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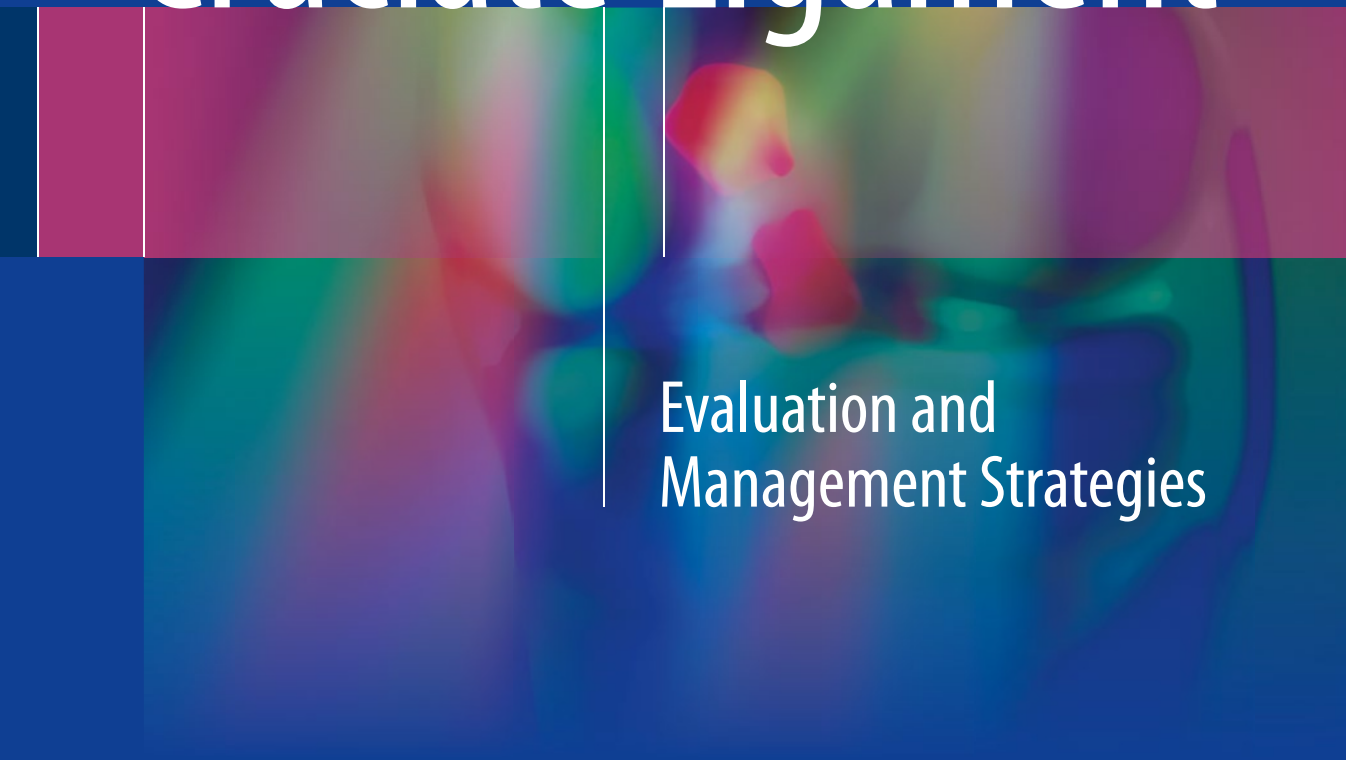
Editor

The Pediatric Anterior Cruciate Ligament



Evaluation and Management Strategies

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To my wife, Preeti, for her love, patience, and support and for sharing her unique and unconventional wisdom,

To my children, Ria and Rohan, for allowing me to miss their performances and to take precious time away from home,

To my parents, Kokila and Navnit, for their blessings and unconditional support through all my endeavors.

Shital N. Parikh, MD

Foreword I

I am very pleased to write a foreword to the "*The Pediatric Anterior Cruciate Ligament*" which has been compiled and edited by Dr. Shital Parikh. This topic has been one that has always been of great interest to me and many other pediatric orthopedic sports medicine practitioners. It has been and remains a controversial topic. This book goes a long way towards addressing a number of the issues related to the pediatric ACL including its injury, repair, and prognosis.

