4 The Epidemiology of Pediatric ACL Injuries

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The Youth Sports Culture

Organized youth sports participation has increased tremendously over the past decade with a concurrent drop in school-based physical education [1]. According to the National Council on Youth Sports, nearly 60 million youth between the ages of 6 and 18 participated in organized athletics in 2008 compared with 52 million in 2000 [1, 2]. The National Federation Of State High School Associations has conducted a high school athletics participation survey every year since 1970, and the trends reflect this phenomenon [3]. In the 1969–1970 school year, there were approximately 850,000 high school football players and 50,000 high school soccer players. This number increased to 1.1 million and 790,000 in 2014. This 16-fold increase in the number of soccer players over the last 45 years is even more dramatic when only females are considered. In 1971, only 700 females played soccer, whereas in 2014, there were 375,000 female soccer players in high school.

As a result, a sports culture has developed in our young patients who rather than play a wide variety of sports during the early stages of physical development are specializing in a single sport at younger ages [1, 4, 5]. This has resulted in sporting activity centered on skill development (pitching, kicking, shooting) rather than generalized fitness. This culture has developed even with multiple advocates for delayed specialization [1, 6–9].

Correlated directly with this culture has been an increase in the rate of injury. Rose et al., in a study of 2721 high school athletes, found there was a direct correlation of injury risk with increased weekly hours of sports participation [1, 10]. This is particularly important when considering ACL injuries as the knee is the most commonly injured joint in the young athlete [10]. Hall et al. examined 546 female basketball, soccer, and volleyball players and found that those athletes involved in a single sport had 1.5-fold relative risk increased risk of patellofemoral pain, Osgood-Schlatter disease, and Sinding-Larsen-Johansson syndrome compared with multisport athletes [1, 11]. This is critical as an association has been reported between the development of patellofemoral pain and a subsequent risk of developing ACL injuries later in adolescence [12].

Once thought to be rare, the youth sporting environment has seen a rapid increase in the incidence of pediatric and adolescent ACL injuries [13]. The increased rate of ACL injury in the young age group has been postulated to be due to a desire for early, single-sport specialization coupled with a demand for peak performance during a time of change, particularly physiologi-

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cally, when neuromuscular control and physical fitness may be lacking [14]. In addition, these injuries may now be more readily diagnosed with the availability of MRI imaging [15], particularly with parental demand for such studies.

This chapter aims to examine the factors in the epidemiology of ACL injuries in young athletes, as well as present the risk factors and prevention strategies.

Trends in ACL Injuries

The knee is the second most commonly injured joint in children and the most commonly injured in athletes [16]. Of these knee injuries, approximately one fourth are ACL injuries [17]. Though initially thought to present as tibial eminence fractures, intra-substance ACL tears are now seen with increasing frequency even in skeletally immature patients [18]. Numerous studies have been conducted analyzing the true incidence of ACL ruptures. Even with a large increase over the past several years in database research, a national registry which tracks the exact number of ACL injuries in the United States does not exist.

In the general population, there is an annual estimated incidence of 1 in 3000 Americans suffering an ACL ruptures [19]. A large study analyzing insurance data from a company specializing in soccer injuries found that 22% of all sports injuries occurred in the knee, and of these knee injuries, 31% were ACL tears. The study found that the incidence of ACL injuries has a very distinct correlation with age, comprising only ~1% of all injuries around age 10 and climbing to 13% at age 18 [20]. The increasing trend in the under 20 age group (a change from prior epidemiologic data) was shown by Mall et al. [21]. They performed an analysis of national surveys using billing codes from 1994 to 2006 and found that the incidence of ACL injuries had increased by nearly 130%, with approximately 33 per 100,000 person-years in 1994 up to 43.5 per 100,000 person-years in 2006. Much of this increase came from patients under the age of 20, with rates of 12.22 per 100,000 person-years in 1994 to 17.97 per 100,000 person-years in 2006. This is not surprising given the activity level of these youth and the demands they place on their knee.

Perhaps the most comprehensive look at the true incidence of ACL tears in the young-age, active cohort comes from the National High School Sports-Related Injury Surveillance Study, spearheaded by Comstock et al. The data collection, originally developed as a corollary to the NCAA Injury Surveillance System, uses a large national sample of high school athletes to perform epidemiologic analysis of all time-loss injuries in this population. The 2015 report showed that 1.2 million injuries occur from high school sports, over 160,000 involving the knee. ACL injuries are the second most common, behind MCL injuries, and account for a quarter of all knee injuries [17].

