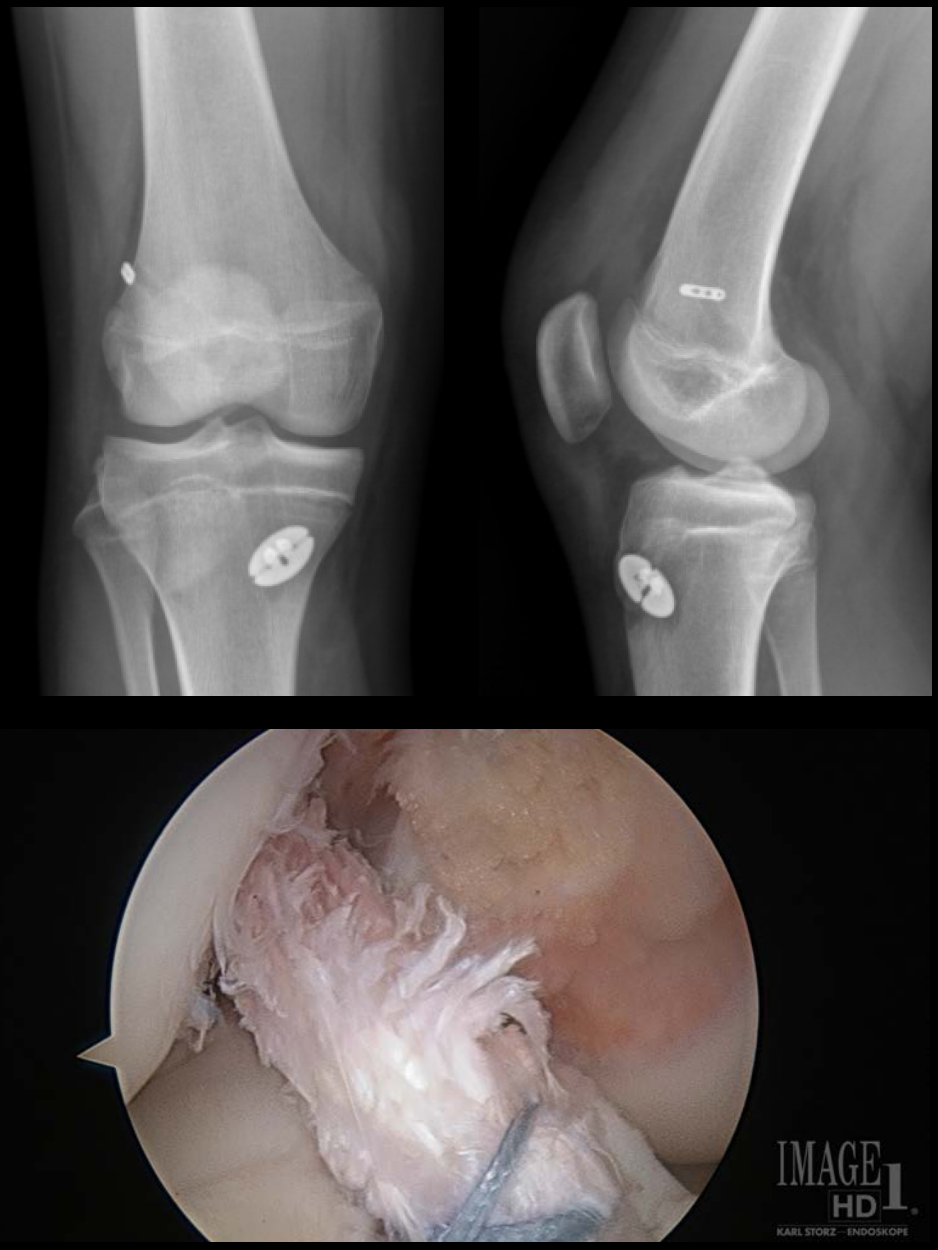
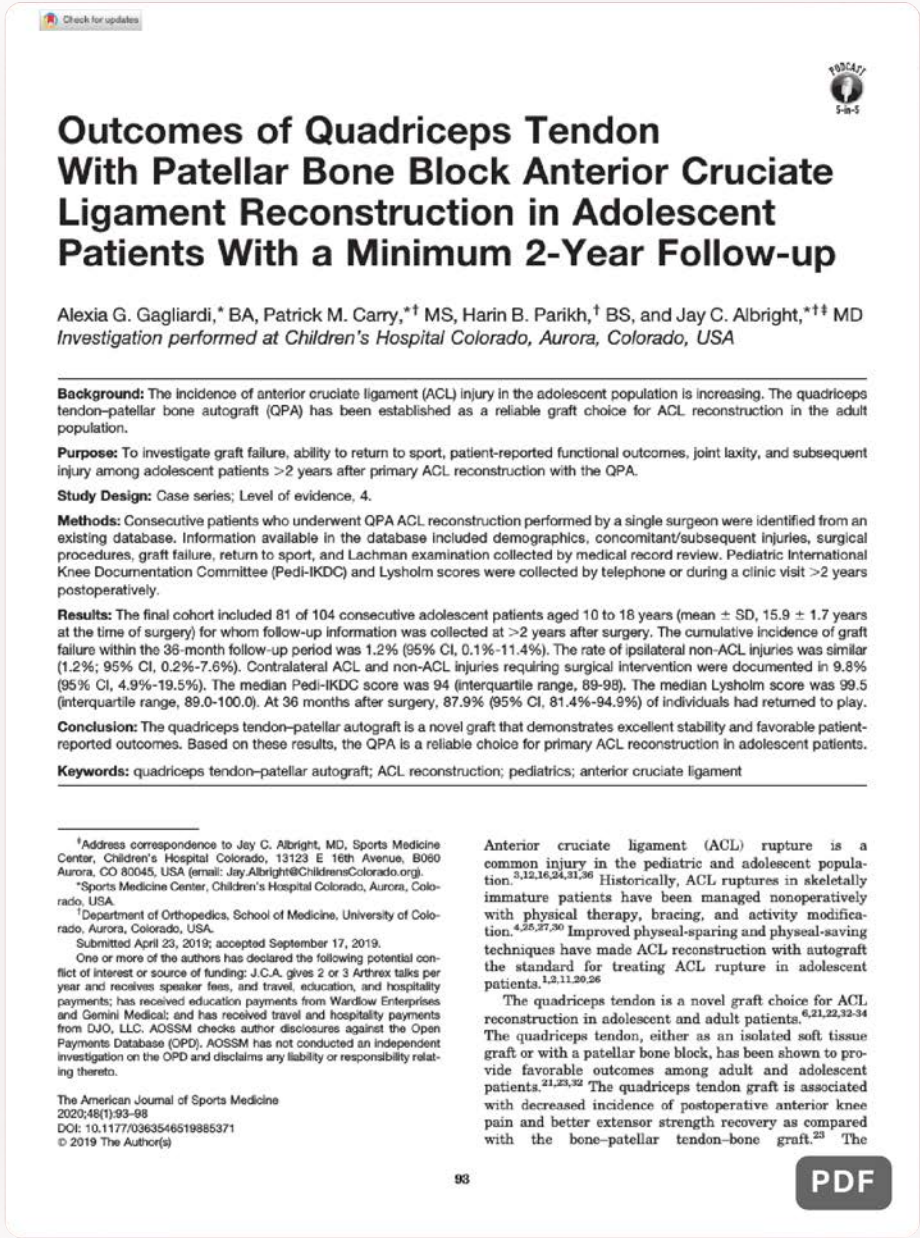


IMAGE1
HD
KARL STORZ – ENDOSKOPE


Psalms

Quad has Very Low Failure Rate in Peds Series

- **1.2% failure** at 36 months
- 81 patients
- 88% return to sport



Check for updates

Outcomes of Quadriceps Tendon With Patellar Bone Block Anterior Cruciate Ligament Reconstruction in Adolescent Patients With a Minimum 2-Year Follow-up

Alexia G. Gagliardi,* BA, Patrick M. Carry,*† MS, Harin B. Parikh,† BS, and Jay C. Albright,*†‡ MD
Investigation performed at Children's Hospital Colorado, Aurora, Colorado, USA

Background: The incidence of anterior cruciate ligament (ACL) injury in the adolescent population is increasing. The quadriceps tendon–patellar bone autograft (QPA) has been established as a reliable graft choice for ACL reconstruction in the adult population.

Purpose: To investigate graft failure, ability to return to sport, patient-reported functional outcomes, joint laxity, and subsequent injury among adolescent patients >2 years after primary ACL reconstruction with the QPA.

Study Design: Case series; Level of evidence, 4.

Methods: Consecutive patients who underwent QPA ACL reconstruction performed by a single surgeon were identified from an existing database. Information available in the database included demographics, concomitant/subsequent injuries, surgical procedures, graft failure, return to sport, and Lachman examination collected by medical record review. Pediatric International Knee Documentation Committee (Pedi-IKDC) and Lysholm scores were collected by telephone or during a clinic visit >2 years postoperatively.

Results: The final cohort included 81 of 104 consecutive adolescent patients aged 10 to 18 years (mean ± SD, 15.9 ± 1.7 years at the time of surgery) for whom follow-up information was collected at >2 years after surgery. The cumulative incidence of graft failure within the 36-month follow-up period was 1.2% (95% CI, 0.1%-11.4%). The rate of ipsilateral non-ACL injuries was similar (1.2%; 95% CI, 0.2%-7.6%). Contralateral ACL and non-ACL injuries requiring surgical intervention were documented in 9.8% (95% CI, 4.9%-19.5%). The median Pedi-IKDC score was 94 (interquartile range, 89-98). The median Lysholm score was 99.5 (interquartile range, 89.0-100.0). At 36 months after surgery, 87.9% (95% CI, 81.4%-94.9%) of individuals had returned to play.

Conclusion: The quadriceps tendon–patellar autograft is a novel graft that demonstrates excellent stability and favorable patient-reported outcomes. Based on these results, the QPA is a reliable choice for primary ACL reconstruction in adolescent patients.

Keywords: quadriceps tendon–patellar autograft; ACL reconstruction; pediatrics; anterior cruciate ligament

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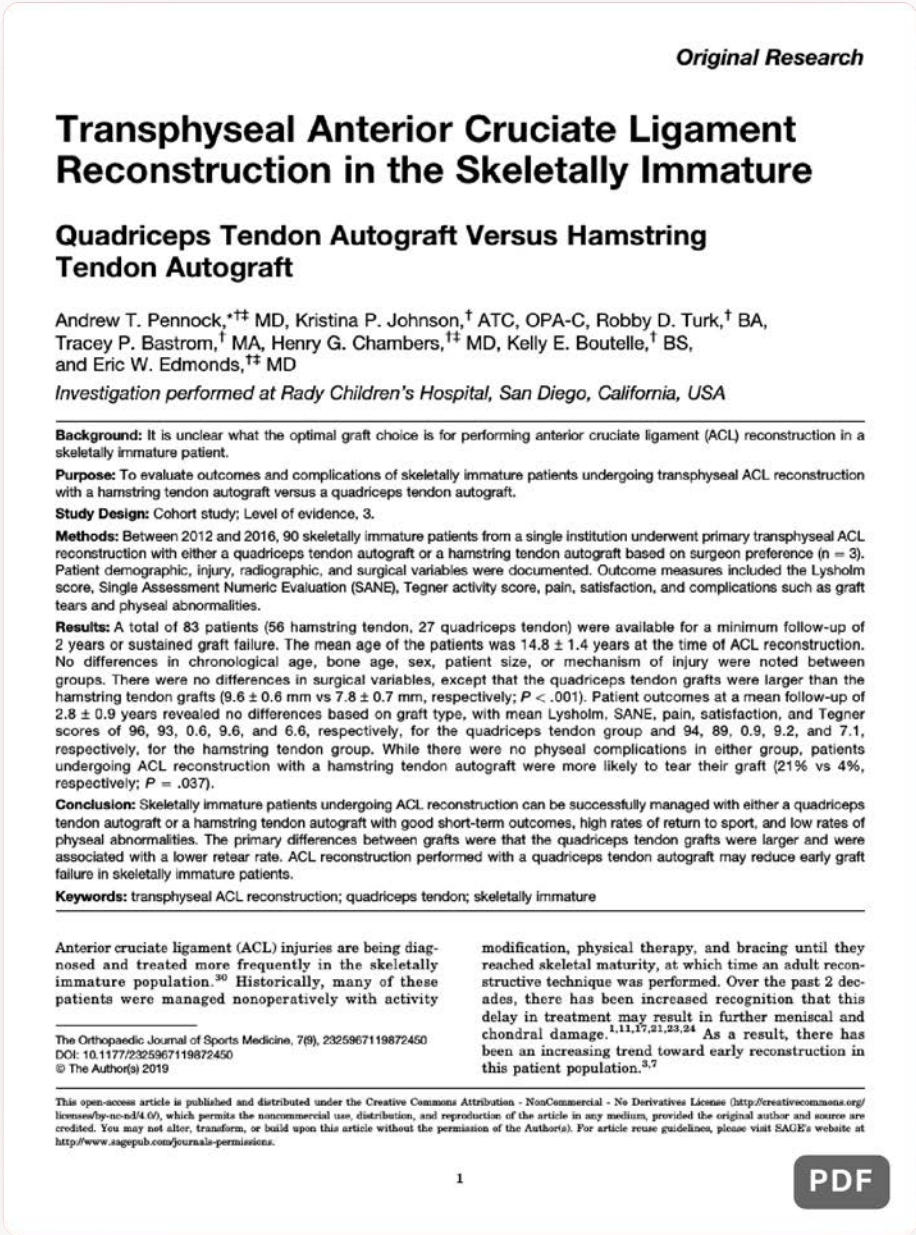
Anterior cruciate ligament (ACL) rupture is a common injury in the pediatric and adolescent population.[3,12,16,24,31,36] Historically, ACL ruptures in skeletally immature patients have been managed nonoperatively with physical therapy, bracing, and activity modification.[4,25,27,30] Improved physeal-sparing and physeal-saving techniques have made ACL reconstruction with autograft the standard for treating ACL rupture in adolescent patients.[1,2,11,20,26]

The quadriceps tendon is a novel graft choice for ACL reconstruction in adolescent and adult patients.[6,21,22,32-34] The quadriceps tendon, either as an isolated soft tissue graft or with a patellar bone block, has been shown to provide favorable outcomes among adult and adolescent patients.[21,23,32] The quadriceps tendon graft is associated with decreased incidence of postoperative anterior knee pain and better extensor strength recovery as compared with the bone–patellar tendon–bone graft.[23] The

PDF

Quad has Lower Failure Rate Than Hamstrings in Kids

- **4% Failure** (Quad n = 27) vs. 21% Failure (Ham n = 56)
- Equivalent PROs (Lysholm, SANE, Tegner)



Original Research

Transphyseal Anterior Cruciate Ligament Reconstruction in the Skeletally Immature

Quadriceps Tendon Autograft Versus Hamstring Tendon Autograft

Andrew T. Pennock,*†‡ MD, Kristina P. Johnson,† ATC, OPA-C, Robby D. Turk,† BA, Tracey P. Bastrom,† MA, Henry G. Chambers,†‡ MD, Kelly E. Boutelle,† BS, and Eric W. Edmonds,†‡ MD

Investigation performed at Rady Children's Hospital, San Diego, California, USA

Background: It is unclear what the optimal graft choice is for performing anterior cruciate ligament (ACL) reconstruction in a skeletally immature patient.

Purpose: To evaluate outcomes and complications of skeletally immature patients undergoing transphyseal ACL reconstruction with a hamstring tendon autograft versus a quadriceps tendon autograft.

Study Design: Cohort study; Level of evidence, 3.

Methods: Between 2012 and 2016, 90 skeletally immature patients from a single institution underwent primary transphyseal ACL reconstruction with either a quadriceps tendon autograft or a hamstring tendon autograft based on surgeon preference (n = 3). Patient demographic, injury, radiographic, and surgical variables were documented. Outcome measures included the Lysholm score, Single Assessment Numeric Evaluation (SANE), Tegner activity score, pain, satisfaction, and complications such as graft tears and physeal abnormalities.