In the short span of approximately 40 years this topic has gone from one which was dismissed as being largely irrelevant to the care of the child to one which is now one of the most discussed and debated topics in the area of sports medicine.

To put this in historic perspective, Dr. George Lloyd-Roberts in his landmark textbook on pediatric orthopedics, *Orthopedics in Infancy and Childhood*, published by Appleton-Century-Crofts in 1971 states, "instability of the knee is a very unusual symptom in children. Torn menisci and anterior cruciate avulsions are seen very rarely." Several years later in "*Turek's Orthopaedics: Principles and Their Application*" it was stated, "in youth, the anterior cruciate is strong and, instead of rupturing at the anterior insertion, the bone is avulsed." This text was published in 1976. It is evident from the foregoing that the potential for an anterior crucial ligament midsubstance tear in this age group was considered to be rare or nonexistent.

With the growth of participation in children's organized sports in subsequent years, injury to the anterior cruciate ligament in this age group began to be recognized, and in many instances required specific treatment because of disability or subsequent injuries to the articular and meniscal cartilage of the knee. The increased recognition of this injury is due to the growth and availability of magnetic resonance imaging, the availability of appropriate arthroscopic tools to be used in this age group, and a refinement and attention to a careful physical examination of the knee looking for ligament instability in this age group including the systematic use of the Lachman Test to assess the extent of injury to the knee even in the young child.

At the present time, a number of studies have suggested that not only does anterior cruciate injury occur in this age group, but that the incident of this injury seems to be increasing. In association with this, the treatment of this injury in the child remains controversial, this controversy includes debate on whether the treatment in the growing child, particularly preadolescent child, should be operative or nonoperative, and in the event that operation is

required, which operation should be performed in this age group. In particular, because of the presence of the physis and the potential for physeal cartilage injury, the debate has been focused on whether transphyseal or extraphyseal interventions are indicated.

The editor is to be congratulated on having gathered a roster of authors who are recognized scholars on this unique subject. In my opinion, this text will be recognized as a must read for anyone dealing with injuries to the young athlete. I am sure going forward it will serve as a foundation for further study and research in this important area of sports injury in the child.

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Foreword II

The treatment approaches and surgical techniques selected by an orthopedic surgeon dealing with pediatric patients are still evolving; however, there have been major advances in the past decade which are emphasized in this important publication. The authors of the chapters have been selected based on their unique expertise and patient derived outcome data to support their treatment recommendations. This book provides a comprehensive and detailed analysis of the inherent problems in treating ACL injuries in the pediatric patient.

As all surgeons know, these knee injuries are not just confined to the ACL disruption, but involve a total traumatic insult to the knee joint that is commonly associated with injury to other ligament structures and secondary restraints, a high rate of meniscus tears needing repair, and articular cartilage injuries. Paramount to treatment is the selection of an ACL surgical technique that does not risk a growth abnormality in this patient population. The various operative procedures to consider in ACL reconstruction are presented, with appropriate emphasis placed on newer primary repair techniques for select proximal one-third ACL ruptures to preserve the remaining ACL and its neurovascular innervation. Of equal importance is the monitoring of postoperative rehabilitation to avoid arthrofibrosis in younger patients who must be compliant with exercises to restore normal knee motion and lower extremity function. There is no doubt that the treatment of the pediatric patient, similar to the adult population, requires a team approach of experienced surgeons, physical therapists, athletic trainers and others that produces an atmosphere that is supportive, caring, and conductive to the healing and rehabilitation process.

A special emphasis is placed on the treatment of young patients with ACL injuries to preserve and repair associated meniscus tears, including red-white tears and complex tears that have disruption in more than one plane [1, 5, 9]. The emphasis on meniscus repairs in adult ACL surgery applies even more to a pediatric population, because the loss of meniscus function is a disaster for future joint function. The principle is to take as much time to repair a meniscus as it takes to perform an ACL reconstruction, which may require added personnel because the gold standard still remains an inside-out technique with multiple well-placed sutures to restore anatomic continuity. Granted, there have been advances in all-inside meniscus repair techniques that are adapted to select longitudinal, circumferential, and radial tears. However, more complex and extensive meniscus tears must be repaired with multiple well-placed superior and inferior sutures using the classical inside-out

technique which has been shown in numerous studies to provide reasonable success rates in the long term. Unfortunately meniscus transplants, even though performed in pediatric patients that are symptomatic after meniscectomy, provide only a short-term benefit [2, 4, 6]. Accordingly, the first meniscus repair procedure needs to be as meticulous and skilled as possible.