A study using this same data set looked specifically at the epidemiology of knee injuries from 2005 to 2010 [22]. They found that approximately 20% of knee injuries required surgery, and of those 65% were for ligamentous injuries. ACL injuries were season ending in nearly half of the athletes who sustained them. Another study using the same data set showed that 76% of ACL injuries resulted in surgery [16]. It also commented on the mechanism of injury with player-to-player contact accounting for 42.8% of injuries and noncontact accounting for 37.9%. The injury mechanisms due to contact occurred with the ground or playing apparatus. This mechanism is different from what is often reported in other studies analyzing adult ACL injuries where non-contact mechanisms resulted in the majority of ACL injuries.

Yet, many of these larger epidemiologic studies solely contain data in regard to age and not degree of skeletal maturity, a key component in determining the type of intervention in this population. Although there has been much recent interest on the skeletally immature population, this still group accounts for only 0.5–3% of ACL injuries [23].

Werner et al. examined trends in pediatric ACL injuries via an analysis of a private insurance claims database from 2007 to 2011. The diagnosis of pediatric ACL injuries each year was compared with the increase seen in adults. From 2007 to 2011 in both the 10–14-year-old and 15–19-year-old age cohorts, there were significant increases in the incidence of ACL injuries when compared to adults; the 10–14-year cohort increased by 19% and the 15–19-year cohort by 18% [18]. These same trends were also seen when examining pediatric ACL reconstructions using the New York Statewide Planning and Research Cooperative System over the course of 20 years, from 1990 to 2009 (Fig. 4.1). Though geographically limited, the authors found a steady increase in pediatric ACL reconstructions in the state, with rates of 17.6 per 100,000 in 1990 to 50.9 in 2009 [24].

As a result, not only is there an increase in the incidence of ACL injuries occurring in the pediatric population but also reconstruction as the method of treatment, perhaps due to the desire to both prevent chondral damage and return patients to sport.

Sport-Specific Risks

An essential part of understanding the increasing trend of pediatric ACL injuries is not simply understanding the rise of single-sport specialization but also the risk factors associated with specific sports that are played by pediatric athletes.

The National High School Sports-Related Injury Surveillance Study found the incidence of knee injuries to be 2.98 knee injuries per 10,000 athletic exposures, with an athlete exposure

