Pediatric Anterior Cruciate Ligament Rehabilitation: A Review

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ABSTRACT

Rehabilitation is crucial in the treatment of ACL injuries, particularly in the pediatric population. Children are often eager to return to their pre-injury level of athletic participation, which may place them at risk for re-injury if rehabilitation protocols are not adequately followed. Contemporary protocols incorporate functional benchmarks rather than solely time-based milestones to better evaluate if patients have adequate strength and function to return to sport activities. Optimization of rehabilitation can lead to safer return to play and minimize the risk of re-injury. Ultimately, successful rehabilitation requires effective communication between the entire care team, including the patient, family, therapist, coaches, trainers, and orthopaedic surgeon in order to optimize recovery from injury.

INTRODUCTION

Increased organized sport participation in children and adolescents has led to an increase in the number of acute and chronic injuries in youth athletes.[1] Among high school athletes, up to 50% of injuries that require surgery involve the knee and 25% of those knee injuries involve the ACL.[2,3] Beck et al. reviewed the incidence of ACL injury in patients aged 6–18 from 1994–2013 and found an average rate of 121 injuries per 100,000 person-years.[4] The highest rates were in 17-year-old males (422 per 100,000) and 16-year-old females (392 per 100,000). An important finding was that over the 20-year period, there was 2.3% average annual increase in the rate of injury.[4] As the rate of injury has increased, so has the number of ACL reconstruction (ACL-R) surgeries in pediatric patients over the last 20 years.[5] Dodwell et al. examined a state-based database and found that from 1990 to 2009 the rate of pediatric ACL-R increased from 17.6 to 50.9 per 100,000.[5]

Many controversies exist regarding the treatment of ACL injuries in the pediatric population, as they are skeletally immature individuals. Reconstruction of the ACL in a manner similar to skeletally mature patients would require disruption of the physis,[6] which could result in growth disturbances.[7] While there have been favorable outcomes regarding initial nonsurgical treatment and delayed reconstruction (until skeletal maturity), these options have resulted in increased knee instability and a higher risk of osteoarthritis later in life.[8–10] Various surgical techniques have been developed in order to provide long-term knee stability in pediatric patients, including physeal sparing as well as partial and complete transphyseal techniques.[11–15] The specific type of procedure to be performed depends on a number of factors, including patient age, activity level, and surgeon preference.

While recent efforts have focused on understanding optimal ACL injury management in the pediatric population, less time has been spent on determining the proper rehabilitation processes that should follow. Adult studies have proven that both post-operative and pre-operative rehabilitation lead to improved functional outcomes.[16] Specific rehabilitation protocols can impact the speed and safety with which patients return to sporting activities.[17] Rehabilitation protocols may vary based on the type of surgery performed; however, both pre- and post-operative rehabilitation are crucial components in managing pediatric ACL injury.[18] The purpose of this paper is to review current trends in pediatric ACL rehabilitation, as well as to identify future areas of study.

NON-OPERATIVE TREATMENT

Nonsurgical treatment has been the traditional approach to ACL injury management in the pediatric population due to the concern of disrupting the physis through surgical reconstruction. Non-operative treatment typically consists of activity modification, physical therapy, and specialized bracing.[19,20] Moksnes, Engebretsen, and Risberg[21] outline a four-phase nonsurgical treatment program that emphasizes range of motion, neuromuscular training, and strengthening. In Phases 1 and 2, patients work closely with physical therapists and are provided with exercises to perform at home; they proceed to the next phase only after meeting specific functional milestones. Phase 3 incorporates jumping and landing, open- and closed-chain strengthening exercises, and plyometric drills. Phase 4 consists of a secondary injury prevention program that focuses on functional stability. If recurrent instability occurs despite activity modification and progressing through the treatment program, surgical reconstruction is recommended.[20]