Results: A total of 83 patients (56 hamstring tendon, 27 quadriceps tendon) were available for a minimum follow-up of 2 years or sustained graft failure. The mean age of the patients was 14.8 ± 1.4 years at the time of ACL reconstruction. No differences in chronological age, bone age, sex, patient size, or mechanism of injury were noted between groups. There were no differences in surgical variables, except that the quadriceps tendon grafts were larger than the hamstring tendon grafts (9.6 ± 0.6 mm vs 7.8 ± 0.7 mm, respectively; $P < .001$). Patient outcomes at a mean follow-up of 2.8 ± 0.9 years revealed no differences based on graft type, with mean Lysholm, SANE, pain, satisfaction, and Tegner scores of 96, 93, 0.6, 9.6, and 6.6, respectively, for the quadriceps tendon group and 94, 89, 0.9, 9.2, and 7.1, respectively, for the hamstring tendon group. While there were no physeal complications in either group, patients undergoing ACL reconstruction with a hamstring tendon autograft were more likely to tear their graft (21% vs 4%, respectively; $P = .037$).

Conclusion: Skeletally immature patients undergoing ACL reconstruction can be successfully managed with either a quadriceps tendon autograft or a hamstring tendon autograft with good short-term outcomes, high rates of return to sport, and low rates of physeal abnormalities. The primary differences between grafts were that the quadriceps tendon grafts were larger and were associated with a lower retear rate. ACL reconstruction performed with a quadriceps tendon autograft may reduce early graft failure in skeletally immature patients.

Keywords: transphyseal ACL reconstruction; quadriceps tendon; skeletally immature

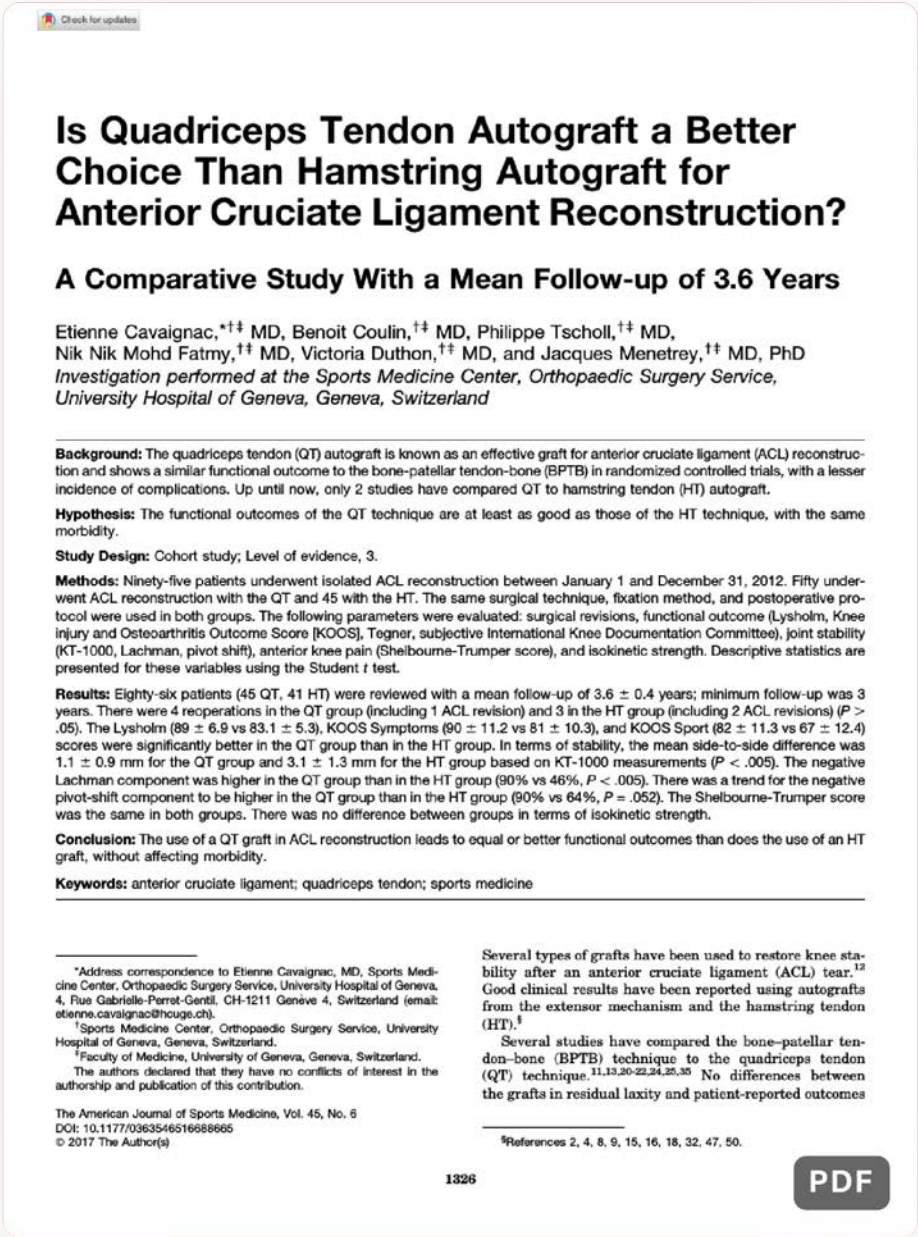
Anterior cruciate ligament (ACL) injuries are being diagnosed and treated more frequently in the skeletally immature population.[30] Historically, many of these patients were managed nonoperatively with activity modification, physical therapy, and bracing until they reached skeletal maturity, at which time an adult reconstructive technique was performed. Over the past 2 decades, there has been increased recognition that this delay in treatment may result in further meniscal and chondral damage.[1,11,17,21,23,24] As a result, there has been an increasing trend toward early reconstruction in this patient population.[3,7]

The Orthopaedic Journal of Sports Medicine, 7(9), 2325967119872450
DOI: 10.1177/2325967119872450

PDF

Quad As Good or Better Than Hamstrings

- Cohort of 95 patients
- Quad had less + Lachman, less + Pivot Shift, lower KT (1 vs 3 mm)
- Quad had better Lysholm, KOOS Symptoms, KOOS Sports



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Is Quadriceps Tendon Autograft a Better Choice Than Hamstring Autograft for Anterior Cruciate Ligament Reconstruction?

A Comparative Study With a Mean Follow-up of 3.6 Years

Etienne Cavaignac,*†‡ MD, Benoit Coulin,†‡ MD, Philippe Tscholl,†‡ MD, Nik Nik Mohd Fatmy,†‡ MD, Victoria Duthon,†‡ MD, and Jacques Menetrey,†‡ MD, PhD
Investigation performed at the Sports Medicine Center, Orthopaedic Surgery Service, University Hospital of Geneva, Geneva, Switzerland

Background: The quadriceps tendon (QT) autograft is known as an effective graft for anterior cruciate ligament (ACL) reconstruction and shows a similar functional outcome to the bone-patellar tendon-bone (BPTB) in randomized controlled trials, with a lesser incidence of complications. Up until now, only 2 studies have compared QT to hamstring tendon (HT) autograft.

Hypothesis: The functional outcomes of the QT technique are at least as good as those of the HT technique, with the same morbidity.

Study Design: Cohort study; Level of evidence, 3.

Methods: Ninety-five patients underwent isolated ACL reconstruction between January 1 and December 31, 2012. Fifty underwent ACL reconstruction with the QT and 45 with the HT. The same surgical technique, fixation method, and postoperative protocol were used in both groups. The following parameters were evaluated: surgical revisions, functional outcome (Lysholm, Knee injury and Osteoarthritis Outcome Score [KOOS], Tegner, subjective International Knee Documentation Committee), joint stability (KT-1000, Lachman, pivot shift), anterior knee pain (Shelbourne-Trumper score), and isokinetic strength. Descriptive statistics are presented for these variables using the Student *t* test.

Results: Eighty-six patients (45 QT, 41 HT) were reviewed with a mean follow-up of 3.6 ± 0.4 years; minimum follow-up was 3 years. There were 4 reoperations in the QT group (including 1 ACL revision) and 3 in the HT group (including 2 ACL revisions) ($P > .05$). The Lysholm (89 ± 6.9 vs 83.1 ± 5.3), KOOS Symptoms (90 ± 11.2 vs 81 ± 10.3), and KOOS Sport (82 ± 11.3 vs 67 ± 12.4) scores were significantly better in the QT group than in the HT group. In terms of stability, the mean side-to-side difference was 1.1 ± 0.9 mm for the QT group and 3.1 ± 1.3 mm for the HT group based on KT-1000 measurements ($P < .005$). The negative Lachman component was higher in the QT group than in the HT group (90% vs 46%, $P < .005$). There was a trend for the negative pivot-shift component to be higher in the QT group than in the HT group (90% vs 64%, $P = .052$). The Shelbourne-Trumper score was the same in both groups. There was no difference between groups in terms of isokinetic strength.

Conclusion: The use of a QT graft in ACL reconstruction leads to equal or better functional outcomes than does the use of an HT graft, without affecting morbidity.

Keywords: anterior cruciate ligament; quadriceps tendon; sports medicine

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DOI: 10.1177/0363546516688665

Several types of grafts have been used to restore knee stability after an anterior cruciate ligament (ACL) tear.[12] Good clinical results have been reported using autografts from the extensor mechanism and the hamstring tendon (HT).[§]

Several studies have compared the bone–patellar tendon–bone (BPTB) technique to the quadriceps tendon (QT) technique.[11,13,20-22,24,25,35] No differences between the grafts in residual laxity and patient-reported outcomes

[§]References 2, 4, 8, 9, 15, 16, 18, 32, 47, 50.

PDF

OrthoCarolina Atrium Health

Quad has Lower Failure Rate and Less Pivot Shift than Hamstrings

- Meta-analysis of 78 studies
- Failure OR = 1.89 (hamstring higher)
- Pivot Shift OR = 1.29 (hamstring higher)

Knee Surgery, Sports Traumatology, Arthroscopy (2020) 28:509–518
https://doi.org/10.1007/s00167-019-05720-y

KNEE

Quadriceps tendon autograft ACL reconstruction has less pivot shift laxity and lower failure rates than hamstring tendon autografts

John Nyland[1,2] · Philip Collis[1,2] · Austin Huffstutler[1,2] · Shikha Sachdeva[1,2] · James R. Spears[1,2] · Joseph Greene[1,2] · David N. M. Caborn[1,2]

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Abstract

Purpose Quadriceps tendon (QT) autograft ACL reconstruction was hypothesized to possess less anterior knee laxity, pivot shift laxity, and lower failure rates than hamstring tendon (HT) autografts.

Methods Terms "hamstring tendon autograft" and "ACL reconstruction" or "quadriceps tendon autograft" and "ACL reconstruction" were searched in Embase and PubMed. Inclusion criteria required that studies included patients treated for primary ACL injury with reconstruction using either a QT autograft (Group 1) or a HT autograft (Group 2) and instrumented anterior knee laxity assessment. Extracted information included surgical fixation method, graft type, graft thickness or diameter, single vs. double bundle surgical method, publication year, time between the index knee injury and surgery, % women, initial and final subject number, subject age, follow-up length, side-to-side anterior knee laxity difference, Lysholm Score, Subjective IKDC score, anterior knee laxity side-to-side difference grade, ipsilateral pivot shift laxity grade, and failure rate. The Methodological Index for Nonrandomized Studies was used to evaluate study methodological quality.

Results The QT group (Group 1) had 17 studies and the HT group (Group 2) had 61 studies. Overall, Group 2 had greater pivot shift laxity (OR 1.29, 95% CI 1.05–1.59, $p=0.005$). Group 2 suspensory femoral fixation had greater pivot shift laxity (OR 1.26, 95% CI 1.01–1.58, $p=0.02$) than Group 1 compression femoral fixation. Group 2 compression femoral fixation also had more anterior knee laxity (OR 1.25, 95% CI 1.03–1.52, $p=0.01$) than Group 1 compression femoral fixation and higher failure rates based on initial (OR 1.69, 95% CI 1.18–2.4, $p=0.002$) and final (OR 1.89, 95% CI 1.32–2.71, $p=0.0003$) subject number. Failure rate for HT compression femoral fixation was greater than suspensory femoral fixation based on initial (OR 2.08, 95% CI 1.52–2.84, $p<0.0001$) and final (OR 2.26, 95% CI 1.63–3.16, $p<0.0001$) subject number.

Conclusions Overall, QT autografts had less pivot shift laxity and lower failure rates based on final subject number than HT autografts. Compression QT autograft femoral fixation had lower pivot shift laxity than suspensory HT autograft femoral fixation. Compression QT autograft femoral fixation had less anterior knee laxity and lower failure rates than compression HT autograft femoral fixation. Suspensory HT autograft femoral fixation had lower failure rates than compression HT autograft femoral fixation. Greater knee laxity and failure rates may be related to a combination of HT autograft diameter and configuration (tissue quality and dimensions, strands, bundles, and suturing method) variability and fixation mode.

Level of evidence Level IV.

Keywords Anterior cruciate ligament · Reconstruction · Patient outcome · Laxity

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00167-019-05720-y) contains supplementary material, which is available to authorized users.

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Introduction

Successful anterior cruciate ligament (ACL) reconstruction involves factors such as surgical approach, graft placement, fixation method, and graft type. In addition to autograft biomechanical properties, other surgical considerations that may influence patient outcomes include graft thickness and insertional dimensions, collagen fiber orientation, and the likelihood of early, long-term, and/or permanent harvest

PDF

Quad Has Lower Graft Failure Rate Compared to HS

875 patients
Retrospective comparative cohorts
In young active patients:

- **HS: 11% failure**
- **Quad: 5% failure**


But Wait! It's Not All Perfect!

Danish Registry Might Show Increased Failure with Quad

- Quad = 4.7% (n = 531)
- Hamstrings = 2.3% (n = 14,213)
- BTB = 1.5% (n = 1835)

Knee Surgery, Sports Traumatology, Arthroscopy
https://doi.org/10.1007/s00167-019-05751-5

KNEE

Quadriceps tendon autograft for anterior cruciate ligament reconstruction is associated with high revision rates: results from the Danish Knee Ligament Registry

Martin Lind[1] · Marc J. Strauss[2] · Torsten Nielsen[1] · Lars Engebretsen[2]

Received: 22 May 2019 / Accepted: 3 October 2019

Abstract
Purpose The quadriceps tendon (QT) has recently gained interest as an anterior cruciate ligament reconstruction (ACLR) autograft. There is a paucity of data from large cohort studies on failures and revision rates after ACLR using the QT graft. The purpose of the present study is to use the Danish Knee Ligament Reconstruction Registry (DKRR) to compare revision rates, objective knee stability and subjective clinical outcomes in patients who have undergone ACLR with QT, hamstring tendon (HT), and patellar tendon (PT) as a graft for ACLR. It was hypothesized that QT autografts would result in similar objective knee stability and revision rates as HT and PT autografts.
Methods Data on primary ACLRs in the DKRR from 2005 through 2017 were analyzed. Knee injury and Osteoarthritis Outcome Scores (KOOS), Tegner activity scale scores, sagittal knee laxity, pivot-shift tests at 1-year follow-up and revision rates at 2-year follow-up were compared for the three autograft cohorts.
Results A total of 531 QT, 14,213 HT and 1835 PT ACLR were registered in the DKLR between 2005 and 2017. QT autograft was associated with statistically significant increased laxity (1.8 mm) compared to HT autograft (1.5 mm) ($p<0.001$) and more positive pivot shift. There was a significant higher revision rate for QT (4.7%), compared to PT (1.5%) and HT (2.3%) autografts at 2-year follow-up ($p<0.002$).
Conclusion Quadriceps tendon autografts for ACLR was associated with higher revision rates than HT and PT grafts. QT graft was also associated with small increased objective knee laxity and more positive pivot shift than HT and PT grafts.
Level of evidence III

Keywords Quadriceps tendon · Hamstring tendon · Patellar tendon · ACL reconstruction · Clinical outcomes

Introduction

The ACL is most often reconstructed using one of two autografts: the patellar tendon (PT) or the hamstring tendon (HT). The choice between these two graft types typically depends on physician preference, with an overall predominance of HT autografts in Scandinavia [19, 20, 23]. The current paradigm is being challenged due to clinical outcomes data reporting a higher revision rate with HT autografts than with PT autografts [6, 28].

