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SYSTEMATIC REVIEWS

Osteoarthritis action alliance consensus opinion - best practice features of anterior cruciate ligament and lower limb injury prevention programs

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Abstract

AIM

To identify best practice features of an anterior cruciate ligament (ACL) and lower limb injury prevention programs (IPPs) to reduce osteoarthritis (OA).

METHODS

This consensus statement started with us performing a systematic literature search for all relevant articles from 1960 through January 2017 in PubMed, Web of Science and CINAHL. The search strategy combined the Medical Subject Heading (MeSH) and keywords for terms: (1) ACL OR "knee injury" OR "anterior cruciate ligament"; (2) "prevention and control" OR "risk reduction" OR "injury prevention" OR "neuromuscular training"; and (3) meta-analysis OR "systematic review" OR "cohort study" OR randomized. We found 166 different titles. The abstracts were reviewed for pertinent papers. The papers were reviewed by at least two authors and consensus of best practice for IPP to prevent OA was obtained by conference calls and e-mail discussions. All authors participated in the discussion.

RESULTS

The best practice features of an IPP have the following six components: (1) lower extremity and core strengthening; (2) plyometrics; (3) continual feedback to athletes regarding proper technique; (4) sufficient dosage; (5) minimal-to-no additional equipment; and (6) balance training to help prevent injuries. Exercises focused on preventing ankle sprains, hamstring injuries and lateral trunk movements are important. Plyometric exercises should focus on correcting knee valgus movement.

Exercises should focus on optimizing the hamstring to quadriceps strength ratio. In order for IPP to be successful, there should be increased education and verbal feedback along with increased athletic compliance. Additional equipment is not necessary. Balance training alone does not significantly reduce injuries, but is beneficial with other exercises. Not enough evidence to recommend stretching and agility exercises, with no ill effects identified. Therefore, we suggest making these optional features.

CONCLUSION

Best practice features for ACL and lower limb IPPs to help prevent OA contain six key components along with two optional.

Key words: Anterior cruciate ligament; Lower limb; Injury prevention program; Knee injury

Core tip: Sports participation can provide health benefits, but also increase the injury risk to the lower limbs especially the anterior cruciate ligament. Many different types of injury prevention programs (IPPs) exist to train athletes to reduce inherent risk factors. The aim of this review is to provide a comprehensive analysis of both systematic and meta-analyses studies to identify the best practice features (lower extremity and core strengthening, plyometrics, continual feedback to athletes regarding proper technique, sufficient doses, minimal-to-no additional equipment, and balance training along with optional components of stretching and agility exercises) of an IPP to help protect the athlete.

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INTRODUCTION

The osteoarthritis action alliance (OAAA) is a broad coalition of public health leaders and stakeholders committed to elevating osteoarthritis (OA) as a national health priority and promoting effective policy solutions that aim to address the individual and national toll of OA. The authors of the paper are members of the OAAA prevention working group. Our goal is to prevent the onset of OA through effective injury prevention and weight management strategies. One of our strategies is to promote widespread implementation of activity-specific rules and policies for organized sports, recreation and school athletics to prevent joint injuries that can lead to OA. We believe that implementing anterior cruciate ligament (ACL) and lower limb injury prevention programs (IPPs) will prevent OA of the knee.

Sports participation can generally enhance one's health benefits *via* regular physical activity. However, there is an increased risk for injuries that occurs in athletics. Lower limbs injuries are very common.

ACL injuries are common in a high-risk sport occurring in 2.1% of college female soccer players per season[1] and 12.3% of female college soccer players report a previous ACL tear[1]. The annual ACL injury incidence does vary with reported rates for amateur athletes (ranging from 0.03% to 1.62% in studies of at least moderate sample size), which are lower than professional sports but higher than national surveys[2].

An injury to the ACL has both significant short-term (time away from sport) and long-term implications. In particular, injury to the ACL of the knee significantly increases a person's risk for (OA) in the injured knee[3,4]. In particular, an ACL injury significantly increases a person's risk for OA in the injured knee with around 20% of ACL-injured knees having moderate or severe radiologic changes (Kellgren and Lawrence grade Ⅲ or Ⅳ)[3]. OA is a chronic, painful, and disabling disease, and it is prevalent in 1 in 3 people around 10-15 years after an ACL injury regardless of treatment (operative or non-operative)[3,5]. Therefore we believe the best practice is to prevent knee injuries and ACL injuries.

