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PREVENTION AND REHABILITATION OF PEDIATRIC ANTERIOR CRUCIATE LIGAMENT INJURIES

INTRODUCTION

While knee injuries are relatively rare in the general paediatric population, the number of intra-articular knee injuries increases substantially with increasing age and sports participation [38]. Over the last decade, knee injuries have become more common in children [56]. Worryingly, the rates of ACL reconstructions in children and adolescents now increase at a rate significantly higher than in the adult population [70], leading to an increased research interest in paediatric ACL injuries.

Individuals with an immature musculoskeletal system require different considerations than adults and adolescents. While successful prevention strategies that target neuromuscular control exist for adolescent individuals [48], children and adolescents may not exhibit the same movement patterns [33]. With regard to treatment after ACL injury, skeletally immature children are different from mature patients both physiologically and psychologically [17,45]. The open epiphyseal growth plates and remaining growth require particular consideration before deciding whether or not surgical treatment should be advised [31], and the ability to adhere to requirements and restrictions in long lasting rehabilitation programs are challenging [47].

The purpose of this article is to review the current knowledge on ACL injury prevention and ACL rehabilitation in individuals who have not yet reached musculoskeletal maturity. However, as there is a scarcity of knowledge on this group, we will supplement with research performed on adolescents and adults.

Materials and methods

In August 2015 we searched PubMed for papers on risk factors, ACL injury prevention and rehabilitation. The studies had to include individuals who were 13 years or younger, or who were skeletally immature based on radiographic assessment. To identify risk factor studies we used the search string “Anterior Cruciate Ligament”[MeSH] AND (Risk[TIAB] OR Predict*[TIAB]) AND

(Child[MeSH] OR Adolescent[MeSH]) NOT Adult[MeSH]. To identify injury prevention studies we used "Anterior Cruciate Ligament"[MeSH] AND Prevent*[TIAB] AND (Child[MeSH] OR Adolescent[MeSH]) NOT Adult[MeSH]. Rehabilitation studies were identified through the search string: "Anterior Cruciate Ligament"[Mesh] AND (Child[Mesh] OR "Adolescent"[Mesh]) AND ("Rehabilitation"[Mesh] OR "rehabilitation"[Subheading] OR "Exercise Therapy"[Mesh]) NOT (Adult[Mesh] OR "prevention and control"[Subheading]). The search strategies resulted in 119 hits on risk factor studies, 57 hits on prevention, and 37 hits on rehabilitation. All abstracts were reviewed for relevance. Reference lists of relevant studies and previous reviews or clinical commentaries were also reviewed to identify studies not found through the primary searches.

PREVENTION

Effective preventive measures should target modifiable risk factors for injury [65]. In the following paragraphs we will therefore describe the knowledge regarding risk factors as well as injury prevention for ACL injuries in children.

Risk factors

The prevalence of ACL injuries is not uniform across age groups. Data from a paediatric medical centre shows that ACL injuries may account for 6.3 % of all sports injuries in 5-12 year olds, but 10.6 % in 13-17 year olds [61]. The rates of ACL reconstruction are also shown to dramatically increase from the age of 15 to 18, with more than 8 times more reconstructions performed than in the 11-14 year category [10]. The ACL injury pattern thus coincides with the general injury pattern in children: There is a low injury risk during middle childhood [16], which increases with age and participation in higher level sports [34]. One interesting exception may be injuries sustained in alpine skiing, where lower extremity injuries are more common in younger age groups [26], and ACL tears and knee sprains may account for 21-47.7 % of all injuries in children and adolescents [44]. The development of new equipment and high-risk snow-park areas for children and adolescents may, in combination with more aggressive styles of skiing, explain the continued increase in skiing injuries

among the youngest skiers [21]. Furthermore, the new ski-sports arising during the previous decade are documented to have a high risk of ACL injuries [58]. Additionally, the use of skiing equipment that is originally designed for adults and wrong adjustment of binding release mechanisms may put the young skiers at risk when a fall occur [3].

