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ACL Injury Prevention: Where Have We Come From and Where Are We Going?

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Abstract

Anterior cruciate ligament (ACL) injuries are one of the most common and severe knee injuries across sports. As such, ACL injury prevention has been a focus of research and sports medicine practice for the past three plus decades. Examining the current research and identifying both clinical strategies and research gaps, the aim of this review is to empower clinicians and researchers with knowledge of where the ACL injury prevention literature is currently, and where it's going in the future. This paper examines the mechanism of ACL injury prevention, screening, implementation, compliance/adherence, techniques for improving implementation , COVID-19, and areas of future research. *Clinical significance:* The time lag between research and practical implementation in general healthcare settings can be as long as 17 years, however, athletes playing sports today are unable to wait that long. With effective programs already established, implementation, and adherence to these programs is essential. Strategies such as coaching education, increasing awareness of free programs, identifying barriers and overcoming implementation obstacles through creative collaboration, are just a few ways that could help improve both ACL injury prevention implementation and adherence.

Key Words *(limit 5): Anterior cruciate ligament, knee, sports,*

Introduction/State of the research

Anterior cruciate ligament (ACL) injuries are one of the most common knee injuries in sport. ACL injuries have doubled over the last two decades, despite the efforts of researchers and clinicians to mitigate risk. [1] Approximately 200,000 to 250,000 ACL injuries occur annually in the United States,[2] costing of over $13,000 USD per surgery.[3] Nearly a quarter of those injuries occur in children under the age of 18.[4; 5] While the overall incidence of ACL injury is greater in men, primarily due to greater participation in contact and team sports, the relative risk of ACL injuries in women is 2 to 8 times greater than men.[4; 6]

ACL injury prevention, namely in female athletes, has been well investigated for over three decades.[7-13] Most of these neuromuscular training programs include a variety of strengthening, plyometric and agility-based drills that address deficits commonly associated with female athletes who have sustained an ACL injury.[14; 15] Several programs, such as the 11+ (formerly known as the FIFA11+),[16; 17] its predecessor the PEP program,[18] and the Knäkontroll or Knee Control program,[19; 20] were designed as dynamic warm-up to increase implementation fidelity, compliance and adherence.[21; 22] Other programs, including the Sportsmetrics program,[23] were designed as stand-alone programs to be performed outside the training environment.

For an IPP to be effective, the design must consider biomechanical, physiological, socio-economic, psychological and ease of implementation perspectives.[24-26] Although a number of intrinsic and extrinsic risk factors for ACL injury have been proposed, biomechanical risk factors have been a focus.[27; 28] Most IPP's attempt to alter dynamic loading through neuromuscular and proprioceptive training.[29-33] The studies that have focused on altering pathokinematics have largely resulted in a reduction of ACL injuries.[8; 9; 14; 19; 34-36] However, ACL IPP studies vary widely both in their approach to injury prevention and their study design validity. Very few studies to date have been conducted as randomized, controlled trials. [37; 38]

Mechanisms of Prevention

There is a great deal of research focused on the mechanism of ACL injuries; with some risk factors, such as sex, age, and sport, having more evidence than others.[39] Unfortunately, without a complete understanding of the risk factors and mechanism of ACL injuries, researchers and clinicians alike are also without a complete understanding of what exactly makes ACL IPPs effective. Multiple meta-analyses have found that effective ACL IPPs include both strength and plyometric exercises, with mixed results on whether balance training is necessary for ACL injury prevention.[40-42] Although balance exercises may not,[40; 43] proximal control exercises (defined as exercises that involve segments proximal to the knee joint) also seem to improve the efficacy of ACL IPPs.[43] Such results could indicate that strengthening, particularly hip and core musculature, could be key in making an ACL IPP effective. However, the interdependence of program components is not well understood, and more importantly, understanding components' efficacy doesn't necessarily give deep insight into the actual mechanism behind ACL IPPs' effects.

