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Anterior Cruciate Ligament Injuries in the Prepubescent and Adolescent Athlete: Clinical and Research Considerations

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Exercise across the lifespan is an important maintenance program for good health. Particularly in the American population, exercise is essential to prevent such conditions as obesity, diabetes, and cardiac problems, which often result in premature death. However, those who exercise by participating in sports from a young age can suffer debilitating injuries that may curtail their ability to exercise throughout their lives, thus hampering their efforts to stay healthy and avoid disease.

EPIDEMIOLOGY

Data presented at the 2006 American Orthopaedic Society for Sports Medicine seminar on allografts[1] indicated that nearly 350 000 anterior cruciate ligament (ACL) reconstructions are performed annually in the United States; 60 000 of those involve allografts. The annual cost of care is estimated to be more than $2 billion.[2] Long-term costs will no doubt be much higher.

Specific to age distribution, the Scandinavian ACL registries[3] of 2004–2007 reported a total of 17 632 injuries, with a median age of injury of 25 years. The skeletally immature population appears to be sustaining rising numbers of ACL injuries[4–6] and higher rates of midsubstance tears.[3,7–9] The general risk of ACL injury in those with open growth plates is still low, but participation in organized sports significantly increases the risk.[10] In a US report by Shea et al[6] of 5- to 18-year-old soccer players, 30.8% of all injuries involved the knee, and 6.7% of all injuries were ACL tears. (Statistics were garnered from insurance data documenting 6 million athlete-years.[11]) In a Finnish population-based cohort study of 14-, 16-, and 18-year-olds (46 472 responding; 78% response rate), 265 cruciate ligament injuries (194 in adolescent boys, 71 in adolescent girls; 92% were ACL tears) reflected an incidence rate of 60.9 per 100 000 person-years.[10] Most interesting were the hazard ratios: 8.5 for adolescent girls and 4.0 for adolescent boys among those participating in organized sports 4 or more times per week.

Why the distribution of ACL injuries in males and females should change with maturation is an interesting research question. Prince et al[12] showed that ACL injuries were more common in immature boys, but after maturation, the risk and incidence in females appeared to increase.[13,14] During this time, numerous changing factors, including hormones, height, weight, long-bone and muscle tendon length, and strength distribution, may play a role in injury susceptibility.

In order to implement risk-factor surveillance and prevention programs for ACL injuries, an understanding of the mechanisms involved in ACL failure is essential. Because sports result in so many ACL injuries in adolescents, the mechanisms involved are probably found in common jump-landing and pivoting maneuvers. Although physical contact with another player does play a role in some injuries, most injuries, especially in females, still appear to be noncontact in nature,[10,15] with up to 70% of ACL injuries in elite females occurring in the absence of contact.[15]

ASSOCIATED INJURIES

By itself, injury to the ACL increases the risk of osteoarthritis later in life, but the risk compounds when other structures are injured. Roos[16] reported that if the menisci can be preserved after the ACL injury, the risk of osteoarthritis is reduced. In a retrospective review of 39 patients 14 years of age or younger (30 girls, 9 boys: mean age = 13.6 years; range, 10 to 14 years), Millet et al[17] found that medial meniscus tears were 4 times more common in those whose ACL injuries were treated 6 weeks after injury, suggesting that the time course from injury to treatment may be an important factor in preserving the menisci. Magnetic resonance imaging scans of skeletally immature patients with ACL tears showed that 36% had meniscal tears when the growth plates were wide open, whereas 52% had medial meniscal tears and 17% had lateral meniscal tears when the growth plates were partially closed. These findings suggest a trend toward fewer meniscal injuries in the skeletally immature population.[12]

OUTCOME OF ACL INJURY

Injured athletes retire sooner from sports than their uninjured counterparts.[18,19] For those with ACL injuries, this may reflect the fact that such injury increases the risk of radiographic osteoarthritis later in life by 105 times.[10] This increased risk of osteoarthritis after ACL injury is an important consideration when deciding whether a nonoperative or operative course of treatment should be undertaken for the skeletally immature patient. Mohtadi and Grant[5] performed a very complete systematic review on the management of ACL injuries in the skeletally

immature; they reviewed 615 studies but found that only 7 provided adequate comparisons between nonoperative and operative groups. The best evidence available, unfortunately, was no better than level 3. The authors concluded that data were inadequate to determine which route of treatment was better for children and adolescents.[5]