A special emphasis is also placed in the rehabilitation chapters in this textbook that include return-to-play objective testing and an emphasis on neuromuscular training to reduce ACL reinjury or contralateral ACL ruptures. There are maturity-impeding factors that must be included in a well-structured neuromuscular training program (such as Sportsmetrics) to condition the athlete and overcome demonstrated neuromuscular control deficits [3, 7, 8]. Thus, the need to proceed cautiously for pediatric ACL patients on return to athletics and the requirement of objective testing to determine coordination, neuromuscular control, and muscle deficits. The reinjury rate after ACL reconstruction in female athletes has been shown to be markedly reduced by neuromuscular training and a recent publication showing an ACL reinjury rate (to either knee) of nearly 20–30% is unacceptable in modern orthopedic treatment paradigms [10]. The recommendations in this book require special emphasis, as it is necessary in the extended postoperative period to institute these advanced training concepts.

Shital N. Parikh, M.D., is an ideal person to be the editor of this publication and is currently a Professor of Orthopedic Surgery at the Cincinnati Children's Hospital Center, having completed his pediatric fellowship at that center under Alvin H. Crawford, M.D., from 2001 to 2002. I have a special professional relationship with Parikh as he completed a Sports Medicine and Arthroscopic Fellowship at Cincinnati SportsMedicine and Orthopedic Center in 2003–2004. His knowledge base from his prior pediatric fellowship was an obvious asset to our staff. As his Fellowship Director, along with our academic staff, we enjoyed his enthusiasm and acknowledged his warm and attentive care of our patients along with his advanced surgical skills. We all wish Parikh the very best as he pursues his academic carrier at the renowned Childrens Hospital, and this book is an example of his contribution to advancing the care of patients with orthopedic related injuries. This book sets a high standard and will undoubtedly be followed in time by a second edition as these treatment advances evolve for the future.

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Preface

The anterior cruciate ligament (ACL) enjoys the accolade of being the most studied and written about ligament in the human body. Its first description is attributed to Galen (circa 170 AD), the Greek physician of the Roman Empire, who cared for the gladiators, and recognized the crucial ligaments in open knee wounds in these soldiers. Hey Groves (1917) is credited for the first description of ACL reconstruction using iliotibial band detached from Gerdy's tubercle, routed through femoral and tibial tunnels and then sutured to the periosteum on the tibia; it formed the basis for modern-day intra-articular ACL reconstruction. The term "Anterior Cruciate Ligament" in pubmed search in early 2017 revealed 17,198 results related to it. Several textbooks have focused on ACL tears and its management, albeit in adults. Despite widespread literature devoted to adult ACL tears, the literature related to ACL tears in the skeletally immature is sparse. There is a paucity of knowledge related to ACL growth and development, age-specific ACL changes, risk factors for ACL tears, ideal interventions for management and prevention of ACL tears based on skeletal immaturity, and long-term outcomes. This book is meant to fill this void.

The field of pediatric sports medicine is still in its infancy and pediatric ACL insufficiency is an evolving and exciting area of interest. In the classic text on *Children's Fractures* by Rang (1974), it was reported that "Complete ligamentous disruption occurs ONLY after growth plate closure." What was once considered to be rare is now accepted to be somewhat common. Increased participation in sports at a younger age, more competitive sports participation, increased professional and public awareness, and improved magnetic resonance imaging diagnostics have led to an increased recognition of ACL tear in the skeletally immature.