Stiff landings (large vertical ground reaction force, shallow hip and knee flexion) are associated with increased knee joint forces, however purely sagittal plane forces likely do not injury the ACL.[44] More so, frontal and transverse plane biomechanics, such as medial knee displacement[45] or valgus collapse (hip adduction, hip internal rotation, and knee abduction),[46; 47] may be associated with ACL injuries. Thus, researchers hypothesized that effective ACL IPPs would change frontal and transverse plane biomechanics. Interestingly, a 2018 meta-analysis found peak knee abduction moment was the only frontal plane variable impacted by ACL IPPs.[48] More often ACL IPPs seemed to change sagittal plane variables, including increased hip flexion (at peak and initial contact), increased peak knee flexion angles, and decreased peak knee flexion moment.[48] There are a number of limitations to biomechanical studies which must be considered when interpreting the ACL IPP biomechanical literature, including: the use of double vs. single limb tasks; non-sport-related tasks; anticipated vs. unanticipated tasks; testing in a laboratory vs.

on a court or field; a lower cognitive demand during laboratory-based tasks; a lack of retention testing; the analysis of only one limb vs two; and many more.[48-50] *Regardless, further exploration is needed into if changing biomechanics is the mechanism of ACL IPPs.*

Whether learning a new task or becoming more efficient, it is logical that for an athlete to change their movement pattern there must be a change in their brain/neural activity.[51] Thus, motor control, neuroplasticity, and brain-behavior have recently garnered more attention, particularly with respect to ACL IPP's mechanism. Grooms et al.[52] found that the augmented neuromuscular training program led to decreases in hip adduction during cutting which was related to decreased activity in knee sensory-visual-spatial and motor planning areas; and that decreases in hip adduction and knee rotation were associated with decreased motor cortex activity.[52] Decreases in motor cortex activity suggest greater efficiency in processing, potentially improving transfer of practiced patterns to complex sporting environments. In a subsequent larger study, Diekfuss et al.[53] found that the augmented neuromuscular training group had larger decreases in peak knee abduction moment then the control group (performing the Sportsmetrics program). The training group also had increases in functional connectivity between brain regions of interest, where the control group had no changes. These studies[52; 53] and others[54] suggest that changes in brain-behavior may be related to changing biomechanics. In particular, employing motor learning principles may make greater biomechanical changes that are also unconscious, allowing the athlete to remain focused on their sport. *While the downstream effects on ACL IPP effectiveness need to be explored, the areas of brain-behavior change and motor learning within ACL IPPs are exciting.*

Historically motor learning principles haven't been a focus in ACL IPP design. While the augmented neuromuscular training discussed in the last paragraph[52; 53] requires significantly technology, employing simple motor learning techniques are possible with minimal/no cost. For example, cues directing an athlete's attention externally are effective at changing movement patterns and may better facilitate movements remaining automatic.[53; 55; 56] Interestingly, the 11+ manual displays pictures of "proper" movement patterns and gives directions such as "Make sure to keep your upper body straight; your hips, knees, and feet should be aligned; DO not let your knees buckle inwards,"[17] all cues which direct focus internally. In contrast, the originally published Sportsmetrics program used external cues such as "Straight as an arrow," "Light as a feather," "Shock absorber," and "Recoil like a spring."[57] These cues are external cues, directing the athlete's attention outside their body, and are analogies, a technique known to facilitate implicit learning.[58] Implicit learning means an athlete develops an internal picture or understanding of a movement/task, rather than following rules or an order of operations. Implicit learning is also known to be effective in promoting automaticity and allowing athletes to better dual task and handle stress.[58] As of yet, there are no studies comparing external and internal cuing as they relate to ACL injury prevention, however *external focus of attention/external cueing and implicit learning are easy strategies that can be implemented with little to no equipment and represent aspects of motor learning that clinicians and researchers should continue to explore.*

Video and real-time visual feedback are other techniques that have been explored in ACL injury prevention.[56; 59-61] To name a few, Harris et al.[62] found that behavior skills training with video feedback improved young female soccer players' skill and retention of a zig-zag drill. The augmented neuromuscular training program used by Grooms et al[52] and Diekfuss et al.[53] projected a rectangle which deformed in real-time based on the athlete's trunk, hip, and knee movements, but the athletes were not given any instructions or explanation regarding the rectangle. Video-based prevention strategies have limitations, in particular these strategies are easier to implement on individual basis and require more equipment. Further, Benjaminse et al.[61] found that male basketball players receiving video feedback had changes in their movement patterns, but female players may need different feedback modalities. *The successes of video and real-time feedback studies seem to support further investigation and attention, as well as corroborate the integration of motor learning principles into ACL IPPs, be that through verbal cues, small sided games, video or virtual reality.*