ACL SURGERY

A major concern with early ACL reconstruction in the skeletally immature patient is growth-plate injury from tunnel placement or graft fixation.[4,20–25] Although the concern is justified, very few reports of growth-plate arrest have been published,[4,8,26] and growth-plate injury is undoubtedly avoidable with meticulous surgery.[27–31] Physeal anatomy is well known, and experience has shown us that the risks of surgery can be minimized with proper technique.[32] The response to ACL surgery, however, is not always predictable: Femoral or tibial overgrowth is possible with stimulation of an active physis secondary to the operative procedure. More problematic can be the occurrence of a growth spurt in close proximity to an ACL reconstruction. This potential for asymmetric long-bone growth may increase, possibly justifying the postponement of ACL reconstruction in some cases.[33]

Recent reports by Henry et al[29] and Marx et al[30] in 2009 were equally optimistic. When comparing early reconstruction in children with delayed reconstruction after skeletal maturity, Henry et al[29] noted fewer medial meniscus tears (16% versus 41%) in those children reconstructed initially and no growth-plate injuries after a mean follow-up time of 27 months. Similarly, Marx et al[30] monitored 55 children (age range, 8 to 16 years; mean, 13 years) for a mean of 3.2 years after ACL reconstruction (range, 1 to 7.5 years), finding no growth arrests and 88% normal or almost-normal Tegner scores (90 of 100 possible points).

REHABILITATION

Although numerous authors have reported on the success or failure of ACL rehabilitation in adults,[34–39] few authors have focused on children. Wells et al[40] reviewed the course of 55 teenagers (40 adolescent girls, 15 adolescent boys: mean, 15.9 $\pm$ 1.65 years), showing that the average time from surgery to recovery of 85% of normal quadriceps strength was 5.42 $\pm$ 2.27 months. Of these patients, 59% achieved 85% or better strength in fewer than 6 months, with 50% returning to full athletic activity in 6 months. Despite the numerous challenges in the rehabilitation of children and adolescents, ranging from their potentially limited focus and attention span to the adult size of most exercise equipment, successful rehabilitation is possible when managed by those who are familiar with the physical, mental, and emotional challenges of these patient groups. Maintaining motivation over time can be important in enabling them to maximize their great physical potential.

FUTURE RESEARCH CONSIDERATIONS

Clinical

- The most urgent need is to resolve the question of the best clinical treatment for ACL injuries in the skeletally immature patient. Although surgical reports (especially from the United States) appear promising, surgery is not without risk. Mohtadi and Grant[5] identified the shortcomings in the current literature and emphasized the need for a randomized trial in which operative and nonoperative groups are matched in terms of age, activity, and other risk factors.
- It is well established that an ACL injury, regardless of treatment, significantly increases the risk of osteoarthritis in adults.[16] It is easy to conclude that the same or perhaps even a worse prognosis would exist for children and adolescents. However, we need to establish whether, in fact, this is true or whether the healing and rehabilitation potential of young people overrides these risks and yields a better prognosis.
- In youngsters who can be successfully treated with a conservative program, is meniscal salvage the key to protecting articular cartilage in the face of a dynamically stable, well-rehabilitated knee? A thorough identification of risk factors and prognostic indicators would help direct parents and physicians in these difficult clinical situations.

Basic Science

- One of the most intriguing questions about the skeletally immature with regard to ligament reconstruction is "Does a ligament grow in a child after implantation and revascularization?" Understanding these mechanisms may prove helpful in providing optimal care at all ages.
- If the prognosis for the skeletally immature with ACL injuries is as poor as in adults with ACL injuries,[16] is there a role for the tissue-engineered repair procedure or a ligament scaffold to augment a repair? Because children appear to have better healing potential than adults, procedures that may not be advisable in adults may be more successful in children.
- Preventing ACL injuries in the young is obviously a high priority to avoid degenerative consequences later in life. An important question remains: Can we successfully conduct risk-factor surveillance in these at-risk groups to identify those who are most vulnerable? Along these same lines, if those with significant risk factors can be identified, should they be advised not to participate in high-risk sports such as soccer and basketball? If the susceptible individuals can be identified, are the injury mechanisms sufficiently well characterized to justify efforts at focused prevention strategies?
- No doubt, the onset of puberty in the skeletally immature patient presents challenges for athletes and appears to influence the injury rate in both boys and girls. Both groups experience a spike in the number of injuries in the early teenage years. Height, weight, muscle performance, and hormones all change during puberty; these alterations in body shape, physiology, and function probably play a role in the increased injury susceptibility. Monitoring the physical development and performance

of children and adolescents may yield many answers for the ACL injury-susceptibility question.

SUMMARY

An ACL injury in a child or adolescent is a major risk factor for the development of early-onset osteoarthritis. Although definitive evidence for recommending surgical management of these injuries is lacking, aggressive surgical treatment appears to provide the best outcome due to meniscal-salvage opportunities, especially in those who remain physically active.

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