Studies suggest that a beneficial effect exists when utilizing both lower limb and ACL IPPs[6,7]. Prevention programs that incorporate a variety of strategies to target modifiable risk factors can be crucial in reducing the number of ACL injuries sustained. The number of athletes needed to treat to prevent one ACL tear varies with estimates at 89-128[7-9] depending on age of participants and inclusion of all ACL tears or non-contact ACL tears only. It is estimated that an ACL reconstruction lifetime cost to society is US $38121[10]. IPP for high risk sports for those 12-25 years of age (IPP for HR 12-25) is estimated to prevent 842 lifetime cases of OA per 100000 individuals and 584 total knee replacements per 100000 are subsequently averted[11]. IPP for HR 12-25 would avert US$ 693 of direct healthcare costs per person per lifetime. As well, other studies have found cost-savings from IPP from prevention of ACL surgeries not just the savings from OA prevented[12-15].

The purpose of this consensus statement is to provide a comprehensive evaluation of the literature to identify the best practice features of an ACL and lower limb IPP and determine essential components that are required to help protect the athlete from sustaining such traumatic injuries, thereby reducing OA. Multiple systematic reviews and meta-analyses have attempted to identify the essential components required for an effective ACL IPP[9,16-31]. Based on a comprehensive review of this literature, OA Action Alliance injury prevention experts recommend that the following six core components: (1) lower extremity and core strengthening; (2) plyometrics; (3) continual feedback to athletes regarding proper

technique; (4) sufficient doses; (5) minimal-to-no additional equipment; and (6) balance training along with optional components of stretching and agility exercises be included in a structured warm-up to maximize effectiveness of ACL and lower extremity IPP's for youth athletes.

MATERIALS AND METHODS

We performed a systematic literature search for all relevant articles from 1960 through January 2017 in PubMed, Web of Science and CINAHL. The search strategy combined the Medical Subject Heading (MeSH) and keywords for terms: (1) ACL OR "Knee injury" OR "anterior cruciate ligament"; (2) "prevention and control" OR "risk reduction" OR "injury prevention" OR "neuromuscular training"; and (3) meta-analysis OR "systematic review" OR "cohort study" OR randomized.

We found 166 different titles. The abstracts were reviewed for pertinent papers. In addition, we performed a manual search of references from reports of randomized controlled trials (RCTs), prior meta-analyses and review articles to identify additional relevant studies. Articles published by the authors of this paper were reviewed for relevant citations. The authors reviewed the search and suggested other papers. All were found in the search criteria.

To be included the paper needed to be a randomized control trial, systematic review or meta-analysis on the effectiveness of IPP for the prevention primarily ACL injury or secondary lower limb injury prevention.

The papers were reviewed by at least two authors and consensus of best practice for IPP to prevent OA was obtained by conference calls and e-mail discussions. All authors participated in the discussion.

RESULTS

Based on a comprehensive review of this literature, OA Action Alliance injury prevention experts recommend that the following six core components: (1) lower extremity and core strengthening; (2) plyometrics; (3) continual feedback to athletes regarding proper technique; (4) sufficient doses; (5) minimal-to-no additional equipment; and (6) balance training along with optional components of stretching and agility exercises be included in a structured warm-up to maximize effectiveness of an ACL and lower extremity IPP's for youth athletes.

Lower extremity and core muscle strength training

We note that hamstring/quadriceps ratio is a noted risk factor for ACL injuries[32]. Hence, these muscle group are considered to be an important risk factors for an ACL injury[16,21,25,32-34]. Eccentric hamstring exercises such as Russian/Nordic exercises should be incorporated as it has been proven to increase hamstring/quadriceps strength ratio and improve eccentric hamstring torque and isometric strength[18,25]. Core strengthening, such as planks, aid in preventing injuries[16,19,23,25,35-40]. It is key to have continual feedback to ensure proper technique with the use of body-weight exercises that focus on the trunk and hamstring strength[26,41].

Plyometrics

Plyometrics is an essential component in an IPP. Studies have shown that oth balance and plyometric training reduces peak valgus knee moments[25], this improves in an athlete's motor control during side-stepping and/or single leg landing tasks. Sports specific Neuromuscular Training (NMT) that focuses on jumping and landing tasks improves ground reaction force and stance time as well as unanticipated cutting maneuvers are important[26,27]. Since excessive medial knee displacement is considered to be a risk factor for an ACL injury, it is important for NMT to include exercises that involve the entire kinetic chain of the lower limb which can be individualized for the team and practice facility[12,26]. Plyometric exercises in programs have included jumping forwards and backwards, jumping side to side, tuck and scissor jumps, and single leg squats[18].