While nonsurgical treatment preserves the growth plate, many studies have demonstrated its shortcomings, including

an increased risk of instability, meniscal injuries, and chondral injuries.[8–10,20,22,23] When treated non-operatively, 19.5% of pediatric patients sustained new meniscal injuries after their initial ACL tear, and cartilage injuries had a prevalence of 7.1% two to three years after the initial ACL tear.[22] Surgery should be recommended if nonsurgical treatment does not provide sufficient functional stability, if patients continue to have episodes of giving way, if a satisfactory activity level is not achieved, or if there is a significant concomitant meniscal injury.[20–22] While some surgeons advocate for delayed reconstruction once the physis matures, others have found that if surgery is delayed by ≥12 weeks, there is a significantly increased chance of irreparable meniscus injury and lateral compartment chondral injury.[24] Furthermore, the severity of the injuries increase with time.[25] A recent systematic review of the literature concluded that early ACL-R leads to less meniscal and chondral damage compared to non-operative or delayed surgical treatment.[23] There are currently no high-level studies that directly compare the efficacy of nonsurgical treatment to surgical reconstruction of the ACL in the pediatric population.[26]

"PRE-HABILITATION"

In the adult population, pre-operative rehabilitation has been shown to improve knee-related functioning, muscle strength, and return-to-sport rates after ACL-R.[16,27] There is little documentation, however, of the effects of pre-habilitation protocols in the pediatric population. In a case study, Greenberg et al. described a brief pre-operative physical therapy regimen before an all-epiphyseal ACL-R, with gait training, assessment of the patient's maturity level, and ability to follow post-operative instructions.[28] The functional goals included no effusion, at least 80% quadriceps strength in the affected leg when compared with the unaffected leg, full extension, at least 120 degrees of active knee flexion, and independence with weight-bearing restrictions. Fabricant et al. recommend activity modification and closed chain rehabilitation following ACL tears in the pediatric population, but no specific recommendations were provided.[29]

POST-OPERATIVE WEIGHT-BEARING

Generally, surgeons encourage early post-operative weight-bearing following ACL-R, but in the pediatric population, a more restricted weight-bearing protocol may preserve the graft tissue and the physis.[28] Some surgeons recommend restricting patients to toe-touch weight-bearing (TTWB) for at least the first week following an all-epiphyseal reconstruction.[28,30] Weight-bearing as tolerated (WBAT) is advised during weeks 2–4 post-ACL-R until the patient has a normalized gait pattern,[30] and full weight-bearing is recommended by post-operative week five.[28] Similarly, according to the Hospital for Special Surgery (HSS) protocol, patients should aim to normalize gait patterns while WBAT during post-operative weeks 4–8.[29] In the presence of a concomitant meniscus repair, surgeons generally limit weight-bearing to allow time for the meniscus to heal.[21,30,31]

RANGE OF MOTION

One of the major goals of post-operative rehabilitation is for the patient to obtain full range of motion (ROM) of the knee. Passive and active exercises are suggested in the early post-operative phase to help improve extension and flexion, including a continuous passive motion machine,[28] wall slides, prone dangling, resting extension with a heel prop, and stationary cycling.[30] Surgeons tend to rely on time-based criteria when restricting knee motion during the rehabilitation protocol.[32] Some surgeons recommend locking the post-operative brace in full extension immediately following surgery for up to three[28] or four[30] weeks, while both ambulating and sleeping. There is wide variability in the literature regarding post-operative ROM goals. One article recommends reaching 50 degrees of knee flexion by post-operative week four and 90 flexion by week five,[28] while another suggests 90 flexion by week two and 120 flexion by week four.[30] Others have recommended 90 flexion by week four, 125 flexion by week eight, and full ROM by week sixteen.[29] Only Akinleye et al.[30] provide specific functional criteria that must be met before unlocking the brace and removing restrictions. Makhni et al. found a wide range of variability in adult ACL-R protocols at academic institutions, similar to the pediatric literature.[33] There is variability in post-operative protocols, but the main goals should be to restore strength and motion as much as possible and to achieve a successful return to play.