Mechanism of ACL IPP
Clinicians/Practitioners
• Effective ACL IPPs include strengthening, plyometric, proximal control, and sometimes balance components. • Using external cues, directing the athletes' attention outside their body or to the outcome can facilitate changes in biomechanics and movements remaining unconscious. • Motor learning principles, such as external focus of attention and implicit learning may be easily implemented in ACL IPPs and require little training and no equipment. • Video or real-time feedback, particularly when working with an athlete individually, may be beneficial in changing movement patterns and another technique to integrate motor learning principles into ACL injury prevention.
Researchers
• The interdependence of ACL IPP components is not well understood, nor the mechanism behind effective ACL IPPs. • Although some ACL IPPs have demonstrated changes in biomechanics the relationship between efficacy and biomechanical change is still not well understood. • Further research into the relationship between brain-behavior changes and biomechanics as well as the downstream effects on ACL IPP efficacy is needed. • The integration of motor learning principles into existing or new ACL IPPs could improve efficacy as well as implementation. • As technology rapidly develops, video, real-time feedback, and virtual reality may be exciting areas of ACL IPP research.

Screening

Identifying ACL injury risk is a controversial topic. A 2016 article by Roald Bahr[63] highlighted the need for proper use of screening test properties, and currently there is a recognition in the research community that no test(s) can accurately predict ACL injury risk.[63] A number of factors contribute to the absence of accurate screening tests. Without clearly identified risk factors or the interaction thereof, it is very difficult to know what variables are needed to screen. Further, screening studies require large sample sizes, and tests do not yet have the sensitivity and specificity to recognize injury risk.[64; 65] Thus, while there may be value in big data and newer methodologies, such as computer learning algorithms, there is yet to be a proven ACL injury screening tool.

Cost is a significant barrier to ACL IPP implementation but also to screening. *Research currently indicates that it is more cost effective to implement ACL IPPs in all athletes, than to screen and select athletes at risk.*[66-68] One study modeled four hypothetical strategies for ACL injury prevention in Australia.[66] The model found that implementing ACL IPPs in all athletes aged 12-25 involved in high risk sports (rugby, Australian rules football, netball, soccer, basketball, and skiing), not only prevented nearly $700/person in future health care costs, but also had the lowest number needed to treat, and prevented the highest number of future knee injuries and total knee replacements.[66]

In addition to identifying athletes at high risk for injury, screening is also used to identify areas for ACL IPP individualization. Particularly in elite sport where more resources (staff, equipment, and time) are available, programs are tailored to what the medical/performance team deems to be the athlete's "needs." Whether programs are tailored strength training[9,30] or based on biomechanics,[69] *further research is needed into the efficacy of individualized ACL IPPs*. Individualized ACL IPPs are much harder to study as each cohort is N=1. However, from a motor learning standpoint giving each athlete the opportunity to find their own motor solutions to movement problems may be more effective.[56; 59; 60] ACL IPPs looking to foster neuroplasticity must facilitate exploratory learning, which could involve video, small sided games or creation of representative learning environments.[56; 70] *ACL IPPs such as these could capture coaches attention as they would likely involve more technical skill work, however motor learning based ACL IPPs may also be more complex in their set up and design requiring collaboration between coaching and clinical/practitioner team, as well as subsequent efficacy research.*

Screening
Clinicians/Practitioners • Clinicians should be wary of tests or algorithms that claim to predict ACL injury. • It is more cost effective, both in implementation as well as in future health care costs, to provide ACL IPPs to all athletes than to screen and select at-risk athletes. **Researchers** • The use of big data and technologically advanced methodologies could enhance researchers/clinicians ability to identify athletes at higher risk for ACL injuries. • Greater understanding of ACL injury mechanism is needed to understand the complex relationship of risk factors and situational influence. • Although difficult to study in a large scale, the efficacy of ACL IPP individualization is needed.