When a patient with ACL tear and open growth plates around the knee presents to a sports medicine specialist, one of two scenarios commonly play out. On the conservative end, the patient is recommended to wait for ACL reconstruction till skeletal maturity and to "take it easy" till then. This approach could potentially risk irreversible damage to the meniscus and cartilage. John C. Kennedy voiced his concern in his 1979 book on *The Injured Adolescent Knee* stating that, "the adolescent knee is not immune to early degenerative changes once instability develops. Youthful enthusiasm, a tendency to minimize complaints and a natural reluctance by the surgeon to perform operative procedures on the adolescent should not stand in the way of sound surgical principles." On the other end of the spectrum, an adult-type

ACL reconstruction is recommended, which would entail drilling and fixation across the distal femoral and proximal tibial physis. These physes around the knee contribute the greatest length to the lower extremities and hence physeal violation could risk growth disturbances leading to angular deformity or limb length discrepancy. Thus both approaches can be fraught with undesirable outcomes. Though the ideal approach for these skeletally immature patients with ACL tear remains controversial, "physeal-respecting" ACL reconstruction techniques have advanced the field of pediatric sports medicine. The treating physician should be able to estimate skeletal immaturity and remaining skeletal growth and then decide on patient-specific treatment option based on a variety of factors. If ACL reconstruction is then chosen to be the best treatment option for the patient, the involved surgeon should be knowledgeable and skilled enough to execute appropriate "physeal-especting" ACL reconstructive techniques, based on the patient's skeletal immaturity and remaining growth.

It is difficult for the busy orthopedic surgeon to formulate the best age-appropriate treatment plan for a child with ACL tear by analyzing the existing literature. Several treatment algorithms have been published to help in medical decision making. Most of the existing literature is, however, low level evidence, with small cohort of patients across varied skeletal ages, and have short- to intermediate-term outcomes. I, with the help of world-renowned and experienced pediatric sports surgeons and scientists, have attempted to synthesize the current knowledge related to ACL deficiency in the skeletally immature in 25 focused chapters in this book. I would like to thank and congratulate all authors for their valuable and timely contribution to this book. Each chapter would review the relevant literature and its practical applications and would discuss the authors' preferred approach based on their vast experience and literature support. This book is meant to be a one-stop resource for pediatric orthopedic surgeons, orthopedic sports medicine surgeons, primary care sports medicine physicians, pediatricians, fellows and residents in training, physician assistants, nurse practitioners, athletic trainers, physical therapists, scientists, and anyone interested in the evolving field of pediatric sports medicine.

I would like to acknowledge my mentors Alvin Crawford, M.D., and Frank Noyes, M.D., for their dedication, guidance, and support throughout my career. Their commitment to our field of orthopedics has always inspired me to "do more." I would also like to thank my colleagues, fellows, and residents at Cincinnati Children's Hospital whose wisdom and constructive criticism has always been thought provoking. They keep me challenged, grounded, and inspire life-long learning. Most importantly, I would like to thank our patients and their families who have entrusted their loved ones to our care. Without them, we have no existence. Lastly, I would like to thank the staff at Springer for their continued help with this project. Their efforts have led to the timely completion of the book.

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1 Pediatric and Adolescent ACL Injury and Sports Medicine: The Early Years

Carl L. Stanitski

Surgeons have cared for athletes and teams for millennia. In the mid-1950s, orthopedic surgeons in large measure became team physicians for collegiate and professional teams, primarily in American football. Orthopedic surgeons were aware of the opinions of emerging leaders in the field and followed their dicta for resolving athlete's injuries. The ultimate metric of success then, as now, was the athlete's return to play at their pre-injury level.

In the United States, organized sports medicine emerged in earnest in the 1970s. Interest in the field became widespread to include experts in exercise physiology, nutrition, sports psychology, biomechanics, physical therapy, and athletic training. Courses in sports medicine were developed, societies were formed, journals were begun, and fellowships were started. A subspecialty was spawned.

Research provided a progressive understanding of the role of the ACL, PCL, menisci, and secondary restraining structures in the normal knee. An appreciation was generated for the premature arthrosis consequences of knee functional instability and concomitant intra-articular damage. Prior to this, a knee injury, even with the early attempts at repair and reconstruction of the damaged tissues, was looked on as a career-ending injury. "The knee was never the same after that injury" was a common lament. "Operative measures generally employed for repair of the anterior crucial ligament are so formidable and extensive that one hesitates to undertake them unless disability is extreme" [1].

The sports medicine field was revolutionized with the advent of the arthroscope, initially brought to North America by Dr. Bob Jackson in 1964. By the mid-1970s, appropriate-sized fiber-optic camera systems for arthroscopy were developed and marketed with commercial success. Additional development of instruments for diagnosis and, later, treatment with arthroscopic guidance were made available. Over the next three decades, the development of endoscopic techniques led to the concept of "if you can see it, you can fix it." Intra- and postoperative anesthetic techniques for pain control allowed for outpatient surgery. Minimally invasive methods provided rapid recoveries and functional return to activity.