Continual feedback

Prevention programs applying both proprioception and technique modification are effective in reducing ACL injuries[26,31,42,43]. Education and verbal feedback from athletic trainers regarding proper technique has shown to decrease peak vertical ground forces from landing (soft landing with bent knee, knee in alignment with the second toe, and proper deceleration techniques) and is a large contributor to the success of IPP's[8,27,34,44]. An external focus (EF) for the acquisition and control of complex motor skills required for sport with positive over negative feedback is recommended[45].

Sufficient doses

IPP need time to take effect therefore at least 6 wk (10 to 15 min at least 3 d per week) should be given for lead time (ideally during a preseason) and then continued during the season with less frequency (1-2 times a week)[8,26]. NMT programs performed for longer times per day and more frequently demonstrated greater NMT prophylactic effects[46] but lower compliance. Combining pre-season and during season is the most effective process to reduce ACL injuries rather than either NMT programs alone[46].

Besides the frequency of IPP's, compliance rates play a major role. Coaches are more likely to perform a 10 min IPP than 20 min or longer[47]. High compliance rates showed 35% lower risks and 39% risk reduction rate compared to intermediate compliance rate[46,48]. Moderate to strong evidence exists to support the importance of compliance especially consistent attendance by involved athletes and commitment to the completion of sessions throughout the intervention period contributed to the effectiveness of the IPP[48,49]. There are fewer ACL, acute knee, and lower extremity

injuries when there is higher compliance rates with the IPP[27,48,50]. We recommend a shorter 10 min program started in the pre-season and continued through the season every week as part of the standard warm-up.

Minimal-to-no additional equipment

A number of neuromuscular warm-up strategies do not require the acquisition of additional equipment, such as a balance board, to produce an effective IPP[35]. Drawbacks of some IPP's is the need for additional equipment, most notably many teams lack this equipment and resources may preclude compliance among participants of IPP[16,35]. Utilizing additional equipment has not shown significant reduction in lower limb injuries[35]. Therefore, we recommend that the best practice IPP have no additional equipment needs.

Balance exercises

Some studies have found prevention programs that only apply balance training did not significantly reduce the overall lower limb injury rate reduce or to modify risk factors for ACL injuries despite good athletic adherence to the intervention[25,42,51]. However, there have been randomized control trials that have shown that balance exercises might be efficacious in preventing other lower extremity, such as ankle ligamentous injuries[25,35]. Balance exercises demonstrated a 41% reduction in ACL injury rate compared to a 66% reduction by preventive NMT without balance exercises[18]. The effectiveness of balance exercises can be enhanced when utilized in conjunction with proprioceptive exercises[17]. We recommend that balance training be done in conjunction but not alone to prevent ACL injuries.

Stretching exercises

Current evidence suggests that stretching alone may confer no injury prevention benefit[35]. A review found that greater durations during an IPP that static stretching was performed was associated with a lower risk for non-contact ACL injuries[30]. We note that one study greatly affected their analysis[30]. There is not enough evidence to support static stretching in ACL injury prevention, although dynamic stretching may be beneficial for other reasons, including perceptions about flexibility[30,35,42]. In conclusion, additional research is needed to understand how stretching influences risk for ACL injury. We recommend stretching as an optional exercise, with dynamic stretching being emphasized over static stretching.

Agility exercises

There is not enough evidence to support agility exercises in ACL injury prevention. However, there is evidence to suggest that the addition of this component provides beneficial effects of reducing non-contact ACL injury rates in sport-specific training by increasing the emphasis and duration of agility training[26,30]. In order to improve lower extremity neuromuscular control/balance, specific drills targeted at improving running technique and coordination could be targeted[25].

DISCUSSION

Unfortunately, ACL injuries are commonly encountered in various sporting activities. The mechanism of ACL injury can be categorized as contact and non-contact[17]. Contact ACL injuries are non-preventable, but utilizing lower limb and ACL IPP's can prevent non-contact ones. Prevention of such injuries is essential given the long-term effects and high economic costs for the patient and health care system[42]. Much of literature focuses on female athletes as equivocal data exists for male athletes[42]. This is because there is a paucity of literature available and controversial data on the effectiveness of IPP's modifying risk factors for ACL injuries and injury reduction rates[42]. However, it is firmly established that IPP's successfully reduce noncontact ACL injury incidence rates in female adolescent athletes[27].