There is donor-site morbidity associated with both PT and HT autografts. The most common complication of PT autograft harvesting is anterior knee pain, which has been reported in up to 40% of patients [13, 21]. In addition, PT grafts cannot be used as an autograft in skeletally immature patients due to the risk of damage to open physes [8]. The most common complications of HT autograft harvesting are sensory deficits related to injury to the infrapatellar branches of the saphenous nerve [9], which also can cause anterior knee pain. Other complications of HT autograft harvesting include theoretically reduced medial knee stability in medial collateral ligament-deficient patients and weakness of knee flexion and internal rotation [9, 10]. Additionally, a meta-analysis reported that PT autografts lead to less residual anterior knee laxity than HT autografts [4].

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Published online: 22 October 2019

PDF

OrthoCarolina Atrium Health

Legitimate Concerns about Danish Study

- Regression towards the mean (500 vs. 14,000)
- Selection bias. Quads were:
  - Younger
  - Higher rate of meniscal injury
  - Higher rate of chondral injury
- Remember registry isn't randomized!

Knee Surgery, Sports Traumatology, Arthroscopy
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LETTER TO THE EDITOR

Higher re-rupture rate in quadriceps tendon ACL reconstruction surgeries performed in Denmark: let's return to the mean

Matthieu Ollivier[1] · Christophe Jacquet[1] · Régis Pailhe[2] · Jérémy Cognault[4] · Etienne Cavaignac[5] · Romain Seil[2]

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Keywords ACL reconstruction · Quadriceps tendon · Patellar tendon · Revision rate · Hamstring tendon

Abbreviations
ACL Anterior cruciate ligament
QT Quadriceps tendon
HT Hamstring tendon
PSM Propensity score matching

Dear Editor,

We read with deep interest the registry study from Lind et al., published recently in the Knee Surgery, Sports Traumatology and Arthroscopy journal [7]. In their analysis, the authors described a higher re-rupture rate after quadriceps tendon (QT) anterior cruciate ligament (ACL) reconstruction as compared to hamstring and patellar tendon grafts. As we are using the QT as primary reconstruction graft in high risk patients, we were surprised by the reported three-fold revision-rate difference between the three groups of patients.

The three following comments might help readers to mitigate the conclusion by Lind et al.: First, a statistical bias should be discussed: the regression towards the mean. Jeremy Siegel [4] uses the term "return to (or toward) the mean" to describe an economic time series in which "returns can be very unstable in the short-term but more stable in the long-time-run. This phenomenon is a period in which the standard deviation of average annual returns declines faster than the inverse of the holding period, implying that the process is not a random walk, but that periods of lower returns are systematically followed by compensating periods of higher returns. To simplify this statistical concept, the following illustration might be helpful: there is a higher chance to obtain a result which is really different from 50% tails/ to 50% heads if 10 coins are flipped instead of 300. This may be similar to surgical outcomes if a small group is compared to a bigger one, for example 531 QT vs 14,213 HT ACL reconstructions.

Second, a selection bias may have occurred in this study. Three of the main predictors of ACL reconstruction failures were found in a higher and statistically significant proportion in the QT group: age, associated meniscus lesions, and rotational instability. QT patients were younger [1] and had a higher rate of associated meniscus injuries [3] as well as cartilage damage. Whereas the rate of high-grade pivot shift varies between 30 and 40% in a general population of ACL injured individuals nearly all of them (98%) presented with a positive preoperative pivot shift [5, 8] in the study by Lind et al. This presupposes that QT were mainly used in high risk individuals which may explain the higher rate of revision surgeries in this group. In addition, the learning curve of many surgeons participating in the Danish ACL reconstruction registry which was associated with a graft that has not been used on a routine basis previously may have affected the results negatively. This has been discussed by the authors, but a more thorough discussion of this finding as

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PDF

Then the Same Authors Show Equivalence to Hamstrings in a RCT…

- No difference at 2 years in:
  - Re-operation or failure
  - PROs
  - Objective knee stability

Original research

Quadriceps tendon grafts does not cause patients to have inferior subjective outcome after anterior cruciate ligament (ACL) reconstruction than do hamstring grafts: a 2-year prospective randomised controlled trial

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ABSTRACT

Objective We performed a randomised controlled trial (RCT) in patients undergoing ACL reconstruction (ACLR) using either quadriceps tendon graft (QT) or semitendinosus/gracilis hamstring (STG) graft. We compared subjective outcome (primary outcome) and knee stability, donor site morbidity and function (secondary outcomes).

Methods From 2013 to 2015, we included 99 adults with isolated ACL injuries in the RCT. Fifty patients were randomised to QT grafts and 49 to STG grafts and followed for 2 years. Patient evaluated outcomes were performed by subjective International Knee Documentation Committee, Knee Injury and Osteoarthritis Outcome Score, Kujala and Tegner activity scores. Knee laxity was measured with a KT-1000 arthrometer. Donor site morbidity was evaluated by the 'donor site-related functional problems following ACLR score'. One-leg hop test tested limp strength symmetry.

Results At 2-year follow-up, there was no difference between the two graft groups regarding subjective patient outcome, knee stability and reoperations. Also, at 2 years, donor site symptoms were present in 27% of patients in the QT group and 50% of patients in the STG group. The donor site morbidity score was 14 and 22 for the QT and STG, respectively. Hop test demonstrated lower limp symmetry for QT graft than STG graft of 91% and 97% respectively.

Conclusion QT graft for ACLR did not result in inferior subjective outcome compared with STG graft. However, QT graft was associated with lower donor site morbidity than STG grafts but resulted in more quadriceps muscle strength deficiency than hamstring grafts. Both graft types had similar knee stability outcome.

Trial registration number NCT02173483.

To cite: Lind M, Nielsen TG, Soerensen OG, *et al*. *Br J Sports Med* 2020;**54**:183–187.

OBJECTIVES

ACL reconstruction (ACLR) is one of the most commonly performed procedures in orthopaedic sports medicine; however, there are still challenges including donor site morbidity, suboptimal post-operative objective knee stability, unsatisfactory subjective clinical outcomes and osteoarthritis development.[1–3] The ACL is primarily reconstructed using one of two autografts: the patellar tendon (PT) or the hamstring tendon (STG). The choice between these two graft types typically depends on physician preference, with an overall predominance of STG autografts in Denmark and Sweden but not in Norway.[4–6] The STG predominance is mainly caused by the ease of STG harvest and that PT autograft is associated with anterior knee pain.[7 8] The current graft choice paradigm is presently being challenged due to large volume registry studies reporting a higher revision rate with STG autografts than with PT autografts.[9 10]

Donor site morbidity is associated with both PT and STG autografts. The most common complication of PT autograft harvesting is anterior knee pain and kneeling discomfort, which has been reported in up to 28%–53% of patients compared with 11%–20% for STG graft usage.[7 8] However, minimal invasive surgical techniques can reduce donor site morbidity after PT autograft harvest.[11] The most common complications of STG autograft harvesting are sensory deficits related to injury to the infrapatellar branches of the saphenous nerve.[12] Sensory nerve injury can also cause anterior knee pain.

There has been increased interest in the quadriceps tendon (QT) as an alternative autologous graft source for ACLR.[13] The QT graft has a long track record in ACL revision and posterior cruciate ligament (PCL) reconstruction surgery. Good outcome profiles for these indications combined with favourable anatomical and biomechanical properties of greater tendon thickness and strength compared with PT and STG grafts have increased the interest in QT graft usage in primary ACLR surgery. Furthermore, harvesting the hamstring tendons lead to muscular weakening, which could be a cause of ACL graft failure as hamstring function protects against anterior tibial translation, especially during sports activities. Also, a recent RCT demonstrated that ACLR performed with QT autografts had lower donor site morbidity and equivalent clinical outcomes scores compared with ACLR with PT autografts after 2 years follow-up.[14] This finding has been supported by a retrospective study by Geib *et al* reporting no difference in clinical outcomes between PT and QT autografts after intermediate follow-up.[15] The present literature on QT autografts for ACLR is limited by small series studies and only one comparative level one study

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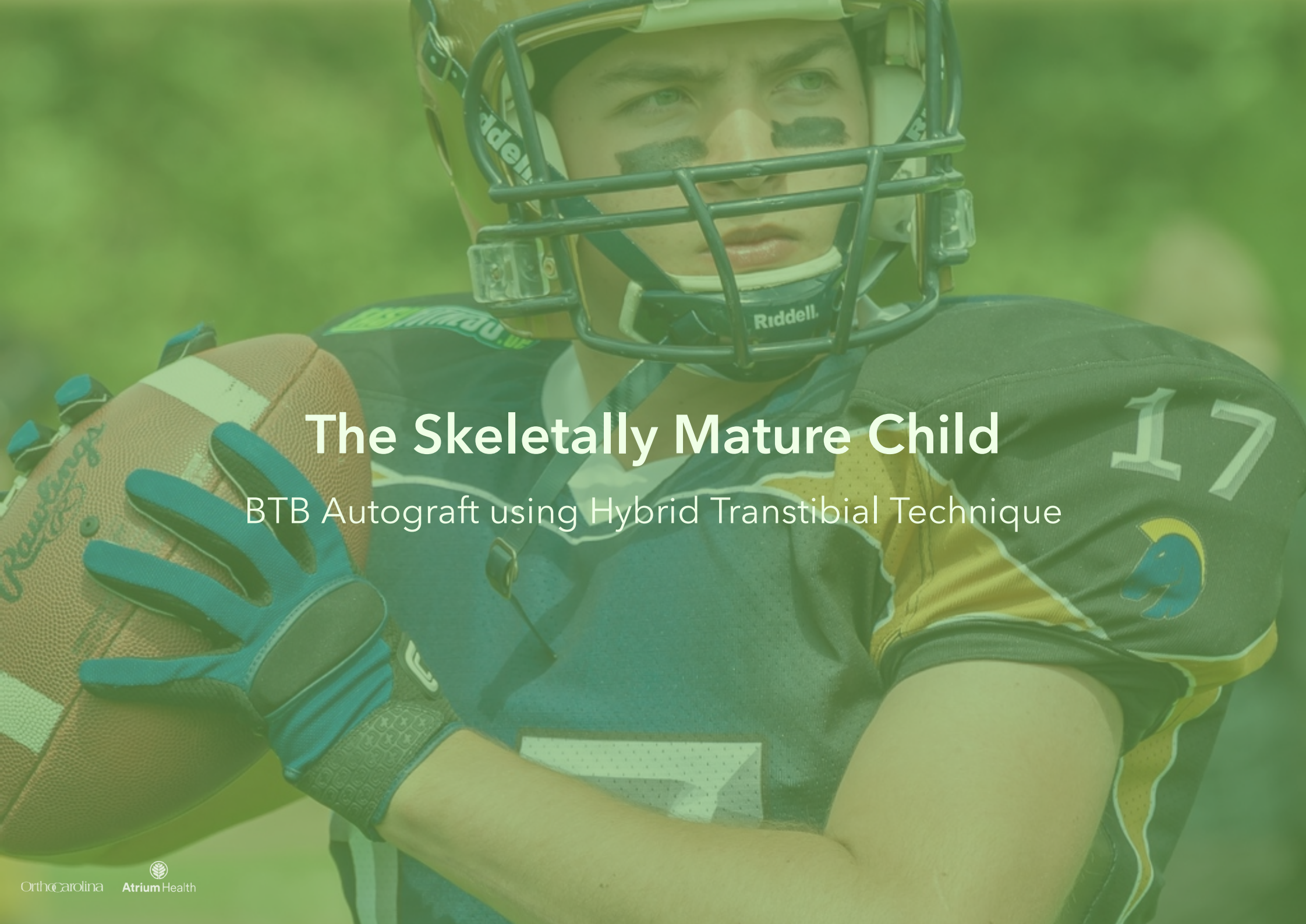

The Skeletally Mature Child

BTB Autograft using Hybrid Transtibial Technique

OrthoCarolina Atrium Health

ORIGINAL ARTICLE

Risk Factors for Early ACL Reconstruction Failure in Pediatric and Adolescent Patients: A Review of 561 Cases

Brian Ho, BA, Eric W. Edmonds, MD,*† Henry G. Chambers, MD,*† Tracey P. Bastrom, MA,† and Andrew T. Pennock, MD*†*

Background: Anterior cruciate ligament (ACL) reconstruction failure is relatively common in young high-risk athletes. The purpose of this study was to examine a single center's 10-year experience with ACL reconstructions in pediatric and adolescent patients to better define short-term failure rates and risk factors for revision ACL surgery.
Methods: This institutional review board-approved retrospective study included all patients who underwent a primary ACL reconstruction between 2002 and 2013. Chart and radiographic review was performed to assess patient demographic, injury, and surgical data including growth plate status, concomitant ligament/meniscus/cartilage injury, surgical procedures, femoral drilling technique, graft source and type, femoral and tibial fixation devices, and graft size. Graft failures had to be confirmed both with clinical examination and magnetic resonance imaging or the patient had to undergo a revision ACL reconstruction. Potential factors associated with failure were evaluated using either parametric or nonparametric analysis as appropriate.
Results: A total of 561 ACL reconstructions were performed that met our inclusion criteria. The average patient age was 15.4 years (range, 5 to 19 y) and 53% of the patients were male. In all, 54 failures were identified for a 9.6% failure rate. Soft tissue grafts were twice as likely to fail compared with patellar tendon grafts (13% vs. 6%; $P < 0.001$). Multivariate analysis revealed that graft choice (soft tissue vs. patellar tendon) was the primary variable predictive of failure ($P < 0.05$), with interactions/mediating effects contributed by maturity (growth plate status) and ACL technique ($P < 0.05$). The average time to failure was 13.6 months and hamstring grafts and anatomic femoral tunnels were both found to fail earlier ($P < 0.05$). During the study period, approximately 8% of patients sustained a contralateral ACL injury.
Conclusions: ACL failure rates in adolescent and pediatric patients vary based on patient age, graft selection, and surgical technique. Bone patellar tendon bone autografts had the lowest failure rate in this high-risk population.
Level of Evidence: Level IV—retrospective case series.

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The authors declare no conflicts of interest.
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Key Words: anterior cruciate ligament reconstruction, pediatrics
(*J Pediatr Orthop* 2016;00:000–000)

Anterior cruciate ligament (ACL) injuries occur across all age groups, but have become increasingly prevalent in pediatric and adolescent athletes as sports training has increased in frequency and intensity.[1] In a recent injury surveillance study conducted on high school athletes in the United States, ACL injuries were found to occur at a rate of 17.6 per 100,000 athletic exposures.[2] Because of the risks of further chondral and meniscal injury if left untreated, most young active patients undergo a reconstructive procedure. In fact, ACL reconstruction is becoming more common within the United States and increased approximately 77% from 1996 to 2006.[3] This trend is particularly true in skeletally immature patients where clinicians are now preferentially opting toward early reconstruction versus delaying surgery until skeletal maturity.[4]

The most common complication after an ACL reconstruction is a traumatic rupture of the graft and the incidence of revision surgeries has been shown to range from 6.5% to 34%.[3] A primary risk factor for graft failure is patient age, with patients under the age of 20 years showing significantly higher failure rates.[5,6] Although pediatric and adolescent patients have been shown to exhibit a higher graft failure rate, no large series have looked specifically at this patient population.