STRENGTHENING

Quadriceps activation and strengthening are important goals early in the rehabilitation phase and can be attained through muscle contractions and straight leg raises.[28–30] Current rehabilitation protocols advocate for progressive strengthening exercises[29,30] along with neuromuscular training to improve strength, proprioception, balance, and muscle endurance.[30] Home exercise programs will help regain strength in the quadriceps, hamstrings, and hip muscles,[28–30] but it is important to consider the patients' age, maturity level, and parental involvement. Isokinetic testing during postoperative weeks 16 and 24 can help guide the rehabilitation program; if the peak torque deficit is less than 25% of the unaffected leg, more advanced and sport-specific training (including double leg hopping, jogging, agility drills, and double leg plyometric drills) may be initiated.[30] According to the HSS protocol, the patient maximizes leg strength during weeks 16 through 20 while the HSS injury prevention program is implemented.[29] One study has found that over 50% of

Figure 1. Early (**A**–**C**), and late (**D**–**E**) ACL rehabilitation exercises.
A. Quad sets, towel is placed under injured leg and patient contracts and relaxes their quadriceps muscle.
B. Straight leg raises. **C**. Quadriceps extensions. **D**. Step ups. **E**. Squats. **F**. One leg squat.

pediatric patients reach 85% of quadriceps strength between two and six months post-ACLR.[34] Another study, however, concluded that it takes longer for the pediatric population to regain quadriceps strength than the adult population; after 15 months, only 25% achieved a limb symmetry index (LSI) of greater than 90% on all strength and functional tests.[35] These results indicate the need for further research to determine the proper strength exercises and duration of rehabilitation for the pediatric population.

FUNCTIONAL TRAINING

The goal of rehabilitation in post-operative ACL-R patients is to achieve a functional and stable knee.[21] Many authors advocate functional exercises throughout the rehabilitation process for this purpose, including specific exercises that target neuromuscular control and muscle strength.[21,28–30] In the Children's Hospital of Philadelphia (CHOP) rehabilitation protocol, early functional exercises (weeks 4–16) include proprioceptive neuromuscular facilitation, progressive resistive exercises, leg presses, balance training, squats, single-leg squats, and step-ups. Progression to running, double-leg hop, plyometrics, and sport-specific activities is initiated only after certain functional milestones are met (**Figure 1**).[20,28,30] Similarly, the functional goals of the HSS protocol are to demonstrate an athletic-ready stance by week 20 and to feel confident with sport-specific movements by week 28.[29] An injury prevention program of neuromuscular training may help to maintain functional stability of the knee with both post-operative and non-operative management.[21]

RETURN TO SPORT

The ultimate goal of the surgical and/or rehabilitation process is to return the patient to the same type, intensity, and frequency of sport as before the injury occurred.[36,37] Returning to play too early places the patient at a greater risk of re-injury,[38] particularly in pediatric and adolescent patients.[39] Previously, subjective self-report measures and time-based criteria were used to assess sport readiness in both the adult and pediatric population.[35,40,41] Objective, functional testing throughout the rehabilitation process will help determine sport readiness at each stage. [21] Functional testing will reveal strength deficits through the presence of abnormal movement patterns, and it should be considered along with factors such as quadriceps strength, range of motion, and dynamic balance.[34,35]

Research on return to sport in the adult population has seen a paradigm shift moving away from time-based criteria towards more function-based criteria in order to individualize progress and plan the safest time to return to sport.[40] Joreitz et al[36] have created a protocol for adults comprised of functional goals, guidelines, and recommendations for returning to sport that is currently being studied. No criterion-based measures have been adequately studied, especially in the pediatric population.[36] Both the HSS and the CHOP protocols use a combination of time and functional criteria for return to sport. The HSS protocol allows return to sport after 28 weeks and achievement of at least 85% functional single leg hop test compared with the unaffected limb as well as dynamic control and lack of apprehension with sport-specific movements.[29] The CHOP protocol, on the other hand, requires that the patient must meet certain functional criteria and be nine months post-operation in order to return to sport.[28,30] There is a need for further research on the most effective criteria to ensure the safest and most efficient return to sport for the pediatric population.

CONCLUSION

Rehabilitation is crucial in the treatment of ACL injuries, particularly in the pediatric population. Children are often eager to return to their pre-injury level of athletic participation, which may place them at risk for re-injury if rehabilitation protocols are not adequately followed. Newer protocols incorporate functional benchmarks rather than time milestones to evaluate if patients have adequate strength and function to return to sport. Ultimately, the physician and therapist in conjunction with patients, parents, coaches, and trainers should clearly outline the goals and specific phases of ACL-R rehabilitation to align expectations, optimize outcomes, and increase the rates of successful return to sport.

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