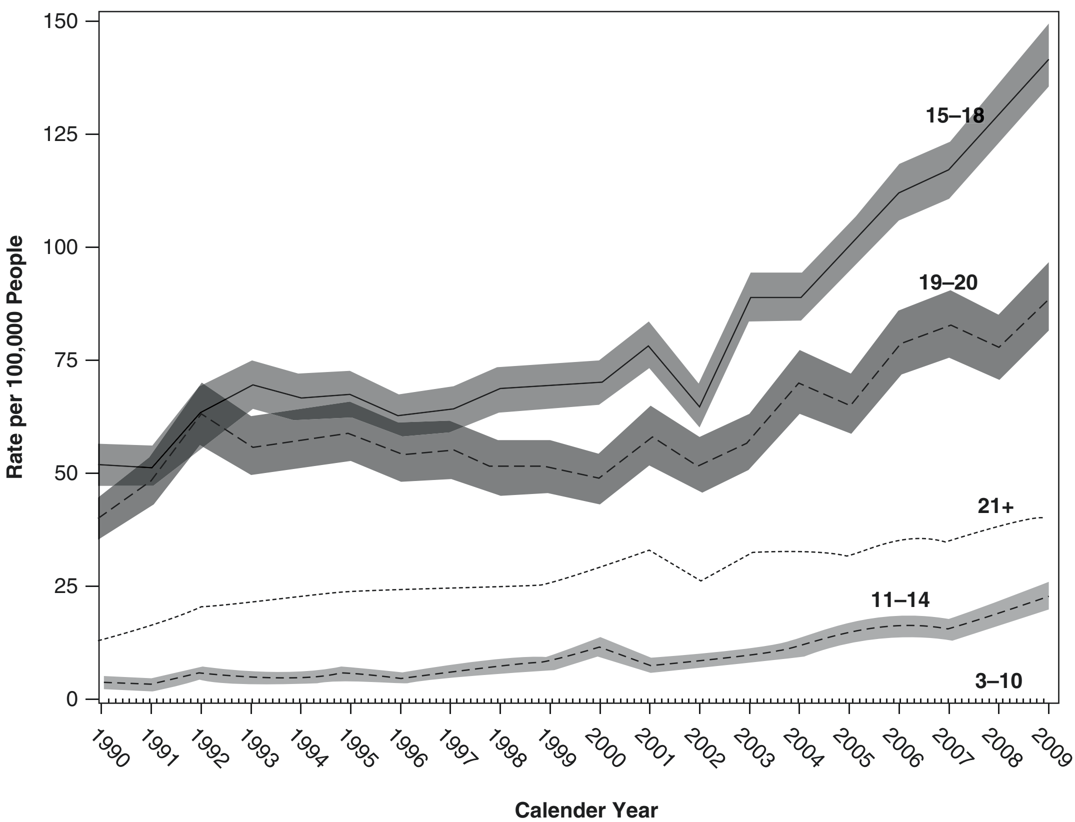

Fig. 4.1 Rate of anterior cruciate ligament reconstructions per 100,000 people stratified by age group in the pediatric population (aged 3–20 years) in New York State, 1990–2009. Shaded areas indicate 95% confidence intervals for rates. (With permission from Dodwell ER, Lamont LE, Green DW, Pan TJ, Marx RG, Lyman S. 20 Years of Pediatric Anterior Cruciate Ligament Reconstruction in New York State. Am. J. Sports Med. 2014;42:675–80.)

defined as a single practice or competition [22]. As may be expected, competition had a significantly higher risk of leading to a knee injury than practice (RR = 3.5) in nearly every sport. Boys football, girls soccer, and girls gymnastics had the highest rates of knee injuries: 6.3, 4.5, and 4.2 injuries per 10,000 athletic exposures, respectively. In competition, these numbers increased drastically for football, girls soccer, and girls gymnastics: 21.1, 10.8, and 9.4 injuries per 10,000 competitive exposures, respectively. ACL injuries comprised 25.4% of all knee injuries, and the highest numbers were seen with the same sports: boys football and girls soccer had 1.17 ACL injuries per 10,000 athletic exposures, and girls gymnastics had 1.14.

In addition, Gornitzky et al. performed a review of the literature to determine specific ACL injury rates in high school patients per 1000 athletic exposures (Table 4.1). A total of 700 ACL tears in over 11 million exposures were analyzed. Football and soccer were again found to be the sports with the highest incidence of ACL injury, with 0.089 and 0.099 injuries per 1000 athletic exposures, respectively. These values are similar to those quoted in the National High School Sports-Related Injury Surveillance Study. Other sports with increased rates of the ACL injury were basketball (0.055 ACL injuries per 1000 exposures), lacrosse (0.063 ACL injuries per 1000 exposures), and field hockey (0.048 ACL injuries per 1000 exposures) [25].

Hence, one could argue that special attention should be placed toward these sports in regard to injury prevention.

Gender Differences

In addition to risk as it relates to the specific sport played, gender also represents a risk factor for ACL injury. The difference in risk for ACL tears based on gender has been quoted in numerous studies, ranging from two to nine times greater for women than men [25]. This same difference is seen throughout the literature for pediatric ACL injuries [15–18, 20, 22, 23, 25–32]. Database analyses have verified these differences as well. Comstock et al. in the National High School Sports-Related Injury Surveillance Study found that female ACL tears comprised 35.1% of knee injuries, whereas male ACL tears comprised

Table 4.1 ACL tear incidence and risk per season by sport and sex (With permission from Gornitzky AL, Lott A, Yellin JL, Fabricant PD, Lawrence JT, Ganley TJ. Sport-Specific Yearly Risk and Incidence of Anterior Cruciate Ligament Tears in High School Athletes: A Systematic Review and Meta-analysis. Am. J. Sports Med. 2015;0363546515617742)

ACL tear incidence and risk per season by sport and sex[a]										
	Female				Male					
Sport	Incidence[b]	95% CI	Risk per season*c*	95% CI	Incidence[b]	95% CI	Risk per season[c]	95% CI	RR[d]	95% CI
Basketball	0.091	0.074–0.111	0.9	0.7–1.1	0.024	0.016–0.034	0.2	0.2–0.3	3.8	2.5–5.8
Field hockey	0.048	0.013–0.124	0.4	0.1–0.9						
Football					0.089	0.079–0.101	0.8	0.7–0.9		
Lacrosse	0.070	0.026–0.152	0.5	0.2–1.2	0.058	0.023–0.119	0.4	0.2–0.9	1.2	0.3–4.2
Soccer	0.148	0.128–0.172	1.1	1.0–1.3	0.040	0.029–0.055	0.3	0.2–0.4	3.7	2.6–5.3
Softball/ baseball	0.027	0.016–0.043	0.2	0.1–0.3	0.003	0.001–0.010	0.03	0.01–0.1	7.9	2.3–41.7
Volleyball	0.018	0.010–0.029	0.1	0.1–0.2						
Wrestling					0.021	0.012–0.034	0.2	0.1–0.3		
Overall	0.081	0.073–0.091	0.7	0.6–0.7	0.052	0.047–0.057	0.4	0.4–0.5	1.6	1.3–1.8

[a]ACL, anterior cruciate ligament; RR, relative risk
[b]Incidence expressed as ACL tears per 1000 exposures
[c]Calculated risk per single athletic season per athlete expressed in percentage
[d]Female RR per exposure as compared with males calculated for sex-comparable sports where possible

only 19.0% of all injuries [17]. These differences hold true even when controlling for the sport played. A study analyzing insurance data from a company specializing in soccer injuries found that of all knee injuries, 37% of ACL tears were female and 24% were male [20].