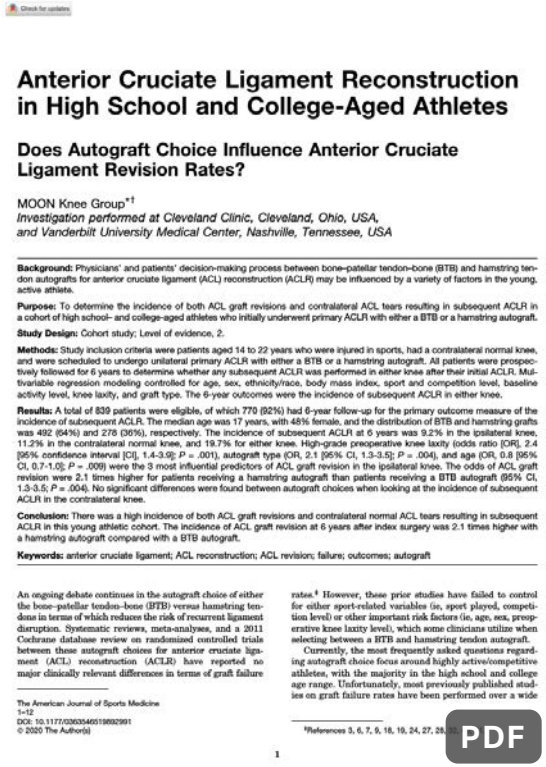
The purpose of this study was to examine a single center's 10-year experience with ACL reconstructions in pediatric and adolescent patients to better define short-term failure rates and risk factors for revision ACL reconstructions. We hypothesized that there would be no difference between bonepatellar tendon-bone (BTB) graft failure rates compared with hamstring graft failure rates and that allograft tissue would have a similar failure rate to autograft tissue when performed in select patients.

METHODS

After institutional review board approval, a retrospective chart review of all patients who underwent a primary ACL reconstruction between November 2002 and August 2013 was performed. Patients [illegible] years of age, those undergoing a [illegible]

PDF

Mean Age 15; 561 patients
HS failure **13%**
BTB failure **6%**



Anterior Cruciate Ligament Reconstruction in High School and College-Aged Athletes

Does Autograft Choice Influence Anterior Cruciate Ligament Revision Rates?

MOON Knee Group*†
Investigation performed at Cleveland Clinic, Cleveland, Ohio, USA, and Vanderbilt University Medical Center, Nashville, Tennessee, USA

Background: Physicians' and patients' decision-making process between bone–patellar tendon–bone (BTB) and hamstring tendon autografts for anterior cruciate ligament (ACL) reconstruction (ACLR) may be influenced by a variety of factors in the young, active athlete.
Purpose: To determine the incidence of both ACL graft revisions and contralateral ACL tears resulting in subsequent ACLR in a cohort of high school– and college-aged athletes who initially underwent primary ACLR with either a BTB or a hamstring autograft.
Study Design: Cohort study; Level of evidence, 2.
Methods: Study inclusion criteria were patients aged 14 to 22 years who were injured in sports, had a contralateral normal knee, and were scheduled to undergo unilateral primary ACLR with either a BTB or a hamstring autograft. All patients were prospectively followed for 6 years to determine whether any subsequent ACLR was performed in either knee after their initial ACLR. Multivariable regression modeling controlled for age, sex, ethnicity/race, body mass index, sport and competition level, baseline activity level, knee laxity, and graft type. The 6-year outcomes were the incidence of subsequent ACLR in either knee.
Results: A total of 839 patients were eligible, of which 770 (92%) had 6-year follow-up for the primary outcome measure of the incidence of subsequent ACLR. The median age was 17 years, with 48% female, and the distribution of BTB and hamstring grafts was 492 (64%) and 278 (36%), respectively. The incidence of subsequent ACLR at 6 years was 9.2% in the ipsilateral knee, 11.2% in the contralateral normal knee, and 19.7% for either knee. High-grade preoperative knee laxity (odds ratio [OR], 2.4 [95% confidence interval [CI], 1.4-3.9]; $P = .001$), autograft type (OR, 2.1 [95% CI, 1.3-3.5]; $P = .004$), and age (OR, 0.8 [95% CI, 0.7-1.0]; $P = .009$) were the 3 most influential predictors of ACL graft revision in the ipsilateral knee. The odds of ACL graft revision were 2.1 times higher for patients receiving a hamstring autograft than patients receiving a BTB autograft (95% CI, 1.3-3.5; $P = .004$). No significant differences were found between autograft choices when looking at the incidence of subsequent ACLR in the contralateral knee.
Conclusion: There was a high incidence of both ACL graft revisions and contralateral normal ACL tears resulting in subsequent ACLR in this young athletic cohort. The incidence of ACL graft revision at 6 years after index surgery was 2.1 times higher with a hamstring autograft compared with a BTB autograft.
Keywords: anterior cruciate ligament; ACL reconstruction; ACL revision; failure; outcomes; autograft

An ongoing debate continues in the autograft choice of either the bone–patellar tendon–bone (BTB) versus hamstring tendons in terms of which reduces the risk of recurrent ligament disruption. Systematic reviews, meta-analyses, and a 2011 Cochrane database review on randomized controlled trials between these autograft choices for anterior cruciate ligament (ACL) reconstruction (ACLR) have reported no major clinically relevant differences in terms of graft failure rates.[1] However, these prior studies have failed to control for either sport-related variables (ie, sport played, competition level) or other important risk factors (ie, age, sex, preoperative knee laxity level), which some clinicians utilize when selecting between a BTB and hamstring tendon autograft.

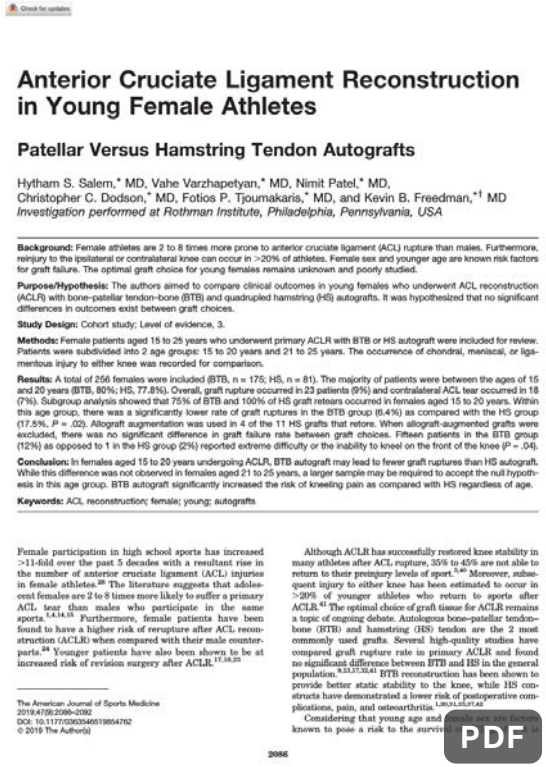
Currently, the most frequently asked questions regarding autograft choice focus around highly active/competitive athletes, with the majority in the high school and college age range. Unfortunately, most previously published studies on graft failure rates have been performed over a wide

The American Journal of Sports Medicine
1–12
DOI: 10.1177/0363546519892991

[illegible]References 3, 6, 7, 9, 18, 19, 24, 27, 28, 32[illegible]

PDF

Ages 14 -22; 770 patients (MOON)
Hamstrings failed at **2.1x the rate of BTBs**



Anterior Cruciate Ligament Reconstruction in Young Female Athletes

Patellar Versus Hamstring Tendon Autografts

Hytham S. Salem,* MD, Vahe Varzhapetyan,* MD, Nimit Patel,* MD, Christopher C. Dodson,* MD, Fotios P. Tjoumakaris,* MD, and Kevin B. Freedman,*† MD
Investigation performed at Rothman Institute, Philadelphia, Pennsylvania, USA

Background: Female athletes are 2 to 8 times more prone to anterior cruciate ligament (ACL) rupture than males. Furthermore, reinjury to the ipsilateral or contralateral knee can occur in >20% of athletes. Female sex and younger age are known risk factors for graft failure. The optimal graft choice for young females remains unknown and poorly studied.
Purpose/Hypothesis: The authors aimed to compare clinical outcomes in young females who underwent ACL reconstruction (ACLR) with bone–patellar tendon–bone (BTB) and quadrupled hamstring (HS) autografts. It was hypothesized that no significant differences in outcomes exist between graft choices.
Study Design: Cohort study; Level of evidence, 3.
Methods: Female patients aged 15 to 25 years who underwent primary ACLR with BTB or HS autograft were included for review. Patients were subdivided into 2 age groups: 15 to 20 years and 21 to 25 years. The occurrence of chondral, meniscal, or ligamentous injury to either knee was recorded for comparison.
Results: A total of 256 females were included (BTB, n = 175; HS, n = 81). The majority of patients were between the ages of 15 and 20 years (BTB, 80%; HS, 77.8%). Overall, graft rupture occurred in 23 patients (9%) and contralateral ACL tear occurred in 18 (7%). Subgroup analysis showed that 75% of BTB and 100% of HS graft retears occurred in females aged 15 to 20 years. Within this age group, there was a significantly lower rate of graft ruptures in the BTB group (6.4%) as compared with the HS group (17.5%, $P = .02$). Allograft augmentation was used in 4 of the 11 HS grafts that retore. When allograft-augmented grafts were excluded, there was no significant difference in graft failure rate between graft choices. Fifteen patients in the BTB group (12%) as opposed to 1 in the HS group (2%) reported extreme difficulty or the inability to kneel on the front of the knee ($P = .04$).
Conclusion: In females aged 15 to 20 years undergoing ACLR, BTB autograft may lead to fewer graft ruptures than HS autograft. While this difference was not observed in females aged 21 to 25 years, a larger sample may be required to accept the null hypothesis in this age group. BTB autograft significantly increased the risk of kneeling pain as compared with HS regardless of age.
Keywords: ACL reconstruction; female; young; autografts

Female participation in high school sports has increased >11-fold over the past 5 decades with a resultant rise in the number of anterior cruciate ligament (ACL) injuries in female athletes.[20] The literature suggests that adolescent females are 2 to 8 times more likely to suffer a primary ACL tear than males who participate in the same sports.[1,4,14,15] Furthermore, female patients have been found to have a higher risk of rerupture after ACL reconstruction (ACLR) when compared with their male counterparts.[24] Younger patients have also been shown to be at increased risk of revision surgery after ACLR.[17,18,25]

Although ACLR has successfully restored knee stability in many athletes after ACL rupture, 35% to 45% are not able to return to their preinjury levels of sport.[1,40] Moreover, subsequent injury to either knee has been estimated to occur in >20% of younger athletes who return to sports after ACLR.[41] The optimal choice of graft tissue for ACLR remains a topic of ongoing debate. Autologous bone–patellar tendon–bone (BTB) and hamstring (HS) tendon are the 2 most commonly used grafts. Several high-quality studies have compared graft rupture rate in primary ACLR and found no significant difference between BTB and HS in the general population.[9,13,17,32,43] BTB reconstruction has been shown to provide better static stability to the knee, while HS constructs have demonstrated a lower risk of postoperative complications, pain, and osteoarthritis.[1,20,31,33,37,42]

Considering that young age and [illegible] are known to pose a risk to the survival [illegible]

The American Journal of Sports Medicine
2019;47(9):2086–2092
DOI: 10.1177/0363546519854762

PDF

Ages 15 - 25; 256 patients
HS failure **17.5%**
BTB failure **6.4%**

Rehabilitation and Return to Sport

Probably Matters More Than Everything Else I Discussed!

OrthoCarolina Atrium Health

The Bach Rules for The First Post-Op Visit

1. Minimal swelling
2. Normal patellar mobility
3. Full symmetric hyperextension
4. 90 degrees of flexion
5. Straight leg raise without a lag

The Majority of Children (>90%) Return to Sport After ACL

Return to Sport and Reoperation Rates in Patients Under the Age of 20 After Primary Anterior Cruciate Ligament Reconstruction

Risk Profile Comparing 3 Patient Groups Predicated Upon Skeletal Age

Frank A. Cordasco,*† MD, MS, Sheena R. Black,‡ MD, Meghan Price,§ BS, Colleen Wixted,§ BS, Michael Heller,† ATC, PES, BES, Lori Ann Asaro,† PA-C, MS, Joseph Nguyen,‖ MPH, and Daniel W. Green,¶ MD, MS
Investigation performed at Hospital for Special Surgery, New York, New York, USA

Background: With sports specialization and level of competition on the rise, anterior cruciate ligament reconstruction (ACLR) in athletes under the age of 20 has increased significantly in recent years. Reports have demonstrated that the revision ACLR rate is higher and return to sport (RTS) rate is lower in this population.

Purpose: To evaluate the 2-year clinical outcomes of 3 cohorts of primary ACLR in pediatric and adolescent athletes under the age of 20 based on skeletal age with a focus on RTS and the incidence of second surgery.

Study Design: Case series; Level of evidence, 4.

Methods: This is a prospective evaluation of 324 athletes younger than 20 years of age who underwent ACLR with minimum 2-year follow-up. The surgical technique was selected predicated on skeletal age, which includes the all-epiphyseal technique with hamstring autograft in the youngest cohort in elementary and middle school (group 1), the partial transphyseal and complete transphyseal with hamstring autograft performed for athletes in the middle cohort (group 2), and bone-tendon-bone autograft in the skeletally mature high school athletes (group 3).

Results: The mean chronological age of the entire cohort was 15 years (range, 8-19 years) with 55% males. The 3 cohorts included 49 patients (15%) in group 1 (mean age, 12 years), 66 (20%) in group 2 (mean age, 14.3 years), and 209 (65%) in group 3 (mean age, 16.2 years). Group 2 athletes had a significantly higher revision ACLR rate (20%) compared with group 1 (6%; $P = .039$) and group 3 (6%; $P = .001$). Similarly, group 2 athletes had significantly lower RTS rates (85%) compared with group 1 (100%) and group 3 (94%).

Conclusion: The rate of revision ACLR was significantly higher and the RTS rates significantly lower in group 2 compared with groups 1 and 3. This age-related risk profile may be used to counsel athletes and parents preoperatively regarding the expectations of surgery with respect to revision ACLR and RTS rates.

Keywords: knee ligament; ACL; pediatric sports medicine; return to sports; revision ACL

With increasing sports specialization and level of competition, there has been a marked increase in intrasubstance tears of the anterior cruciate ligament (ACL) in both the pediatric and adolescent populations.[4,13,29,33] Dodwell et al[14] demonstrated that the rate of ACL reconstruction (ACLR) in the young and adolescent population in New York State increased from 17.6 per 100,000 people in 1990 to 50.9 per 100,000 people in 2009. Werner et al[41] used a national database to evaluate 44,000 pediatric and adolescent patients with an ACL tear from 2007 to 2011 and noted a 15.7% increase in ACLR rates in the 15- to 19-year-old cohort and a 27.6% increase in the 10- to 14-year-old cohort.