Implementation

ACL injury prevention is possible, or more precisely, the risk of an ACL injury can be reduced in many sports.[71-74] With good research support to back the use of ACL IPPs, but not screening, the challenge for clinicians and researchers alike is to prove effectiveness in real-world settings. Implementation success takes time. In general health research, the time lag between successful program delivery and use in practice can be as high as 17 years.[75] There are a few studies, such as the Norwegian female handball ACL injury prevention study, that follow successful implementation of an ACL injury prevention program (ACL IPP).[76] In the study's first season coaches delivered the neuromuscular training program. As compliance was low, physical therapists took charge of program delivery during the second intervention season, increasing the compliance and successfully reducing ACL injuries. Following the study, responsibility shifted back to the coaches to continue the IPP. Unfortunately, the number of ACL injuries increased to even higher than pre-intervention. To mitigate this negative trend, the researchers organized a series of regional coaching seminars, free of charge, to increase knowledge and improve attitudes. The coaches received an instructional DVD and both the prevention and performance benefits were emphasized. Thirteen years after the intervention, the number of ACL injuries among the same group of female athletes was reduced by 50%. The injury reduction was attributed to increased coaching awareness, a new study showing a 50% reduction in severe knee injuries bolstering coaches' "buy-in", increased media attention, and a new prevention webpage.[76] However, this "success story" is not normal.

Over the last 10 years, the 11+ has been widely distributed by FIFA (Fédération Internationale de Football Association), which theoretically would increase the global exposure of the IPP in the soccer community.[16] However, in a study among amateur soccer coaches in Germany more than half of the coaches were unaware of the 11+.[77] In most sports, the coach is key for IPP implementation and compliance, especially amongst non-elite and youth athletes, where fitness or medical staff are not as robust. Thus, a lack of coaching awareness emphasizes the importance of improving the knowledge translation from national sport federations to local sports clubs. It also emphasizes the value of coaching education. *Coaching education programs should include both theoretical and practical use of ACL IPPs to ensure better knowledge of available programs as well as how to use and implement them.*

The 11+ is an effective IPP, but several studies have pointed out barriers to implementation. O`Brien and Finch[78; 79] analyzed the injury prevention perceptions of soccer coaches, fitness coaches and physiotherapists from youth male soccer academies[78] and from professional male soccer teams in 4 different countries.[79] All participants fully supported the use of IPPs, acknowledging the need for prevention programs, and agreed that to enhance the impact of IPPs requires a detailed understanding of each team's specific implementation context. Among the youth soccer staff, the impression was that the 11+ needed modification to achieve a better reach; including suggestions like modifying the program's content to contain more challenging exercises, as well as greater exercise variations and progressions.[78; 79] A survey of female soccer coaches in the US found that cost was the primary barrier to IPP implementation.[80] Dix et al.[80] elaborated that "cost," was probably not the cost of the IPP itself, since most prevention program are available for free. Rather, many coaches who did not use an ACL IPP viewed IPP implementation as not a coaches' responsibility, thus cost was associated with hiring additional staff, such as fitness staff.[80] Coaches who did not use an ACL IPP also identified a lack of practical training in instructing an IPP as a barrier.[80] *These findings further support including ACL IPPs in coaching education, but also improving awareness that many ACL IPPs are free, and effective regardless of whether implemented by a coach or by a medical professional.*[68]

A study from Canada examined facilitators and barriers to implementation of the iSPRINT program among junior high school athletes,[81] a program previously shown to reduce the risk of sport related injury in youth.[82] Facilitators of implementation success included evidence strength and quality, adaptability, implementation climate, culture and having a high level of compatibility. Barriers to implementation included intervention complexity, planning and readiness for implementation. Statements like the IPP was "too time consuming" or "boring" are also well-known barriers.[83; 84] Thus, strategies to help implementation may include modifying the program, decreasing the number of components, or reducing the equipment required.[81]

Researchers could consider developing shorter, yet still effective programs. *Clinicians/practitioners working with teams should collaborate with coaches, athletes, parents, and other stakeholders to identify barriers and strategize implementation solutions.* It is important keep in mind, though, that changes or modifications the content of a IPP should be followed by a re-evaluation of the program's effectiveness.[85]

Implementation

Clinicians/Practitioners

- Coaching education should include background on ACL IPPs, the benefits of program use, as well as instructions on how to teach the program to their team(s).
- Coach-led ACL IPPs can be as effective in preventing injury as ACL IPPs led jointly by coaches and medical staff.
- Most ACL IPPs are free!
- Key stakeholders, including clinicians/practitioners, coaches, parents, and athletes should work together to identify barriers and collaborate to strategize implementation solutions.