There are a number of theories behind the causation of this gender differential risk which have been thoroughly examined in the adult and pediatric literature. The differences can be divided into intrinsic anatomic factors of the knee, extrinsic biomechanical factors of the surrounding muscles, and hormonal factors [33, 34]. The first intrinsic factor often cited is the increased Q angle in female [35]. A second risk factor is narrow notch width. A narrow notch is thought to result in impingement of the ACL, placing the athlete at risk for rupture. Notch width values of <17 mm have been found to be associated with increased ACL injury [36], and women have been found to have narrower notch width indices when compared to men. This has also been verified with CT imaging [37].

Extrinsic factors, namely, the biomechanical forces exerted on the knee joint by the quads and hamstrings, are also thought to contribute to the increased risk for ACL injuries seen in females. Female athletes preferentially fire their quads over their hamstrings when encountering anterior tibial translation. This is different from nonathletes and male athletes who compensate for this translation with hamstring activation [38, 39]. This differential neuromuscular activation also results in different jumping and landing mechanics. Studies have found that female athletes have a tendency of landing from a jump in increased extension, thus increasing the forces that are exerted across the knee and increasing the chances of an injury [40]. Laxity of the musculature and capsule of female knees relative to males has also been implicated in allowing for the rotational moment leading to ACL injury [41].

Fortunately, interventions exist to correct these extrinsic differences and can be particularly beneficial for young female athletes [42–46]. The most consistently successful intervention is the implementation of a neuromuscular training program, which includes strengthening, stretches, and warm-ups, focusing on increasing the control of certain muscle groups and improving the biomechanics of landing [44]. In a recent meta-analysis, Myer et al. found that the impact of these prevention programs was influenced by the age of the participant. Those who participated in the prevention program had half the probability of an ACL injury than those who did not, and participants in their mid teens (14–18 years) had a 72% reduction in their risk of ALC injury compared to late teens (18–20) who had a 52% reduction in their risk [46].

Associated Injuries

Once the culture in which these injuries take place is understood and the risk factors are identified, it is important to note that additional injuries can oftentimes be just as debilitating for the pediatric athlete who has many years of high-impact sporting activity ahead of them. These include medial and lateral meniscus tears as well as chondral injuries.

Werner et al. in their private insurance claims database analysis from 2007 to 2011 found the incidence of concomitant injuries/treatment increased over the same time period as ACL injuries. Increases in the meniscus repair and debridement from 2007 to 2011 in the 10–14-year and 15–19-year cohorts were significant when compared to adults. Approximately 50% of all patients from ages 15 to 19 with ACL tears who underwent intervention also had a partial meniscectomy, and 25% of patients from 10 to 19 had a meniscal repair [18].

The incidence of these secondary injuries increases with the amount of time the knee remains unstable [47–51]. Millett et al. demonstrated that delays in surgery as little as 6 weeks were associated with an increased incidence of medial meniscus tears [47]. Lawrence et al. found similar results in delays greater than 12 weeks as well as an increased incidence of lateral hemi-joint chondral injuries [48]. More recently, Newman et al. further analyzed the risk factors for these secondary injuries and found that in younger patients (<14 years of age), a delay greater than 3 months was most predictive of secondary chondral injuries [51]. To achieve more granularity in this timing, Anderson et al. classified repairs into acute (<6 weeks after injury), subacute (6–12 weeks), and chronic (>12 weeks) and found worsening damage of both the cartilage and meniscus with increased time [49]. Thus, when examining pediatric ACL injuries, care should be taken to recognize that there is a significant incidence of secondary injuries which are exaggerated by delays in care, perhaps reflecting the trend toward more surgical intervention in this population.

Outcomes

Although the treatment of these injuries will be covered extensively in the following chapter, it is essential to note that treatment of these injuries is critical. A number of recent studies have examined the outcomes of ACL reconstructions in pediatric patients, both skeletally immature and mature, and have found positive results [52–56]. Traditionally, ACL injuries in skeletally immature athletes were treated conservatively with bracing and activity modification until the patient was near maturity, for the fear of physeal injury with growth disturbance.

In 2002, Aichroth et al. published a prospective study examining the outcomes of ACL ruptures in children and adolescents who were treated with and without surgery. Of the patients treated conservatively, nearly half showed radiographic signs of degeneration before they reached 20 [57]. The marked degeneration seen in pediatric ACL deficiency can likely be attributed to the noncompliance with activity modifications and exuberant sporting activity that these patients engage in despite the inherent instability of the knee.

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