Pediatric and adolescent sports care was initially ignored as it developed within the banner of "sports medicine" writ large. Prior attitudes regarding injuries to the scholastic-aged athlete were engrained. Notions that "children do not get significant injuries until they are mature" and "children heal any injury without difficulty" were the guidelines of the day. ACL tears in the prepubescent patient were looked upon as curiosities.

It always seemed to this author that the scholastic-aged athlete accounted for the largest number of sports participants. In 1972, there

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were 4 million senior school (grades 9–12) athletes participating in school- and community-sponsored programs. This number grew exponentially with the onset of Title IX which mandated equal opportunities for sports participation (and injury) for girls/women as those for boys/men. Within this athletic participation, children did get injuries, usually not serious and with resolution with minimal intervention. However, enough of these participants did have injuries, usually about the knee, that had potential long-term negative outcomes. This view was not incorporated into the general sports medicine practitioner's attitude that care of these youthful athletes was really not equivalent to "sports medicine," i.e., caring for upper-level collegiate and professional teams. On the other hand, it was looked upon by pediatric orthopedic surgeons as not being true pediatric orthopedics, i.e., care of clubfoot, scoliosis, and DDH.

A pioneering sports medicine clinic devoted to the scholastic athlete was begun in 1977 at Boston Children's Hospital, directed by Dr. Lyle Micheli, my mentor, colleague, and friend. This unit provided multidisciplinary care and incorporated clinical research with presentations and publications in this field. This approach served as a role model for development of such clinics around the world. Textbooks were written with a focus on pediatric and adolescent athletes [2, 3].

The clinical diagnosis of an ACL tear was improved with the understanding of Lachman and pivot-shift tests and the use of arthrometers to quantify anterior tibial translation. Development of imaging modalities, mainly CT and MRI, enhanced the orthopedist's diagnostic capability and, in addition to the clinical findings, led to treatment protocols. Data was presented regarding arthroscopically documented ACL injuries in prepubescent athletes which were highly associated with a hemarthrosis [4].

Differentiation between a mid-substance ACL tear and a tibial eminence fracture was emphasized that the latter was not the juvenile equivalent of an ACL tear. The former was due to a low load rapidly applied versus the latter that was associated with a high load applied slowly resulting in interstitial elongation of the ACL and no tear but rather a resultant chondro-epiphyseal avulsion fracture. The outcomes of the treated tibial eminence fracture were excellent in contrast to the nonhealing torn ACL sequelae.

Historically, the initial focus was on nonoperative treatment for an ACL injury in the skeletally immature patient due to concern for surgical damage to the distal femoral and/or proximal tibial physes, the sites of major growth in the lower extremity. This was especially true in the physiological "no man's land" of adolescence. Growth must be considered as a fourth dimension with its attendant variability of onset, rate, magnitude, and duration. During this rapidly changing physiologic background, variabilities in strength, coordination, and endurance are superimposed on growth evolution, and all these factors must be considered during diagnosis and treatment. Failures of nonoperative management were primarily due to patient's lack of compliance with the rehabilitation program with intra-articular injury at the time of the initial injury to the ACL or subsequent intra-articular damage due to continued functional instability, especially if the patient tried to return to high levels of sports activity requiring pivoting, acceleration, and deceleration. I refer to this combination of injuries as the "ACL plus" knee.

Early reports of ACL reconstruction procedures in this young-aged population had significant research design faults including absent or inappropriate assessments of physiologic maturity, lack of gender specificity, small number of patients, and short follow-up times. Despite the title of the papers regarding "pediatric and adolescent ACL tear," when the data was analyzed, most of the patients were quite skeletally and physiologically mature teenagers.

A classification of ACL surgical reconstruction procedures was presented which took into account the three "Ts"—tissues, tunnels, and techniques. The classification was based on the site and amount of physeal transgression and included physeal sparing, partial transphyseal, and complete transphyseal methods [5] (Figs. 1.1, 1.2, and 1.3). An extra-articular procedure has also been reported, initially used for patients with congenital absence of the ACL [6].