In the general ACL injured population in Scandinavia, football, handball and alpine skiing are responsible for the majority of injuries [22]. Data from our prospective ACL cohort study in Oslo also show that alpine skiing is the most common injury activity in patients 12 years or younger, while football is the second largest injury activity [46]. ACL injury activity may to a large extent be determined by climate conditions. While researchers from Miami showed that American football was the most common injury activity in 9-15 year olds [18], a paper from Grenoble showed that 89 % of ACL injured 11-15 year olds suffered their injury during alpine skiing [5]. To our knowledge, exposure-adjusted incidence rates of ACL injuries in children do not exist. In addition to the injuries occurred during sports, paediatric ACL injuries also occur during non-organised activities such as trampoline jumping and playing [46]. The large proportion of non-organised activity in children is also known to make incidence calculations and risk factor estimations difficult [54].

While female adolescent and adult athletes have shown a 2-3 fold higher risk of ACL injuries than male athletes [68], there is no clear evidence of sex being a risk factor in children. The increased incidence of ACL injuries in females during puberty have been coupled with changes in neuromuscular control, specifically poorer control of landing forces. As children enter puberty, they demonstrate stiffer landings with more medial knee motion and poorer hip/core control, and these biomechanical changes seem to be more evident in females than males [30,51]. Altered neuromuscular control of the knee and hip are reported risk factors for both primary ACL injury [29,49], and a second ACL injury [50] in adolescents. These movement patterns may be directly linked to the injury mechanisms of noncontact ACL injuries, which are characterized by knee valgus and decreased knee flexion [37]. Padua et al.[49] recently found elite-youth football players with poorer technique in a jump-landing trial to be at higher risk of ACL injuries. These players were aged 11 to 18 years, and 25

% were less than 13 years of age. However, studies of movement patterns as risk factors for ACL injuries in an exclusively paediatric population do not yet exist.

We identified six retrospective case-control studies on anatomical risk factors for ACL injury in skeletally immature children or adolescents. Compared to skeletally immature children without ACL injuries, ACL injured children are found to have a narrower intercondylar notch [11,55], and an increased medial [66] or lateral [6] tibial slope. Another recent study [7] suggested ACL injured children had increased patellar tendon length and higher Insall-Salvati ratio, possibly pointing to patella alta as a risk factor for paediatric ACL injuries.

ACL prevention programs

Neuromuscular training programmes designed to improve movement patterns have been highly successful in adolescent populations – both in terms of reducing the number of ACL injuries [48] and changing movement patterns [63]. Several successful programmes exist, and most are used as a warm-up before regular practice or games. To our knowledge, there are three studies including athletes 13 years or younger reporting on ACL injuries.

In a cluster-randomised study, Walden et al. [67] showed a 64 % reduction in ACL injuries in female 12-17 year old football players using a twice weekly 15-minute programme targeting core stability, balance and proper knee alignment. The most compliant teams showed an even higher effect with an 88 % injury reduction [27]. To our knowledge, this is the only study where ACL injury is the primary outcome and the study group includes those 13 years or younger.

Using a nonrandomised design, Kiani et al. [32] reported a 77 % reduction in knee injury incidence in 13-19 year old female football players after a prevention programme focusing on balance, strength and core stability. Although the main outcome was all knee injuries, noncontact knee injuries were also significantly reduced and the control group suffered five ACL injuries versus zero in the intervention group.

In a cluster-randomised study, Steffen et al. [60] did not find a significant effect of the FIFA “11” programme in female football players aged 13-17 years (Four ACL injuries in the intervention group vs five in the control group). The “11” focused on core stability, balance, dynamic stabilization and

eccentric hamstrings strength. The authors noted a low compliance to the programme which might explain the lack of effect. Consequently, the "11" has been reviewed, updated and renamed "FIFA 11+" to improve compliance. The "11+" was recently reported to reduce the ACL injury rate by 76 % in a randomised controlled trial on collegiate male soccer players. The authors also observed that the more consistently the program was utilized, the greater the injury prevention benefit was for the athlete [57].