Skeletally immature athletes with an ACL tear historically have been treated with initial nonoperative management followed by an adult-type reconstruction once skeletal maturity is reached.[15] Studies

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PDF

Knee Surgery, Sports Traumatology, Arthroscopy
https://doi.org/10.1007/s00167-018-4830-9

KNEE

Over 90 % of children and adolescents return to sport after anterior cruciate ligament reconstruction: a systematic review and meta-analysis

Jeffrey Kay[1] · Muzammil Memon[1] · Robert G. Marx[2] · Devin Peterson[1] · Nicole Simunovic[3] · Olufemi R. Ayeni[1,4]

Received: 19 October 2017 / Accepted: 3 January 2018

Abstract
Purpose To evaluate the rate at which children and adolescent athletes return to sporting activities after anterior cruciate ligament (ACL) reconstruction.
Methods Three databases, PubMed, MEDLINE, and EMBASE, were searched from database inception until September 9, 2017 by two reviewers independently and in duplicate. The inclusion criteria were English language studies that reported return to sport outcomes. Book chapters, conference papers, review articles, and technical reports were excluded. The rate of return to sports was combined in a meta-analysis of proportions using a random-effects model.
Results Overall, 20 studies with a combined total of 1156 ACL reconstructions met the inclusion criteria, with a mean age of 14.3 years (range 6–19) and a mean follow-up time of 6.5 years (range 1–22). All studies were level IV evidence (14 retrospective case series and 6 prospective case series). The pooled rate of return to any sport participation was 92.0% [95% confidence interval (CI), 86–96%]. The pooled rate of return to pre-injury level of sport was 78.6% (95% CI 71–86%) and that to competitive level of sport was 81.0% (95% CI 62–94%). A total of 93 of the 717 assessed athletes (13%) sustained re-injuries with graft ruptures, and in 91 of 652 patients (14%), contralateral ACL injuries were reported on final follow-up.
Conclusion Pooled results suggest a high rate of return to sport following ACL reconstruction in children and adolescent athletes; however, this is associated with a relatively high rate of graft rupture and a similar rate of contralateral ACL injury. This study provides clinicians with evidence-based data on the ability of children and adolescent athletes to return to sport after ACL reconstruction, an important consideration for athletes of this population with ACL injuries.
Level of evidence IV, systematic review of level IV studies.

Keywords Pediatric · Adolescent · Child · Anterior cruciate ligament reconstruction · Sport

Introduction

More than 120,000 anterior cruciate ligament (ACL) reconstructions are performed per year in the US [27]. In the pediatric population, the rate of ACL reconstruction has been steadily increasing over the past 20 years [12], owing in part to the increased sport participation by younger athletes [13]. It has been estimated that 50.9 [95% confidence interval (CI) 48.8–53.0] per 100,000 children aged 10–19 undergo ACL reconstruction per year [12].

Historically, non-operative or delayed treatment of pediatric ACL injuries has been preferred over surgical reconstruction to avoid iatrogenic growth plate disturbances, and to allow for increased psychological maturity for compliance with postoperative rehabilitation [1]. However, delayed reconstruction has been shown

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Published online: 13 January 2018

PDF

A commentary by Charles L. Cox, MD, MPH, is linked to the online version of this article at jbjs.org.

Return to Sport After Pediatric Anterior Cruciate Ligament Reconstruction and Its Effect on Subsequent Anterior Cruciate Ligament Injury

Travis J. Dekker, MD, Jonathan A. Godin, MD, MBA, Kevin M. Dale, MD, William E. Garrett, MD, PhD, Dean C. Taylor, MD, and Jonathan C. Riboh, MD
Investigation performed at the Department of Orthopaedic Surgery, Duke University Medical Center, Durham, North Carolina

Background: Anterior cruciate ligament (ACL) graft failure and contralateral ACL tears are more frequent in children and adolescents than adults. The reasons for higher subsequent injury rates in this population are incompletely understood.

Methods: We analyzed a continuous cohort of patients who were <18 years of age. Subjects underwent isolated, primary ACL reconstruction with autograft between 2006 and January 1, 2014, and had a minimum 2-year follow-up. Return-to-sport characteristics were described, and multivariable Cox regression modeling was used to identify predictors of a second ACL injury. Candidate variables included patient factors (age, sex, physeal status, tibial slope, notch width index), surgical characteristics (graft type, surgical technique), measures of recovery (time to return to sport, duration of physical therapy), and patients' preoperative and postoperative sports involvement (primary and secondary sports, number of sports).

Results: A total of 112 subjects met inclusion criteria; of these patients, 85 (76%) had complete follow-up data and were analyzed. The mean age (and standard deviation) was 13.9 ± 2.1 years (range, 6 to 17 years); 77% had open physes. The mean follow-up was 48.3 ± 15.3 months. Seventy-seven patients (91%) returned to sports, and 84% returned to the same sport. The mean Marx activity score at the time of the latest follow-up was 13.7 ± 3.5 points. Patients were involved in fewer sports after ACL reconstruction, 1.48 ± 0.92 compared with 1.83 ± 1.01 sports before reconstruction ($p = 0.002$). Sixteen patients (19%) sustained an ACL graft rupture, 11 patients (13%) sustained a contralateral ACL tear, and 1 of these patients (1%) sustained both. The overall prevalence of a second ACL injury was 32%. Time to return to sport was the only significant predictor of a second ACL injury, with a slower return being protective (hazard ratio per month, 0.87 [95% confidence interval, 0.73 to 0.99]; p = 0.04).

Conclusions: Pediatric athletes return to sports at a high rate (91%) after ACL reconstruction. Unfortunately, the prevalence of a second ACL injury is high at 32%. Within this population, an earlier return to sport is predictive of a second ACL injury.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Peer Review: This article was reviewed by the Editor-in-Chief and one Deputy Editor, and it underwent blinded review by two or more outside experts. It was also reviewed by an expert in methodology and statistics. The Deputy Editor reviewed each revision of the article, and it underwent a final review by the Editor-in-Chief prior to publication. Final corrections and clarifications occurred during one or more exchanges between the author(s) and copyeditors.

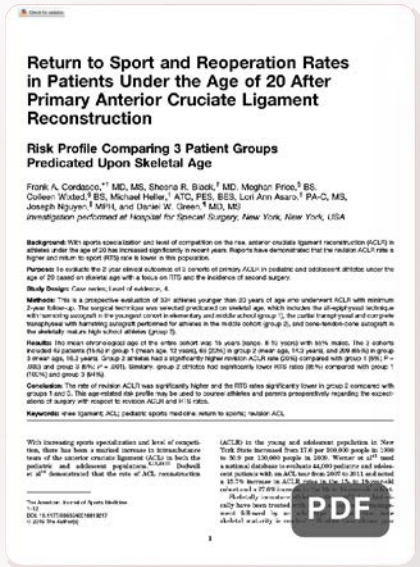
Anterior cruciate ligament (ACL) injuries and, as a result, ACL reconstructions are increasingly common in children and adolescents. Data from the Scandinavian registries, New York State registry, National Survey of Ambulatory Surgery, and PearlDiver database all show strong upward trends in the number of ACL surgical procedures performed in patients younger than 18 years of age[1-4]. The rising prevalence of ACL injuries in young patients is hypothesized to be related to increases in youth sports participation, early sports specialization, and increased awareness of these injuries among the public and physicians[5,6]. Recent literature demonstrating improved functional outcomes and decreased risks of meniscal

Disclosure: No external sources of funding contributed to this study. The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJS/C863).

PDF

This In Turn Leads to High Rates of Second ACL Injury

- **25% - 35%** of children will have another ACL tear during their active years!
- Almost evenly distributed between **graft tears** and **contralateral ACL tears**
- Highest risk group are the "**tweeners**" or early adolescents (**20% graft failure rate)**



Return to Sport and Reoperation Rates in Patients Under the Age of 20 After Primary Anterior Cruciate Ligament Reconstruction

Risk Profile Comparing 3 Patient Groups Predicated Upon Skeletal Age

Frank A. Cordasco,*† MD, MS, Sheena R. Black,† MD, Meghan Price,‡ BS, Colleen Wixted,‡ BS, Michael Heller,† ATC, PES, BES, Lori Ann Asaro,‡ PA-C, MS, Joseph Nguyen,‡ MPH, and Daniel W. Green,§ MD, MS
Investigation performed at Hospital for Special Surgery, New York, New York, USA

Background: With sports specialization and level of competition on the rise, anterior cruciate ligament reconstruction (ACLR) in athletes under the age of 20 has increased significantly in recent years. Reports have demonstrated that the revision ACLR rate is higher and return to sport (RTS) rate is lower in this population.

Purpose: To evaluate the 2-year clinical outcomes of 3 cohorts of primary ACLR in pediatric and adolescent athletes under the age of 20 based on skeletal age with a focus on RTS and the incidence of second surgery.

Study Design: Case series; Level of evidence, 4.

Methods: This is a prospective evaluation of 324 athletes younger than 20 years of age who underwent ACLR with minimum 2-year follow-up. The surgical technique was selected predicated on skeletal age, which includes the all-epiphyseal technique with hamstring autograft in the youngest cohort in elementary and middle school (group 1), the partial transphyseal and complete transphyseal with hamstring autograft performed for athletes in the middle cohort (group 2), and bone-tendon-bone autograft in the skeletally mature high school athletes (group 3).

Results: The mean chronological age of the entire cohort was 16 years (range, 8 to years) with 60% males. The 3 cohorts included 40 patients (14.5%) in group 1 (mean age, 12 years), 60 (22%) in group 2 (mean age, 14.3 years), and 209 (63.5%) in group 3 (mean age, 16.3 years). Group 2 athletes had a significantly higher revision ACLR rate (20%) compared with group 1 (5%; $P = .0083$) and group 3 (6%; $P < .001$). Similarly, group 2 athletes had significantly lower RTS ratios (66%) compared with group 1 (162%) and group 3 (84%).

Conclusion: The rate of revision ACLR was significantly higher and the RTS rates significantly lower in group 2 compared with groups 1 and 3. This age-related risk profile may be used to counsel athletes and parents preoperatively regarding the expectations of surgery with respect to revision ACLR and RTS rates.

Keywords: knee ligament; ACL; pediatric sports medicine; return to sports; revision ACL

With increasing sports specialization and level of competition, there has been a marked increase in transactions of the anterior cruciate ligament (ACL) in both the pediatric and adolescent populations.[4,19,37] Dodwell et al[4] demonstrated that the rate of ACL reconstruction (ACLR) in the young and adolescent population in New York State increased from 17.6 per 100,000 people in 1990 to 30.9 per 100,000 people in 2005. Werner et al[37] used a national database to evaluate 44,000 pediatric and adolescent patients with an ACL tear from 2007 to 2011 and noted a 15.7% increase in ACLR rates in the 15- to 19-year-old cohort and a 27.6% increase in [illegible]

Medically [illegible] have been treated [illegible] and 6.8 need [illegible] skeletal maturity is [illegible]

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A commentary by Charles L. Cox, MD.
Refer to the online version of this article at jbjs.org

Return to Sport After Pediatric Anterior Cruciate Ligament Reconstruction and Its Effect on Subsequent Anterior Cruciate Ligament Injury

Travis J. Dekker, MD, Jonathan A. Godin, MD, MBA, Kevin M. Dale, MD, William E. Garrett, MD, PhD, Dean C. Taylor, MD, and Jonathan C. Hsu, MD
Investigation performed at the Department of Orthopaedic Surgery, Duke University Medical Center, Durham, North Carolina

Background: Anterior cruciate ligament (ACL) graft failure and contralateral ACL tears are more frequent in children and adolescents than adults. The reasons for higher subsequent injury rates in this population are inconsistently understood.

Methods: We analyzed a series of patients who were <18 years of age. Subjects underwent isolated, primary ACL reconstruction with autograft between 2006 and January 1, 2014, and had a minimum 2-year follow-up. Patients sport characteristics were identified, and multivariable Cox regression modeling was used to identify predictors of a second ACL injury. Candidate variables included patient factors (age, sex, physeal status, tibial slope, notch width index), surgical characteristics (graft type, surgical technique), measures of recovery (time to return to sport, dynamic postoperative thresholds), and patients' preoperative and postoperative sports involvement (primary and secondary sports, number of sports).

Results: A total of 112 subjects met inclusion criteria; of these patients, 85 (76%) had complete follow-up data and were analyzed. The mean age (and standard deviation) was 13.9 ± 2.1 years (range, 6 to 17 years); 73% had open physes. The mean follow-up was 48.3 ± 15.3 months. Seventy-seven patients (91%) returned to sports, and 84% returned to the same sport. The mean Marx activity score at the time of the latest follow-up was 13.7 ± 3.1 points. Patients were involved in fewer sports after ACL reconstruction, 1.48 ± 0.92 compared with 1.83 ± 1.01 sports before reconstruction ($p = 0.0122$). Sixteen patients (19%) sustained an ACL graft rupture, 11 patients (13%) sustained a contralateral ACL tear, and 2 of these patients (2%) ruptured both. The overall prevalence of a second ACL injury was 32%. Time to return to sport was the only significant predictor of a second ACL injury, with a slower return being protective (hazard ratio per month, 0.82 [95% confidence interval, 0.73 to 0.96]; $p = 0.04$).

Conclusions: Pediatric athletes return to sports at a high rate (91%) after ACL reconstruction. Unfortunately, the prevalence of a second ACL injury is high at 32%. Within this population, an earlier return to sport is predictive of a second ACL injury.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Free Review: This article is commented on by Richard Dashiell and Timothy Foley, and it is accompanied by a video presentation by these two authors in which they discuss their respective methodology and debate the implications of their articles, and it is followed by three letters to the Editor in the January 2008 issue. Final corrections and clarifications received during one or more exchanges between the author(s) and reviewers.

Disclosure: The author(s) received no financial support from any organization for the preparation of this manuscript. No commercial entity or corporation is associated with this work. The Disclosure of Potential Conflicts of Interest forms are provided with the online version of the article (http://links.lww.com/JBJS/E63).

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Anterior cruciate ligament (ACL) injuries and, as a result, ACL reconstructions are increasingly common in children and adolescents. Data from the Scandinavian registries, New York State registry, National Survey of Ambulatory Surgery, and Pediatric Health Information System all show rising age and female sex-specific rates of ACL surgical procedures performed in patients younger than 18 years of age[1-3]. The rising prevalence of ACL injuries in young patients is hypothesized to be related to increases in youth sports participation, early sports specialization, and increased awareness of these injuries among the public and physicians[4-6]. Recent literature demonstrating improved functional outcomes and decreased rates of secondary

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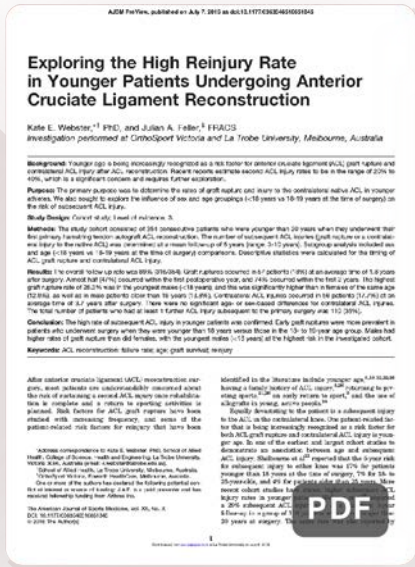

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Exploring the High Reinjury Rate in Younger Patients Undergoing Anterior Cruciate Ligament Reconstruction

Kate E. Webster,*† PhD, and Julian A. Feller,‡ FRACS
Investigation performed at OrthoSport Victoria and La Trobe University, Melbourne, Australia

Background: Younger age is being increasingly recognized as a risk factor for anterior cruciate ligament (ACL) graft rupture and contralateral ACL injury after ACL reconstruction. Recent reports estimate second ACL injury rates to be in the range of 20% to 40%, which is a significant concern and requires further exploration.

Purpose: The primary purpose was to determine the rates of graft rupture and injury to the contralateral native ACL in younger athletes. We also sought to explore the influence of sex and age groupings (<16 years vs 16-19 years at the time of surgery) on the risk of subsequent ACL injury.

Study Design: Cohort study; Level of evidence, 3.

Methods: The study cohort consisted of 364 consecutive patients who were younger than 20 years when they underwent their first primary hamstring tendon autograft ACL reconstruction. The number of subsequent ACL injuries (graft rupture or a contralateral injury to the native ACL) was determined at a mean follow-up of 5 years (range, 2-12 years). Subgroup analysis included sex and age (<16 years vs 16-19 years at the time of surgery) comparisons. Descriptive statistics were calculated for the timing of ACL graft rupture and contralateral ACL injury.

Results: The overall follow-up rate was 89% (326/364). Graft ruptures occurred in 67 patients (18%) at an average time of 1.6 years after surgery. Almost half (47%) occurred within the first postoperative year, and 74% occurred within the first 2 years. The highest graft rupture rate of 28.2% was in the youngest males (<16 years), and this was significantly higher than in females of the same age (12.9%) as well as in male patients older than 16 years (14.6%). Contralateral ACL injuries occurred in 56 patients (17.2%) at an average time of 2.7 years after surgery. There were no significant age- or sex-based differences for contralateral ACL injuries. The total number of patients who had at least 1 further ACL injury subsequent to the primary surgery was 112 (35%).