Current evidence supports that the implementation of NMT and decrease in ACL tear incidence is age-related[20]. The change in biomechanics and the onset of ACL injuries indicate that there is a potential optimal time to start these programs. This would be before the onset of changes in biomechanics and increase in ACL injuries[20]. Therefore, initiation of IPP should be during early adolescence prior to these changes[20].

Regardless, it is imperative that IPP's incorporate a wide variety and combination of strategies to help target ACL injury prevention. The comprehensive review of both systematic and meta-analyses studies are discussed in order to identify the best practice features of an ACL and lower limb IPP and determine the six essential components: (1) lower extremity and core strengthening; (2) plyometrics; (3) continual feedback to athletes regarding proper technique; (4) sufficient doses; (5) minimal-to-no additional equipment; and (6) balance training along with optional components of stretching and agility exercises that are required to help protect the athlete from sustaining such traumatic injuries.

Lower extremity and core muscle strength training

Of the lower extremity components, hamstring injuries are fairly commonly. The hamstrings are noted to be an antagonist of the quadriceps and provide a protective posterior force on the tibia[18]. The ACL's anteromedial bundle is under the most tension during the last 30° of knee extension, therefore this posterior force could be protective by decreasing anterior translation[18]. The quadriceps muscle contraction *via* the patella tendon-tibia shaft angle determines the anterior shear force that is generated during knee extension as well as during the contact phase of landing[18]. Inherently, there exists an aberrant ratio of hamstrings to quadriceps neuromuscular activation[18,26,27,35]. In order to reduce such forces, programs should incorporate exercises

such as isometric warm-up exercises, hamstring flexibility, and eccentric strength training (Russian/Nordic hamstring exercises), walking lunge, and single toe raise (gastrocnemius/soleus exercises) increase the muscle power to stabilize the knee to reduce injuries[17,18,25,35].

Core strength is another important factor in reducing the risk of other injuries[35]. Evidence supports that core muscle weakness may raise the risk of groin strain and knee joint injuries[18,35]. Athletes who injured their ACLs were noted to have increased lateral trunk flexion and knee abduction angles[18]. Exercises incorporating planks (front and side), sit-ups and abdominal curl are important[18,35].

Another risk factor that should be targeted is excessive knee valgus motion. Certain movements in a sport adds stress to the medial passive and active stabilizing knee structures that predisposes one to an ACL injury[26]. Specific NMT of the entire kinetic chain of the lower limb that are targeted for individual sports and their specific conditions of play are particularly required[26]. For example, female basketball players exhibit increased medical knee displacement than female soccer players due to increased internal ACL loading[26]. Therefore, it is important to have sport specific NMT focusing on jumping and landing tasks as well as the stop phase of a sidestep cutting maneuver for basketball that are based on ground reaction force and stance time data[26].

Furthermore, the importance of ankle injuries can not be ignored. There is sufficient evidence that balance exercises might be effective in preventing ankle ligament injuries[52]. Exercises that focus on the dynamic balance and strengthening such as single leg balance exercises. This can be performed by standing on one leg while throwing a ball with a partner, resisting a push from a partner while balancing on one leg, hopping across a line on the field or court, and one legged squat exercises should also be added[35]. A program involving a combination of balance, eccentric hamstring, plyometrics and strength exercises could be efficacious in preventing lower limb injuries[25]. Therefore, there is consensus that a multifaceted exercise program that is aimed at reducing general lower limb injuries is efficacious especially when combining strengthen and proximal control training[18,25].

Plyometrics

NMT programs utilizing plyometric exercises and a preseason component were noted to be most beneficial[10,26]. Plyometric exercises often incorporate sidestepping and/or single leg squats, jumping forwards and backwards, jumping side to side, and tuck and scissor jumps[18,25]. This is to target the elevated knee abduction moment as well as to increase the knee flexion range by focusing on increasing power, muscle strength, and speed and improving motor control to reduce the peak knee valgus moments[8,12,17,18,25]. Evidence shows that there is a 17%-26% reduction in ground reaction force on landing after 6-9 wk of training along with asymmetrical landing patterns reducing the side to side asymmetry landing force[18]. This is especially important considering that high ground reaction forces are identified as one of the risk factors for future non-contact ACL injuries in female athletes[18]. Overall, individual components of NMT programs such as plyometrics, strengthening, and proximal control training have been estimated to lead to ACL injury risk reduction of 61%, 68%, and 67% respectively[18].