Several other studies on older participants have shown a positive effect of neuromuscular training programmes. In their meta-analysis of 14 ACL prevention studies in female athletes, Myer et al. [48] found a larger effect in 14-18 year olds compared to older athletes, with an estimated 72% ACL injury reduction (a younger age group was not included due to scarcity of data). The authors concluded that the best time for implementation of ACL injury prevention may therefore be before or in the beginning of adolescence.

Three studies have also examined whether neuromuscular training can improve movement patterns associated with ACL injuries in paediatric populations [8,9,23]. Disappointingly, none of these studies showed improvement of movement patterns following existing prevention programmes, or following a specialised paediatric programme.

For alpine skiing injuries an interesting proposal on how to reduce the rates of injuries in children and adolescents has been stated by Meyers et al. [44] *"As with all high-risk sports the answer may lie in increased wisdom and responsibility of both the skier and the parent to ensure an adequate level of ability, self-control and simply common sense as they venture out on the slopes"*.

REHABILITATION

Injury rehabilitation involves a dynamic planned process, which first and foremost consists of gradually progressed targeted exercises. Treatment algorithms outline the general direction of treatment plan; for example early surgical intervention or primary non-operative treatment of ACL injuries in skeletally immature individuals. Regardless of treatment algorithm, the success of rehabilitation is dependent on introducing the most effective principles of active interventions at the right time in adequate dosage [2].

Rehabilitation algorithms

Several treatment algorithms have been described in the literature for children and adolescents following ACL injury [4,35,36,41,46]. The importance of rehabilitation after ACL injury and reconstruction is uncontroversial, and the evidence supporting the implementation of active rehabilitation programs for adults with ACL injury is strong [15,20,25]. Despite the amount of published literature concerning different aspects of rehabilitation after ACL injury and reconstruction, there is no clear consensus on type or dose of exercises to include in rehabilitation programs [53,64]. However, a relatively large number of children, adolescents, and adults do not fully recover after ACL injury - regardless of surgery or not. Children and adolescents often present with deficits in quadriceps muscle strength, reduced scores on patient-reported outcome measures, and have a high incidence of re-injuries regardless of non-operative or surgical treatment [24,40]. Successful return to pre-injury activities is highly variable in the literature, although the numbers from recent publications describe 55-70% return to pre-injury activity level [1,24,25,46]. Consequently, there seems to be a need for developing and systemizing rehabilitations principles after ACL injuries and ACL reconstruction in both children and adolescents.

There is a trend that rehabilitation programs for adult ACL injured patients have moved in a more aggressive direction including early weight-bearing, more powerful strength training, and challenging neuromuscular exercises [12,69]. In contrast, the rare descriptions of rehabilitation programs in skeletally immature patients are limited to brief overviews of post-operative rehabilitation protocols. The protocols tend to advocate a more conservative approach with longer periods of non-weight bearing, bracing, and a delayed return to sport in comparison to the more functional based adult protocols [42,47]. Furthermore, there seems to be a consensus on the use of a knee brace during sports activities, although no solid studies has been published within the area of bracing and ACL injuries in children [39].

Moksnes et al. [47] published a functional treatment algorithm that highlights that the post-injury rehabilitation should be performed exhaustively before further treatment decisions are made in

skeletally immature children. Treatment decisions are based on the functional knee stability measured through functional performance tests and the child's experience in their desired activities. There is substantial support in the literature that rehabilitation should be supervised [13], and performed exhaustively before a decision on further treatment is made for an ACL injured patient [39,45]. Pre-operative rehabilitation is beneficial because it increases the likelihood of a successful outcome after ACL reconstruction – and is in many cases effective in restoring functional knee stability to a level that eliminates the need for a surgical ACL reconstruction [15,25,69]. Children with ACL injuries should be monitored and assessed by an orthopedic surgeon and a physical therapist working together, evaluating if a structured rehabilitation program has been successful or not in providing functional stability of the knee before long-term treatment decisions are made.