Conclusion: The high rate of subsequent ACL injury in younger patients was confirmed. Early graft ruptures were more prevalent in patients who underwent surgery when they were younger than 16 years versus those in the 16- to 19-year age group. Males had higher rates of graft rupture than did females, with the youngest males (<16 years) at the highest risk in the investigated cohort.

Keywords: ACL reconstruction; failure rate; age; graft survival; reinjury

After anterior cruciate ligament (ACL) reconstruction surgery, most patients are understandably concerned about the risk of sustaining a second ACL injury once rehabilitation is complete and a return to sporting activities is planned. Risk factors for ACL graft rupture have been identified in the literature to include younger age,[5,24,32,36] having a family history of ACL injury,[5,36] returning to pivoting sports,[21,36] an early return to sport,[5] and the use of allografts in young, active people.[24]

Equally devastating to the patient is a subsequent injury to the ACL in the contralateral knee. One patient-related factor that is being increasingly recognized as a risk factor for both ACL graft rupture and contralateral ACL injury is younger age. In one of the earliest and largest cohort studies to demonstrate an association between age and subsequent ACL injury, Shelbourne et al[28] reported that the 5-year risk for subsequent injury to either knee was 12% for patients younger than 18 years at the time of surgery, 7% for 18- to 25-year-olds, and 4% for patients older than 25 years. More recent cohort studies have [illegible] injury rates in younger [illegible] a 20% subsequent ACL [illegible] 5 (range, 1-9 years) [illegible] 20 years at surgery. The [illegible]

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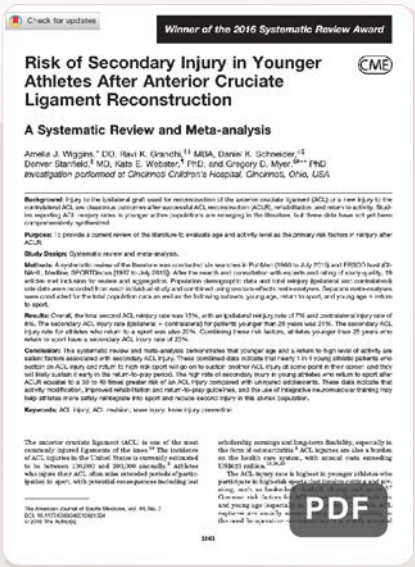

Check for updates

Winner of the 2016 Systematic Review Award

CME

Risk of Secondary Injury in Younger Athletes After Anterior Cruciate Ligament Reconstruction

A Systematic Review and Meta-analysis

Amelia J. Wiggins,* DO, Ravi K. Grandhi,†‡ MSA, Daniel K. Schneider,†§ Denver Stanfield,† MD, Kate E. Webster,¶ PhD, and Gregory D. Myer,†#** PhD
Investigation performed at Cincinnati Children's Hospital, Cincinnati, Ohio, USA

Background: Injury to the ipsilateral graft used for reconstruction of the anterior cruciate ligament (ACL) or a new injury to the contralateral ACL are disastrous outcomes after successful ACL reconstruction (ACLR), rehabilitation, and return to activity. Studies reporting ACL reinjury rates in younger active populations are emerging in the literature, but these data have not yet been comprehensively synthesized.

Purpose: To provide a current review of the literature to evaluate age and activity level as the primary risk factors of reinjury after ACLR.

Study Design: Systematic review and meta-analysis.

Methods: A systematic review of the literature was conducted via searches in PubMed (1966 to July 2015) and EBSCO host (CINAHL, Medline, SPORTDiscus [1967 to July 2015]). After the searches and consultation with experts and citation quality, 19 articles met inclusion for review and aggregation. Population demographic data and total reinjury (ipsilateral and contralateral) side data were recorded from each included study and combined using random-effects meta-analyses. Separate meta-analyses were conducted for the total population rate as well as the following subsets: young age, return to sport, and young age + return to sport.

Results: Overall, the total second ACL reinjury rate was 15%, with an ipsilateral reinjury rate of 7% and contralateral injury rate of 8%. The secondary ACL injury rate (ipsilateral + contralateral) for patients younger than 25 years was 21%. The secondary ACL injury rate for athletes who return to a sport was also 20%. Combining these risk factors, athletes younger than 25 years who return to sport have a secondary ACL injury rate of 23%.

Conclusion: This systematic review and meta-analysis demonstrates that younger age and a return to high level of activity are salient factors associated with secondary ACL injury. These combined data indicate that nearly 1 in 4 young athlete patients who undergo an ACL injury and return to high risk sport will go on to sustain another ACL injury at some point in their career, and they will likely sustain it early in the return-to-play period. The high rate of secondary injury in young athletes who return to sport after ACLR equates to a 30- to 40-times greater risk of an ACL injury compared with uninjured adolescents. These data indicate that activity modification, improved rehabilitation and return-to-play guidelines, and the use of integrative neuromuscular training may help athletes more safely reintegrate into sport and reduce second injury in this at-risk population.

Keywords: ACL injury; ACL revision; knee injury; knee injury prevention

The anterior cruciate ligament (ACL) is one of the most commonly injured ligaments of the knee.[12] The incidence of ACL injuries in the United States is commonly estimated to be between 120,000 and 200,000 annually.[9] Athletes who injure their ACL often miss extended periods of participation in sport, with potential consequences including [illegible] scholarship earnings and long-term [illegible] in the form of osteoarthritis.[9] ACL injuries are also a burden on the health care system, with annual costs exceeding US$38.35 million.[18,26,27]

The ACL injury rate is highest in younger athletes who participate in high-risk sports and [illegible] and pivoting, such as basketball, soccer, and football.[12,17] Common risk factors for [illegible] and young age (especially [illegible] and female sex) [illegible] are usually [illegible] the need for specialized [illegible]

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PDF

OrthoCarolina Atrium Health

Secondary ACL Prevention Is Critical In Children!

(Will Make a Much Bigger Difference Than Your Technical Abilities During Surgery...)

- Use of **RTS Criteria** Can Decrease Re-Injury by **85%!**
- **Less than 25%** of children meet RTS Criteria at 6 Months
- Most children have neuromuscular deficits that persist up to **1 year**
- Uniform criteria for safe RTS still remain elusive

[Athletic Training]

Strength and Functional Performance Recovery After Anterior Cruciate Ligament Reconstruction in Preadolescent Athletes

Elliot M. Greenberg, PT, DPT, OCS, CSCS,*† Eric T. Greenberg, PT, DPT, SCS, CSCS,‡ Theodore J. Ganley, MD,§ and J. Todd R. Lawrence, MD, PhD§

Background: In the skeletally immature population, the incidence of anterior cruciate ligament (ACL) injuries and ACL reconstructions appears to be increasing. Differences in surgical techniques, physiology, and emotional maturity may alter the rehabilitation progression and impact the outcomes when compared with adults. Reports of objective strength recovery and performance-based outcome measures after pediatric ACL reconstruction (ACLR) are limited.

Study Design: Retrospective case series.

Level of Evidence: Level 4.

Methods: All patients that underwent all-epiphyseal ACLR from January 2008 to August 2010 were identified. Isokinetic peak quadriceps/hamstring torque values and functional performance measures in unilateral hopping tasks were extracted and compared with the noninjured limb. A limb symmetry index (LSI) of ≥90% was considered satisfactory.

Results: Complete data were available for 16 patients (mean age, 12.28 years; range, 8.51-14.88 years). By a mean 7 months (range, 5.02-12.56 years) postoperatively, only 9 of 16 (56%) were able to achieve a satisfactory LSI for quadriceps strength. For hamstring strength, 15 of 16 (94%) were able to achieve satisfactory LSI. By a mean of 12 months (range, 5.39-24.59 months) postoperatively, only 6 of 16 subjects (38%) were able to achieve satisfactory performance on all functional hop tests. At a mean 15.42 months (range, 8.58-24.39 months) postsurgery, only 4 of 16 (25%) subjects were able to achieve an LSI of ≥90% on all testing parameters.

Conclusion: For some pediatric patients, significant strength and functional deficits may be present at greater than 1 year after ACLR. This population may require more prolonged rehabilitation programs to allow for adequate recovery of strength and function because of unique characteristics of normal growth and development.

Keywords: knee; pediatric; anterior cruciate ligament; strength; functional hop test

Anterior cruciate ligament (ACL) injuries seem to be increasing in the skeletally immature population.[9,21] Currently, there is no consensus in the literature regarding optimal management of these patients,[11,12] as both early and delayed reconstruction pose inherent risks to the pediatric knee. However, the risks associated with delaying treatment and recent surgical advances have influenced many surgeons to favor earlier reconstruction within this population.[5,11,18,21]

The increase in surgical procedures performed within this population has led to a natural increase in the need for postoperative rehabilitation. Rehabilitation progression,

From †Sports Medicine and Performance Center at The Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, ‡Stony Brook University, Department of Physical Therapy, Stony Brook, New York, §Division of Orthopaedic Surgery, The Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, and ||Department of Orthopaedic Surgery, University of Pennsylvania, Philadelphia, Pennsylvania

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Original article

Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study

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ABSTRACT

Background Knee reinjury after ACL reconstruction is common and increases the risk of osteoarthritis. There is sparse evidence to guide return to sport (RTS) decisions in this population.

Objectives To assess the relationship between knee reinjury after ACL reconstruction and (1) return to level I sports, (2) timing of RTS and (3) knee function prior to return.

Methods 106 patients who participated in pivoting sports participated in this prospective 2-year cohort study. Sports participation and knee reinjury were recorded monthly. Knee function was assessed with the Knee Outcome Survey—Activities of Daily Living Scale, global rating scale of function, and quadriceps strength and hop test symmetry. Pass RTS criteria were defined as scores >90 on all tests, failure as failing any.

Results Patients who returned to level I sports had a 4.32 ($p=0.048$) times higher reinjury rate than those who did not. The reinjury rate was significantly reduced by 51% for each month RTS was delayed until 9 months after surgery, after which no further risk reduction was observed. 38.2% of those who failed RTS criteria suffered reinjuries versus 5.6% of those who passed (HR 0.16, $p=0.075$). More symmetrical quadriceps strength prior to return significantly reduced the knee reinjury rate.

Conclusions Returning to level I sports after ACL reconstruction leads to a more than 4-fold increase in reinjury rates over 2 years. RTS 9 months or later after surgery and more symmetrical quadriceps strength prior to return substantially reduce the reinjury rate.

INTRODUCTION

In total, 250 000 ACL injuries are estimated to occur annually in the USA.[1] The short-term and long-term consequences include muscle weakness, functional deficits, lower sports participation, increased risk of knee reinjury and knee osteoarthritis (OA).[2–5] Up to 30% of young active patients who undergo reconstruction suffer a second ACL rupture in the first few years after surgery,[3 4] leading to poorer health-related quality of life.[6 7] The most devastating outcome, however, is the significantly increased rate of knee OA in those ACL-injured individuals who also sustain a meniscus injury. Within 5 years, 50% of patients may undergo meniscus surgery,[8] increasing their prognosis of post-traumatic knee OA from 0–13% to 21–48%.[4] We can reduce this high rate of knee OA through prevention of secondary meniscus injuries. In the USA alone, halving the OA rate after ACL injury could lead to $1.1 billion in cost savings annually.[9]

Intent to return to level I (jumping, pivoting and hard cutting) sports[10–12] is the main reason why a patient with an ACL rupture undergoes ACL reconstruction.[3] Younger age and participation in pivoting sports are also unfortunately consistent predictors of another ACL rupture after ACL reconstruction.[13–17] Activity restrictions based on post-surgical time (a surrogate for biological healing) and functional status (assessed with test batteries) have been advocated to enable the safest possible return to sport (RTS).[18 19] There is currently no clear evidence to guide whether participation in level I sports should be delayed or what level of function the patient should achieve prior to returning to level I sports.[20]

The aims of this study were therefore to assess if the 2-year risk of a knee reinjury after ACL reconstruction was associated with (1) return to level I sports, (2) timing of return to level I sports and (3) knee function prior to return to level I sport.

MATERIAL AND METHODS

Participants

This cohort consists of the ACL-injured patients in the Norwegian arm (n=150) of the Delaware-Oslo ACL Cohort Study (n=300) who underwent ACL reconstruction (n=106).[2] Patients were consecutively screened for inclusion at the Norwegian Sports Medicine Clinic between 2007 and 2011. We included patients who had sustained a unilateral ACL rupture within 3 months of enrolment (verified by MRI and ≥3 mm side-to-side difference in anterior laxity measured by KT-1000[TM]). Other inclusion criteria were age between 13 and 60 years and preinjury participation in level I or II sports[10] at least twice weekly. Patients were excluded if they had current or previous injury to the contralateral knee, previous knee injury on the index knee, or concomitant grade III knee ligament injury, fracture or full-thickness cartilage defects. Patients with meniscus injuries were excluded only if they had pain or effusion during plyometric activities that had not resolved 3 months from injury. Approval from the Regional Committee for Medical Research Ethics was obtained, and written informed consent was acquired, prior to inclusion.

Treatment algorithm

All patients underwent our [illegible] preoperative rehabilitation [illegible] treatment (surgery or conservative

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Title: Low Proportion of Skeletally Immature ACL Reconstructed Patients Met Return-to-Sports Criteria at 7 Months

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Where Do We Stand With RTS Testing?

- Debate remains active!
- No test or battery of tests has been unequivocally proven to reduce re-injury
- However, in 2020 you should really be doing SOMETHING for RTS testing
- Clear area for research

Sports Medicine
https://doi.org/10.1007/s40279-019-01093-x

SYSTEMATIC REVIEW

What is the Evidence for and Validity of Return-to-Sport Testing after Anterior Cruciate Ligament Reconstruction Surgery? A Systematic Review and Meta-Analysis

Kate E. Webster[1] · Timothy E. Hewett[2,3,4,5]

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Abstract

Background Anterior cruciate ligament (ACL) return-to-sport (RTS) test batteries are popular and are employed to test athletes' sport performance and help ensure a safe return to sport.

Objective To perform a systematic review and meta-analysis to determine: (1) the proportion of patients who passed RTS test batteries after ACL reconstruction, (2) whether passing RTS test batteries increased rates of return to play, and (3) whether passing RTS test batteries reduced subsequent rates of knee and ACL injury.

Methods Five databases (PubMed, MEDLINE, Embase, CINAHL, and SPORTDiscus) were searched to identify relevant studies and data were extracted regarding the number of patients who passed the RTS test battery, as well as subsequent RTS rates and re-injury data when available. Results were combined using proportional and risk-ratio meta-analyses.

Results Eighteen studies met eligibility criteria. Proportional meta-analysis showed that only 23% of patients passed RTS test batteries. One study showed that passing an RTS test battery led to greater RTS rates. Two studies showed passing RTS test batteries did not significantly reduce the risk of a further knee injury (risk ratio (RR) = 0.28 (95% CI 0.04–0.94), $p = 0.09$) and five studies showed that passing RTS test batteries did not reduce the risk for all subsequent ACL injuries (RR = 0.80 (95% CI 0.27–2.3), $p = 0.7$). However, passing an RTS test battery did significantly reduce the risk for subsequent graft rupture (RR = 0.40 (95% CI 0.23–0.69), $p < 0.001$], although it increased the risk for a subsequent contralateral ACL injury (RR = 3.35 (95% CI 1.52–7.37), $p = 0.003$].

Conclusion These analyses shows that there are equivocal findings in terms of the validity of current RTS test batteries in relation to reduction of the risk of graft rupture and contralateral ACL injuries. These findings have implications for RTS advice given to patients based on the results of RTS test batteries, and further work is needed to validate the criteria currently used and determine the true value.