Researchers

- Common barriers to implementation include, duration and number of components, thus developing and testing shorter ACL IPPs could help facilitate use.
- In some environments, such as soccer academies, developing programs with more challenging components and a greater diversity of exercises and progressions could facilitate ACL IPP implementation.

Compliance / Adherence

The effectiveness of any intervention is determined jointly by its efficacy and user adherence.[85] Adherence and compliance are terms often used interchangeably, however have important differences (Table 1).[86] Many studies have proven that severe knee injuries can be prevented,[42; 87; 88] however few studies have investigated the compliance, and none, to the authors knowledge, have examined adherence.[89] Soligard et al.[9] testing the effect of the 11+, found a 32% reduction of injuries among female youth soccer players. In a secondary analyses comparing players with a high compliance (1.5 session per week) to players with intermediate compliance (0.7 sessions per week) they found that players with high compliance had a 35% lower injury risk.[89] Such findings were echoed in data from Canada[90] as well as by Silvers-Granelli et al.[89] who found the same pattern in collegiate male soccer players; higher program compliance lead to greater benefit with respect to decreased injury risk and severity of injury.

The Swedish Knäkontroll study found an impressive 64% reduction ACL injury risk among female youth soccer players.[72] The compliance analyses showed that players with high compliance had significantly reduced ACL injury risk compared to players with low compliance.[19] *Thus, the relationship between high compliance and reduction of injuries is clear, however more real-world strategies to improve compliance are needed.*

Table 1

Compliance and Adherence as defined by McKay and Verhagen[86]
Compliance – "refers to the act of an individual conforming to professional recommendations with regard to prescribed dosage, timing, and frequency of an intervention." **Adherence -** "is a process influenced by the environment, recognizing that behaviour is shaped by social contexts as well as personal knowledge, motivation, skills, and resources."

Techniques for Enhancing Implementation, Compliance, and Adherence

O'Brien and Finch stated: "To succeed in implementing the prevention exercises we need to understand how coaches, players and team members perceive the programs. Who should be responsible for injury prevention, when should it be performed, (who, when and how?). These questions need to be modified/customized to the sport and age group." [91] This quote touches on a progression that could help optimize IPP implementation, compliance, and adherence, *recognizing and taking responsibility, identifying the key stake holders and the culture, identifying barriers, strategizing solutions unique to the group.*

One successful strategy to bolster adherence is to let the IPP act as a warm-up.[92] Using the ACL IPP as a warm-up relies on high player attendance at training sessions to assure that most players get a “high enough” IPP dose to have a preventive effect,[93] however it also bolsters comradery and decreases reliance on individual motivation or behavior. A common complaint from coaches regarding ACL IPPs as warm-ups was that the programs took away valuable or limited training session time. In response, Whalan et al.[94] tested rearranging the order of the 11+. The study found that by *simply performing the strengthening portion of the 11+ after the training session (the dynamic stretching and running portions still used as a warm-up) player compliance improved and the number of severe injuries and total injury burden decreased.*[94]

Several studies have demonstrated an effect of the 11+ on athlete performance.[95-97] As coaches are key to implementation and compliance, particularly at the youth and non-elite levels, improved performance may act as another attractive message to coaches and players convincing them to use an IPP regularly. Further, in professional soccer injuries negatively influence the team performance,[92] *thus if reducing injuries and enhancing athletic performance are not enough to earn coach “buy-in,” improved player availability and team performance may*.

Using role-models is another way that approach prevention with both athletes and coaches. An Australian study found that community-level athletes respond to non-elite role-models, while coaches role-models are a combination of both high level and non-elite athletes.[98] Role-models that appeal to the coach’s moral obligations to keep the players healthy could be successful in bolstering ACL IPP implementationand adherence.[98]

Compliance/Adherence
Clinicians/Practitioners • There is a clear relationship between compliance with effective ACL IPPs and injury reduction.