Rehabilitation principles

Modern rehabilitation is progressed through phases or stages based on sound clinical reasoning, sequenced functional achievements and the completion of functional milestones [2]. At the same time, knowledge on tissue-specific biologic healing processes should be respected and will guide the time-line of progression. Rehabilitation exercises in children are less focused on muscular strength and hypertrophy, with the primary emphasis being on neuromuscular stimulation and maintenance of multi-joint functional stability [14,47]. The rehabilitation is usually organized in four phases [19]. Within each phase specific functional milestones and achievement goals are identified. Some goals will be primary in each phase; for example achieving full knee extension and quadriceps activation early after the knee injury in the first phase. Throughout the first two phases the child should be guarded from pivoting activities, and possibly also wear a protective brace in school and training. Exercises to facilitate proper alignment and adequate landing techniques have been successfully implemented in injury prevention programs [28,43,59], and are recommended through phase two and three of pediatric ACL rehabilitation. Secondary prevention strategies with emphasis on maintained neuromuscular functional stability are encouraged in phase 4 following the return to the desired activity level.

Clinical relevant summary

ACL injury prevention using neuromuscular training is highly successful in the adolescent population [48]. Swart et al. [62] also concluded these programmes are cost-effective. Still, the level of evidence for ACL prevention in children is markedly lower. Additional concern arises as the neuromuscular characteristics believed to lead to ACL injury may be more common after the start of the growth spurt [33,52], and existing neuromuscular programmes have not yet shown to improve movement patterns in children [8]. We identified only three studies on ACL injury prevention which included those 13 years or younger. All studies were on female football players, had a large proportion of adolescents, and only one was a randomised study with ACL injury as the primary endpoint [67]. This study also showed the largest effect with up to 88 % injury reduction in optimally compliant players [27]. Based on the positive results of this high quality study, we recommend female football players start ACL injury prevention programmes at the age of 12.

Several questions remain to be answered before successful ACL injury prevention in children can be achieved. There is little knowledge on ACL injury prevention in alpine skiing, which in some countries may be the main arena for paediatric ACL injuries. There is also a lack of studies on modifiable risk factors for ACL injury in children. While retrospective case-control studies on anatomical factors are far more feasible to conduct, they provide little insight into how the injuries can be prevented. Lastly, the lower prevalence of ACL injuries in children compared to adolescents also indicates a lower cost-effectiveness of potentially successful preventive measures. Thus, implementation of injury prevention programmes in adolescents remains a high priority.

Following an ACL injury skeletally immature children and adolescents should participate in a structured rehabilitation program progressed through staged phases with functional progression milestones [15,46]. Premature surgical intervention before rehabilitation is completed may lead to unnecessary surgery with inherent surgical procedure risks, idiopatic growth disturbances, and a reduced likelihood of successful post-operative outcome. However, we consider it just as important that physical therapists and orthopaedic surgeons collaborate and perform teamwork that can secure the initiation of surgical ACL reconstruction when a young patient experiences an unstable knee

despite adequate rehabilitation. The child and their parents must be informed and educated on the possible outcomes – including the relatively low return to pre-injury level rates and high re-injury rates following both non-operative and surgical treatment following an ACL injury.

CONCLUSION

Although limited, current evidence supports implementation of injury prevention programmes in female football players from the age of 12. Supervised active rehabilitation where progression is guided by functional milestones is also advocated. Future identification of modifiable risk factors is needed to design prevention programmes for younger children. Description of rehabilitation principles, content and progression should be included in future publications. There is a need for international multicenter studies on treatment algorithms and rehabilitation to increase knowledge on the short and long-term outcomes following existing algorithms.

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