Key Points

Current return-to-sport criteria do not appear to decrease the risk of subsequent anterior cruciate ligament (ACL) injury in athletes.

Though passing return-to-sport criteria reduced the risk of subsequent graft rupture by 60%, it increased the risk of a contralateral ACL rupture by 235%.

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1 Introduction

Most athletes who undergo anterior cruciate ligament (ACL) reconstruction surgery plan to return to their pre-injury level of sport [1]. However, only approximately half of [illegible]

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Editorial

Keep calm and carry on testing: a substantive reanalysis and critique of 'what is the evidence for and validity of return-to-sport testing after anterior cruciate ligament reconstruction surgery? A systematic review and meta-analysis'

Jacob John Capin[1], Lynn Snyder-Mackler[2], May Arna Risberg[3,4], Hege Grindem[3,5,6]

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Clinicians rely on rigorous systematic reviews to guide practice. We therefore suspect many clinicians will note the results of the 2019 systematic review and meta-analysis by Webster and Hewett, 'What is the Evidence for and Validity of Return-to-Sport Testing after Anterior Cruciate Ligament Reconstruction Surgery? A Systematic Review and Meta-Analysis'. We agree that it is important to evaluate the association between return-to-sport (RTS) test batteries and outcomes after ACL reconstruction. The third review question in Webster and Hewett (2019) is particularly pertinent: 'Is passing RTS test batteries associated with reduced rates of subsequent knee injury (all knee injuries and ACL injury)?'[1] We are authors of several of the original data papers cited in the systematic review, and we are concerned about the study methodology and its conclusions. We highlight major problems with including two studies and present revised analyses that demonstrate the impact these studies had on the conclusions.

METHODOLOGICAL CONCERNS

First, we question the validity of pooling studies with substantial clinical and methodological diversity.[2] The meta-analysis combined studies where only some athletes returned to sport[3–5] and studies where all, or mostly all, returned to sport;[6,7] studies with skeletally immature patients[3] and studies with elite athletes;[4] and studies where substantially different RTS test batteries were used. Our second concern is that Webster and Hewett[1] did not assess risk of bias, a fundamental precept of systematic review methodology clearly stated in the PRISMA reporting guideline.[8–10] Assessment of study quality (as performed by Webster and Hewett[1]) does not quantify risk of bias.[11] A risk of bias assessment identifies factors within studies that can skew results, and these factors must be considered carefully in the decision to pool data and in the conclusion. Important bias domains for review question[illegible] study participation[illegible] (iii) methods used [illegible]

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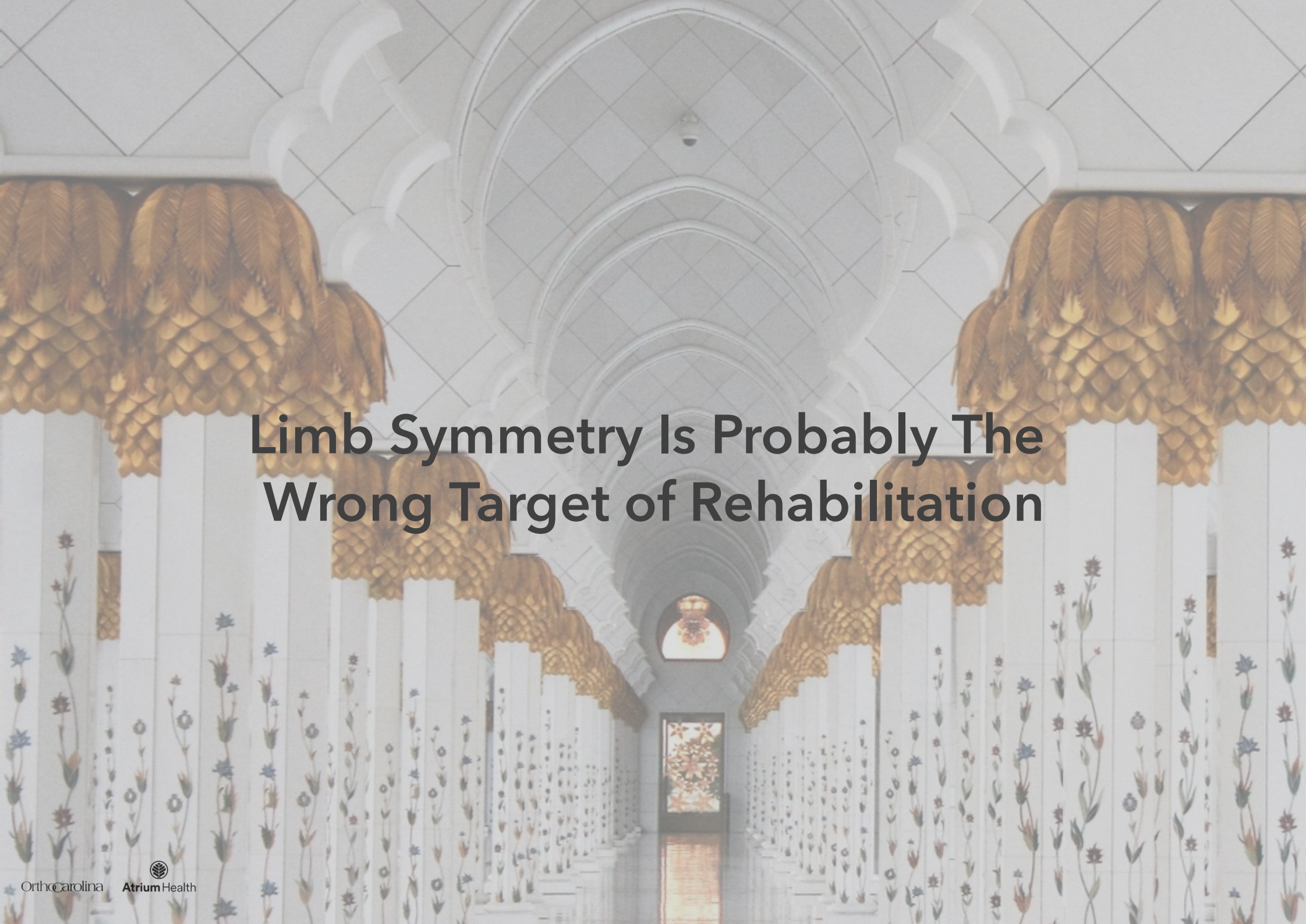
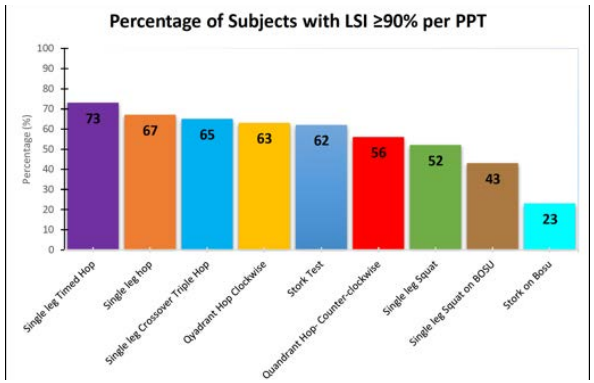
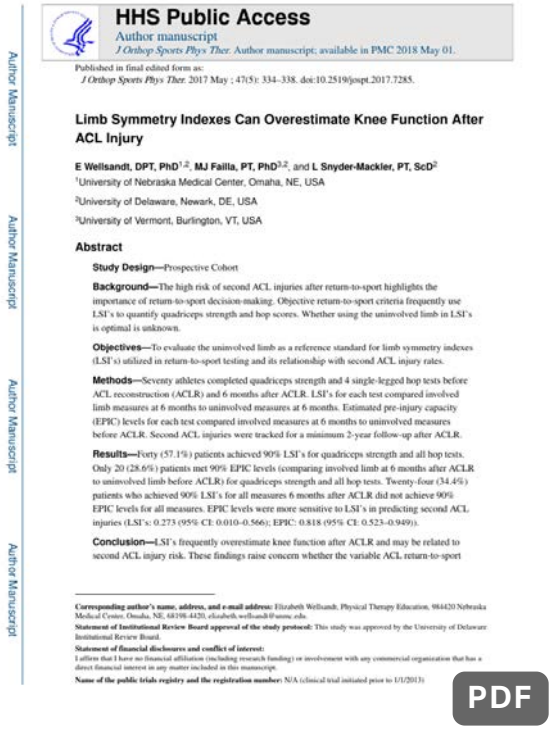


Limb Symmetry Is Probably The Wrong Target of Rehabilitation



Problem #1: Kids Aren't Symmetric To Begin With



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Limb Symmetry Indexes Can Overestimate Knee Function After ACL Injury

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[2]University of Delaware, Newark, DE, USA

[3]University of Vermont, Burlington, VT, USA

Abstract

Study Design—Prospective Cohort

Background—The high risk of second ACL injuries after return-to-sport highlights the importance of return-to-sport decision-making. Objective return-to-sport criteria frequently use LSI's to quantify quadriceps strength and hop scores. Whether using the uninvolved limb in LSI's is optimal is unknown.

Objectives—To evaluate the uninvolved limb as a reference standard for limb symmetry indexes (LSI's) utilized in return-to-sport testing and its relationship with second ACL injury rates.

Methods—Seventy athletes completed quadriceps strength and 4 single-legged hop tests before ACL reconstruction (ACLR) and 6 months after ACLR. LSI's for each test compared involved limb measures at 6 months to uninvolved measures at 6 months. Estimated pre-injury capacity (EPIC) levels for each test compared involved measures at 6 months to uninvolved measures before ACLR. Second ACL injuries were tracked for a minimum 2-year follow-up after ACLR.

Results—Forty (57.1%) patients achieved 90% LSI's for quadriceps strength and all hop tests. Only 20 (28.6%) patients met 90% EPIC levels (comparing involved limb at 6 months after ACLR to uninvolved limb before ACLR) for quadriceps strength and all hop tests. Twenty-four (34.4%) patients who achieved 90% LSI's for all measures 6 months after ACLR did not achieve 90% EPIC levels for all measures. EPIC levels were more sensitive to LSI's in predicting second ACL injuries (LSI's: 0.273 (95% CI: 0.010–0.566); EPIC: 0.818 (95% CI: 0.523–0.949)).

Conclusion—LSI's frequently overestimate knee function after ACLR and may be related to second ACL injury risk. These findings raise concern whether the variable ACL return-to-sport

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Statement of Institutional Review Board approval of the study protocol: This study was approved by the University of Delaware Institutional Review Board.

Statement of financial disclosures and conflict of interest:
I affirm that I have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript.

Name of the public trials registry and the registration number: N/A (clinical trial initiated prior to 1/1/2013)

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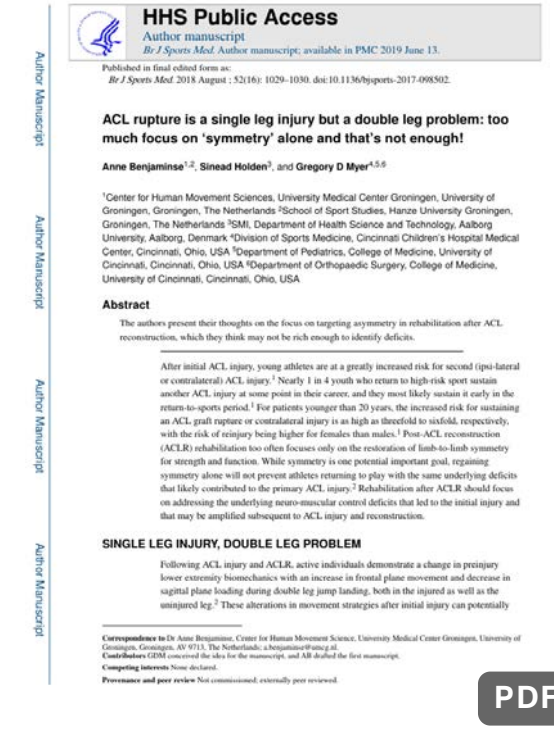
Problem #2: The Other Limb Deconditions After ACLR: Symmetry Can Overestimate Function



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ACL rupture is a single leg injury but a double leg problem: too much focus on 'symmetry' alone and that's not enough!

Anne Benjaminse[1,2], **Sinead Holden**[3], and **Gregory D Myer**[4,5,6]

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Abstract

The authors present their thoughts on the focus on targeting asymmetry in rehabilitation after ACL reconstruction, which they think may not be rich enough to identify deficits.

After initial ACL injury, young athletes are at a greatly increased risk for second (ipsi-lateral or contralateral) ACL injury.[1] Nearly 1 in 4 youth who return to high-risk sport sustain another ACL injury at some point in their career, and they most likely sustain it early in the return-to-sports period.[1] For patients younger than 20 years, the increased risk for sustaining an ACL graft rupture or contralateral injury is as high as threefold to sixfold, respectively, with the risk of reinjury being higher for females than males.[1] Post-ACL reconstruction (ACLR) rehabilitation too often focuses only on the restoration of limb-to-limb symmetry for strength and function. While symmetry is one potential important goal, regaining symmetry alone will not prevent athletes returning to play with the same underlying deficits that likely contributed to the primary ACL injury.[2] Rehabilitation after ACLR should focus on addressing the underlying neuro-muscular control deficits that led to the initial injury and that may be amplified subsequent to ACL injury and reconstruction.

SINGLE LEG INJURY, DOUBLE LEG PROBLEM

Following ACL injury and ACLR, active individuals demonstrate a change in preinjury lower extremity biomechanics with an increase in frontal plane movement and decrease in sagittal plane loading during double leg jump landing, both in the injured as well as the uninjured leg.[2] These alterations in movement strategies after initial injury can potentially

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Contributors GDM conceived the idea for the manuscript, and AB drafted the first manuscript.

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

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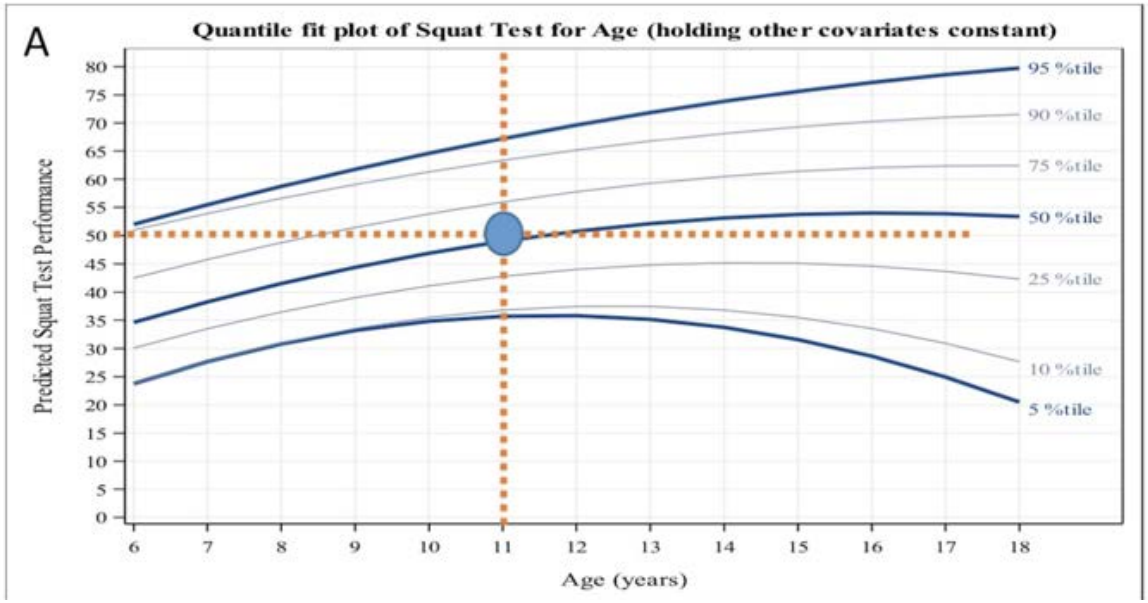
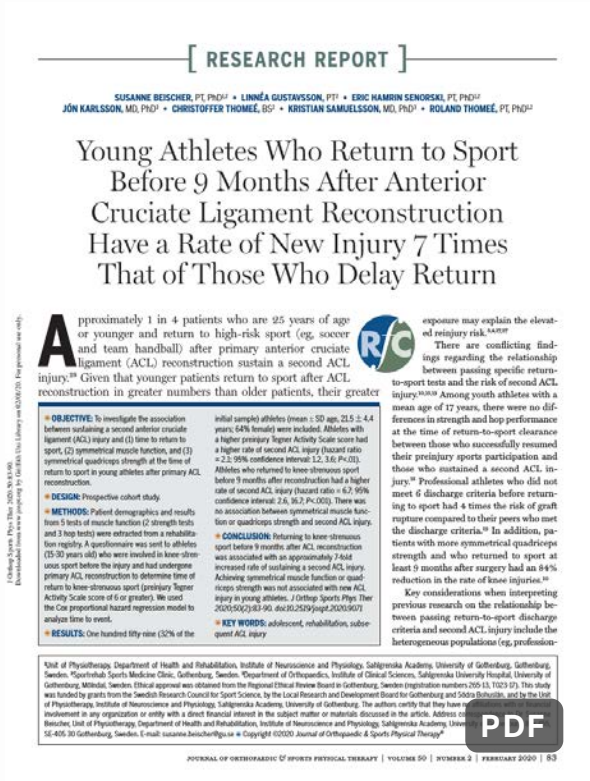
Problem #3: ACL Injury Is a Double Leg Problem: Achieving Symmetry Isn't Enough

Can We Do Better By Comparing Kids To Norms?