Continual feedback

Continual feedback on proper technique by the certified athletic trainer or sports physical therapist has been shown to be efficacious in reducing ACL injuries. The benefit may best be seen in sports with emphasis on landing and cutting maneuvers by altering landing patterns in frontal plan[18,26], with the use of plyometric exercises to teach proper landing technique. Vocal cues during plyometric exercises such as "land light like a feather" can emphasize soft landing with the proper positioning of knees bent, patellar alignment with the second toe, and proper deceleration[8,18,27]. Emphasis on biomechanical technique correction and individualized feedback that athletes receive appears to be a central element among the most successful programs that reduce ACL injury rate[34].

Sufficient doses

For a NMT program to be successful, frequency and duration as well as adherence to the program is vital in reducing ACL injuries. The actual number of completed training sessions is likely more valuable than the prescribed number of sessions when considering the effectiveness of programs[53,54]. Evidence supports prevention program should be performed two (2) or more times a week for a minimum of six weeks[26]. Duration longer than 6 wk does not necessarily improve the effectiveness of the programs[34]. Current analyses suggest performing preventive NMT interventions less than 20 min per session once a week during in-season can reduce 38%-39% of ACL injury risk[46]. Fewer than two NMT session per week during the in-season without previous 6 wk pre-season NMT workouts of more than one session per week is less likely to demonstrate the prophylactic effects on ACL injury reduction than two or more sessions for 6 or more weeks[46]. In addition, the IPP studies with statistically significant reductions in ACL injury rates had athletes performing preseason neuromuscular training[53,54]. Therefore, it is recommended that a NMT program be performed for 10 to 20 min (higher compliance is seen with the shorter 10 min) at least two days per week in the preseason and at least 1 session per week during the season.

Additionally, better compliance is needed for sufficient training effects to reduce injuries[35]. Compliance is a major issue and one should monitor the compliance for

the training program to ensure the desired protective transformations in reaction times, fatigue resistance and the correct movement patterns is obtained[26,55]. Adjustment to the program may be needed if compliance diminishes to fit the individual team needs. There is an inverse dose-response relationship seen between NMT compliance and incidence rates of ACL injury[12,49,50]. More specifically, it was noted that athletes with a low or moderate compliance rate had a risk of injuring their ACLs 4.9 and 3.1 times greater, respectively, than their counterparts who had high compliance rates[49]. It is also speculated that the decrease in player compliance as the season progresses may be due to reduction of player attendance at training sessions over the season[55]. In order for an ACL IPP to be effective, the overall compliance rate needs to be more than 66%[49].

The importance of player level compliance in addition to team compliance is sometimes underestimated[55]. It is possible that that motivational barriers and facilitators among coaches over the entire season may need to be further investigated in order to maintain a high compliance rate for the NMT program[55]. Consistent attendance by involved athletes and commitment to the completion of NMT throughout the season contributes to the effectiveness of the IPP[49]. We recommend addressing issues of compliance with coaches and administration to determine reasons for reduced compliance and in order to correct these barriers.

Minimal-to-no additional equipment

A number of neuromuscular warm-up strategies do not require the acquisition of additional equipment[35]. Balance work (using balance boards) and neuromuscular exercises (without balance boards) revealed that ankle sprains were reduced by 36% and 50%, respectively[35]. However, neuromuscular strategies alone can reduce injuries without requiring the need to purchase additional equipment which would require resources many teams do not have available to them[35]. Since a NMT programs can be performed with similar outcomes with and without additional equipment, we recommend no additional equipment.

Balance exercises

We recognize that in one review balance was associated with worse outcomes from IPP but this association was only with total hours of balance training and this was skewed by the inclusion of one study with an excessive amount of balance training[30]. Balance exercises are considered effective when used in conjunction with other types of exercises for IPP[18,26,35,42,51,56]. There is strong evidence for the prevention of ankle ligament injuries for the use of neuromuscular control and balance exercise, in addition a multifaceted program for the prevention of lower limb injuries[25]. Balance programs may reduce ankle injuries, but the effects could be enhanced by utilizing proprioceptive exercises[17,25,30].