Should We Just Be Waiting Longer To Return Kids to Sport?

Riboh says... YES!



[RESEARCH REPORT]

SUSANNE BEISCHER, PT, PhD[1] • LINNÉA GUSTAVSSON, PT[2] • ERIC HAMRIN SENORSKI, PT, PhD[1,2] JÓN KARLSSON, MD, PhD[2] • CHRISTOFFER THOMEÉ, BS[2] • KRISTIAN SAMUELSSON, MD, PhD[2] • ROLAND THOMEÉ, PT, PhD[1,2]

Young Athletes Who Return to Sport Before 9 Months After Anterior Cruciate Ligament Reconstruction Have a Rate of New Injury 7 Times That of Those Who Delay Return

Approximately 1 in 4 patients who are 25 years of age or younger and return to high-risk sport (eg, soccer and team handball) after primary anterior cruciate ligament (ACL) reconstruction sustain a second ACL injury.[28] Given that younger patients return to sport after ACL reconstruction in greater numbers than older patients, their greater exposure may explain the elevated reinjury risk.[6,9,29]

There are conflicting findings regarding the relationship between passing specific return-to-sport tests and the risk of second ACL injury.[6,9,30] Among youth athletes with a mean age of 17 years, there were no differences in strength and hop performance at the time of return-to-sport clearance between those who successfully resumed their preinjury sports participation and those who sustained a second ACL injury.[30] Professional athletes who did not meet 6 discharge criteria before returning to sport had 4 times the risk of graft rupture compared to their peers who met the discharge criteria.[31] In addition, patients with more symmetrical quadriceps strength and who returned to sport at least 9 months after surgery had an 84% reduction in the rate of knee injuries.[32]

Key considerations when interpreting previous research on the relationship between passing return-to-sport discharge criteria and second ACL injury include the heterogeneous populations (eg, profession-

OBJECTIVE: To investigate the association between sustaining a second anterior cruciate ligament (ACL) injury and (1) time to return to sport, (2) symmetrical muscle function, and (3) symmetrical quadriceps strength at the time of return to sport in young athletes after primary ACL reconstruction.

DESIGN: Prospective cohort study.

METHODS: Patient demographics and results from 9 tests of muscle function (2 strength tests and 3 hop tests) were extracted from a rehabilitation registry. A questionnaire was sent to athletes (15-30 years old) who were involved in knee-strenuous sport before the injury and had undergone primary ACL reconstruction to determine time of return to knee-strenuous sport (preinjury Tegner Activity Scale score of 6 or greater). We used the Cox proportional hazard regression model to analyze time to event.

RESULTS: One hundred fifty-nine (32% of the initial sample) athletes (mean ± SD age, 21.5 ± 4.4 years; 64% female) were included. Athletes with a higher preinjury Tegner Activity Scale score had a higher rate of second ACL injury (hazard ratio = 2.2; 95% confidence interval: 1.2, 3.6; $P<.01$). Athletes who returned to knee-strenuous sport before 9 months after reconstruction had a higher rate of second ACL injury (hazard ratio = 6.7; 95% confidence interval: 2.6, 16.7; $P<.001$). There was no association between symmetrical muscle function or quadriceps strength and second ACL injury.

CONCLUSION: Returning to knee-strenuous sport before 9 months after ACL reconstruction was associated with an approximately 7-fold increased rate of sustaining a second ACL injury. Achieving symmetrical muscle function or quadriceps strength was not associated with new ACL injury in young athletes. *J Orthop Sports Phys Ther* 2020;50(2):83-90. doi:10.2519/jospt.2020.9007

KEY WORDS: adolescent, rehabilitation, subsequent ACL injury

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Ethical approval was obtained from the Regional Ethical Review Board in Gothenburg, Sweden (registration numbers 265-13, 702-17). This study was funded by grants from the Swedish Research Council for Sport Science, by the Local Research and Development Board for Gothenburg and Södra Bohuslän, and by the Unit of Physiotherapy, Institute of Neuroscience and Physiology, Sahlgrenska Academy, University of Gothenburg. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Susanne Beischer, Unit of Physiotherapy, Department of Health and Rehabilitation, Institute of Neuroscience and Physiology, Sahlgrenska Academy, University of Gothenburg, SE-405 30 Gothenburg, Sweden. E-mail: susanne.beischer@gu.se

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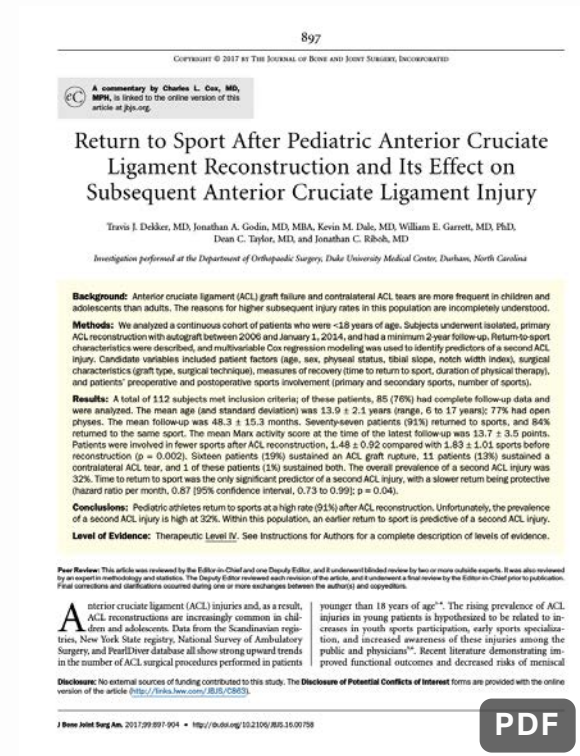
7x risk reduction by waiting longer than 9 months for RTS



A commentary by Charles L. Cox, MD, MPH, is linked to the online version of this article at jbjs.org.

Return to Sport After Pediatric Anterior Cruciate Ligament Reconstruction and Its Effect on Subsequent Anterior Cruciate Ligament Injury

Travis J. Dekker, MD, Jonathan A. Godin, MD, MBA, Kevin M. Dale, MD, William E. Garrett, MD, PhD, Dean C. Taylor, MD, and Jonathan C. Ribbans, MD

Investigation performed at the Department of Orthopaedic Surgery, Duke University Medical Center, Durham, North Carolina

Background: Anterior cruciate ligament (ACL) graft failure and contralateral ACL tears are more frequent in children and adolescents than adults. The reasons for higher subsequent injury rates in this population are incompletely understood.

Methods: We analyzed a continuous cohort of patients who were <18 years of age. Subjects underwent isolated, primary ACL reconstruction with autograft between 2006 and January 1, 2014, and had a minimum 2-year follow-up. Return-to-sport characteristics were described, and multivariable Cox regression modeling was used to identify predictors of a second ACL injury. Candidate variables included patient factors (age, sex, physeal status, tibial slope, notch width index), surgical characteristics (graft type, surgical technique), measures of recovery (time to return to sport, duration of physical therapy), and patients' preoperative and postoperative sports involvement (primary and secondary sports, number of sports).

Results: A total of 112 subjects met inclusion criteria; of these patients, 85 (76%) had complete follow-up data and were analyzed. The mean age (and standard deviation) was 13.9 ± 2.1 years (range, 6 to 17 years); 77% had open physes. The mean follow-up was 48.3 ± 15.3 months. Seventy-seven patients (91%) returned to sports, and 84% returned to the same sport. The mean Marx activity score at the time of the latest follow-up was 13.7 ± 3.5 points. Patients were involved in fewer sports after ACL reconstruction, 1.48 ± 0.92 compared with 1.83 ± 1.01 sports before reconstruction ($p = 0.002$). Sixteen patients (19%) sustained an ACL graft rupture, 11 patients (13%) sustained a contralateral ACL tear, and 1 of these patients (1%) sustained both. The overall prevalence of a second ACL injury was 32%. Time to return to sport was the only significant predictor of a second ACL injury, with a slower return being protective (hazard ratio per month, 0.87 [95% confidence interval, 0.73 to 0.99]; $p = 0.04$).

Conclusions: Pediatric athletes return to sports at a high rate (91%) after ACL reconstruction. Unfortunately, the prevalence of a second ACL injury is high at 32%. Within this population, an earlier return to sport is predictive of a second ACL injury.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Peer Review: This article was reviewed by the Editor-in-Chief and one Deputy Editor, and it underwent blinded review by two or more outside experts. It was also reviewed by an expert in methodology and statistics. The Deputy Editor reviewed each revision of the article, and it underwent a final review by the Editor-in-Chief prior to publication. Final corrections and clarifications occurred during one or more exchanges between the author(s) and copyeditors.

Anterior cruciate ligament (ACL) injuries and, as a result, ACL reconstructions are increasingly common in children and adolescents. Data from the Scandinavian registries, New York State registry, National Survey of Ambulatory Surgery, and PearlDiver database all show strong upward trends in the number of ACL surgical procedures performed in patients younger than 18 years of age[1-4]. The rising prevalence of ACL injuries in young patients is hypothesized to be related to increases in youth sports participation, early sports specialization, and increased awareness of these injuries among the public and physicians[5,6]. Recent literature demonstrating improved functional outcomes and decreased risks of meniscal

Disclosure: No external sources of funding contributed to this study. The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJS/C863).

PDF

13% risk reduction for every extra month you wait to RTS

Original article

Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study

Hege Grindem,[1] Lynn Snyder-Mackler,[2] Håvard Moksnes,[3] Lars Engebretsen,[3,4] May Arna Risberg[1,4]

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ABSTRACT

Background Knee reinjury after ACL reconstruction is common and increases the risk of osteoarthritis. There is sparse evidence to guide return to sport (RTS) decisions in this population.

Objectives To assess the relationship between knee reinjury after ACL reconstruction and (1) return to level I sports, (2) timing of RTS and (3) knee function prior to return.

Methods 106 patients who participated in pivoting sports participated in this prospective 2-year cohort study. Sports participation and knee reinjury were recorded monthly. Knee function was assessed with the Knee Outcome Survey—Activities of Daily Living Scale, global rating scale of function, and quadriceps strength and hop test symmetry. Pass RTS criteria were defined as scores >90 on all tests, failure as failing any.

Results Patients who returned to level I sports had a 4.32 ($p=0.048$) times higher reinjury rate than those who did not. The reinjury rate was significantly reduced by 51% for each month RTS was delayed until 9 months after surgery, after which no further risk reduction was observed. 38.2% of those who failed RTS criteria suffered reinjuries versus 5.6% of those who passed (HR 0.16, $p=0.075$). More symmetrical quadriceps strength prior to return significantly reduced the knee reinjury rate.

Conclusions Returning to level I sports after ACL reconstruction leads to a more than 4-fold increase in reinjury rates over 2 years. RTS 9 months or later after surgery and more symmetrical quadriceps strength prior to return substantially reduce the reinjury rate.

INTRODUCTION

In total, 250 000 ACL injuries are estimated to occur annually in the USA.[1] The short-term and long-term consequences include muscle weakness, functional deficits, lower sports participation, increased risk of knee reinjury and knee osteoarthritis (OA).[2–5] Up to 30% of young active patients who undergo reconstruction suffer a second ACL rupture in the first few years after surgery,[3 4] leading to poorer health-related quality of life.[7] The most devastating outcome, however, is the significantly increased rate of knee OA in those ACL-injured individuals who also sustain a meniscus injury. Within 5 years, 50% of patients may undergo meniscus surgery,[8] increasing their prognosis of post-traumatic knee OA from 0–13% to 21–48%.[4] We can reduce this high rate of knee OA through prevention of secondary meniscus injuries. In the USA alone, halving the OA rate after ACL injury could lead to $1.1 billion in cost savings annually.[9]

Intent to return to level I (jumping, pivoting and hard cutting) sports[10–12] is the main reason why a patient with an ACL rupture undergoes ACL reconstruction.[3] Younger age and participation in pivoting sports are also unfortunately consistent predictors of another ACL rupture after ACL reconstruction.[13–17] Activity restrictions based on post-surgical time (a surrogate for biological healing) and functional status (assessed with test batteries) have been advocated to enable the safest possible return to sport (RTS).[18 19] There is currently no clear evidence to guide whether participation in level I sports should be delayed or what level of function the patient should achieve prior to returning to level I sports.[20]

The aims of this study were therefore to assess if the 2-year risk of a knee reinjury after ACL reconstruction was associated with (1) return to level I sports, (2) timing of return to level I sports and (3) knee function prior to return to level I sport.

MATERIAL AND METHODS

Participants

This cohort consists of the ACL-injured patients in the Norwegian arm (n=150) of the Delaware-Oslo ACL Cohort Study (n=300) who underwent ACL reconstruction (n=106).[3] Patients were consecutively screened for inclusion at the Norwegian Sports Medicine Clinic between 2007 and 2011. We included patients who had sustained a unilateral ACL rupture within 3 months of enrolment (verified by MRI and ≥3 mm side-to-side difference in anterior laxity measured by KT-1000[21]). Other inclusion criteria were age between 13 and 60 years and preinjury participation in level I or II sports[10] at least twice weekly. Patients were excluded if they had current or previous injury to the contralateral knee, previous knee injury on the index knee, or concomitant grade III knee ligament injury, fracture or full-thickness cartilage defects. Patients with meniscus injuries were excluded only if they had pain or effusion during plyometric activities that had not resolved 3 months from injury. Approval from the Regional Committee for Medical Research Ethics was obtained, and written informed consent was acquired, prior to inclusion.

Treatment algorithm

All patients underwent our [illegible] preoperative rehabilitation [illegible] treatment (surgery or continued [illegible]

To cite: Grindem H, Snyder-Mackler L, Moksnes H, *et al*. *Br J Sports Med* 2016;**50**:804–808.

PDF

51% risk reduction for every month you wait to RTS up to 9 months

OrthoCarolina Atrium Health

My Recommendations in 2020

1. Understand most kids go back to sports, and **1 in 3 will sustain another ACL injury ->** educate your patients and families
2. The vast majority of children **are not ready to RTS at 6 months, 9 months likely a safer estimate**
3. Growing body of evidence for use of RTS testing, but **no "perfect test" yet**
4. The goal of rehabilitation should be to address pre-injury deficiencies in both limbs and restore age appropriate levels of strength and function - **NOT just to restore limb symmetry**

Thank You!

Please contact me with any questions

jonathan.riboh@orthocarolina.com