Additionally, balance training may be required to build proximal segment stability in order to further enhance trunk control[18]. An asymmetrical landing pattern and landing favoring one foot is a risk factor for ACL injury which can be altered by incorporating balance training along with plyometrics[18]. Balance training demonstrated improvement in the center of pressure measurements and a reduction in GRF during a single leg landing[18]. Balance and plyometric training improve an athlete's motor control during tasks like sidestepping and/or single leg landing, reducing peak valgus knee moments (a risk factor of non-contact ACL injuries)[25]. Therefore, NMT programs that incorporate plyometrics, and strengthening exercises have demonstrated effectiveness in reducing ACL injury risk factors[16,17].

Stretching exercises

Stretching during warm-up routine before exercise has been historically advocated to prevent injury[35]. However, current evidence time and again does not support static stretching alone for injury prevention benefit[35]. Although studies have shown that static and dynamic stretching may have a positive impact on reducing injury rates when performed in an ACL prevention program[30]. Previous studies have found that static stretching has no overall impact on preventing general musculoskeletal athletic injuries, but may have some relationship with reducing ligamentous injuries[30]. Perhaps a beneficial effect in ACL injury reduction could be due to static stretching modifying the structural properties of ligamentous tissues[30]. One downside of eliminating stretching from an IPP is athletes believe stretching is an essential part of an IPP and removal might decrease compliance[57].

Agility exercises

Agility exercises are activities that improve the ability to move and change direction under control both quickly and effectively[30]. Increasing the emphasis and duration of agility training in an IPP is beneficial in reducing non-contact ACL injury rates[30,35,43]. Lower extremity mechanics during landing and cutting tasks are affected by a fatigue-producing agility training programs[30]. Therefore, timing of the agility training intervention may be important. Specific agility exercises like shuttle run, diagonal run, bounding run or zigzag running with pressure technique should be supplemented by landing technique with feedback so that the players learn to avoid the high-risk landing and cutting positions[26,35,43].

Limitations

A comprehensive review of literature containing both systematic and meta-analysis studies contain different limitations. The combination of mixed design studies can lead to difficult interpretations and incorrect results[17]. Furthermore, the heterogeneous treatment protocols with exercise programs having varying intensity levels is another concern[17]. Most of the studies can be

generalized to only the young female population as there is a dearth of studies on the males[18]. Additionally, the limitations of systematic review include those inherent in determining the results of studies of varying design (*e.g.*, frequency, duration, and start of training); how the training was performed; who supervised; the components of the training program; and how exposure data was determined[7,27,46,49]. To identify the exact essential exercise for IPP that are responsible for the reduction of injury incidence is not possible because of these inconsistencies. Furthermore, different types of neuromuscular training were applied to different sports, ages and study designs which makes the analysis challenging to identify imperative aspects of neuromuscular training[7,46].

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Thank you to Jennifer Hootman.

COMMENTS

Background

Sports participation can increase the risk for injuries to the lower limbs especially the anterior cruciate ligament (ACL). When utilizing injury prevention program (IPP)'s, a variety of strategies to help target risk factors can be crucial in reducing the number of knee and ACL injuries, and therefore future knee osteoarthritis (OA). A comprehensive review of multiple systematic reviews and meta-analyses have identified the essential components to be lower extremity and core strengthening, plyometrics, continual feedback to athletes regarding proper technique, sufficient doses, minimal-to-no additional equipment, and balance training along with optional components of stretching and agility exercises to be included in a structured warm-up to maximize effectiveness of an ACL and lower extremity IPP's for youth athletics. The authors believe that participating in 10 min of IPP most days of the week that contain these features will diminish knee OA and reduce health care costs.

Research frontiers

The authors recommend future studies looking at compact 10-15 min programs in multiple groups and ages followed out for many years to determine the reduction of knee OA and health care costs.

Innovations and breakthroughs

IPP's have been important in modifying inherent risk factors in athletes to help reduce the number of ACL injuries and subsequent OA. Retrieved literature has provided an in depth overview of the various techniques that are pertinent in the various strategies utilized in IPP's.

Applications

This review suggests that IPP's should contain the six strategies in order to be effective in preventing athletes from sustaining ACL and lower limb injuries and subsequent OA. These should become incorporated into every high-risk sports training program.

Terminology

IPP's that incorporate a variety of strategies in NMTs to help target risk factors can be crucial in reducing the number of ACL and lower limb injuries sustained and subsequent OA.

Peer-review

The authors provide comprehensive study on lower limb injury prevention.

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