- Clinicians/practitioners may find that education and discussions with coaches may be helpful in convincing them to implement an ACL IPP. In particular, education on the physiological and performance benefits of ACL IPPs as well as the benefits endowed by greater player availability may be convincing.
- Role-models may be beneficial for demonstrating and leading both players and coaches in ACL IPP implementation and compliance.

Researchers

- More information on ACL IPP dosage could allow for an understanding of a minimum dosage needed to achieve injury reduction as well as the dose-response relationship.
- Compliance and program fidelity should be reported in ACL IPP literature.

COVID-19

COVID-19 (2019 novel coronavirus, SARS-CoV-2) was declared a global pandemic in March 2020.[99] Due to the circumstances surrounding the COVID-19 pandemic, most countries suspended sport to mitigate the spread of infection, and many athletes found themselves in lockdown, unable to train outside or access gyms/facilities. Lockdown conditions represented a massive obstacle to attaining or maintaining optimal performance and physiological fitness. Suboptimal preparation and fitness are known risk factors for injury,[100-102] as is match congestion,[103-105] leading many researchers and clinicians to hypothesize that increased injury rates would occur upon return to sport after COVID-19.[106-109]

The Bundesliga in Germany was the first major sporting league to return to competition. In the first three weeks of matches post-lockdown, the injury rate increased three-fold, from 0.27 to 0.74 injuries per match.[110] Thus far, only anecdotal reports of increased knee injuries rates exist in young female athletes, but increased numbers of ACL injuries have been reported in the NFL.[111; 112] The only comparisons for the COVID-19 lockdown are to unanticipated season breaks such as the player's union strike in the NFL (National Football League).[113] Table 1 describes the ACL injuries in the pre- and regular season in 2011 after a lockout which shortened preseason and the 2020 COVID-19 shortened season. As predicted,[106-109] higher ACL injury rates have been observed, yet the full physical, psychological, nutritional and economic implications of the pandemic are still largely unknown.[114]

Table 1. Number of ACL injuries in the NFL seasons around the 2011 Lockout and 2020 COVID-19 affected season[111; 112]

	Preseason/Off-Season Organized Team Activities (OTA)	Regular Season/Post-Season
2010 (Full season)	64 Games/11 ACL injuries	331 Games/35 ACL injuries
2011 (NFL Lockout, Limited Preseason Training)	64 Games/13 ACL injuries	331 Games/35 ACL injuries
2012 (Full season)	64 Games/29 ACL injuries	331 Games/33 ACL injuries
2018 (Full season)	64 Games/ 13 ACL injuries	331 Games/21 ACL injuries
2019 (Full season)	64 Games/ 17 ACL injuries	331 Games/32 ACL injuries
2020 (COVID-19, Data as of January 3, 2021)	No Preseason Games/11 ACL injuries	256 Games/41 ACL injuries

Abbreviations: ACL Anterior Cruciate Ligament, COVID-19 2019 Novel Coronavirus, NFL National Football League, OTA Organized Team Activities,

It is critical for the sports medicine community to continue to guide athletes and sporting organizations as they resume training and competition. Balancing finances with the implications on athletes' health is obligatory. For example, scheduling an adequate preseason and avoiding match congestion are two well-supported risk mitigation strategies.[100-105] Fewer games means less revenue, however financial viability must be weighed against both the quality and safety of play. Especially for younger and non-elite athletes for whom games are not revenue generating, leagues/clubs should use meticulous caution in scheduling and planning seasons. After lockdowns, particularly if athletes are limited in their training intensity and volume, athletes may need another, or longer, preseason to rebuild their chronic loads and prepare them for the intensity of full team training sessions and games. Tournaments or periods of congested matches should not be scheduled until athletes have adequate fitness (both cardiovascular as well as rebuilt strength), with particular attention to young athletes who participate on multiple teams. *Whether via interpreting existing literature to ensure athletes build adequate fitness and physical preparation or explicitly implementing ACL IPPs, clinicians and practitioners must use their clinical reasoning and best judgement as there is no precedent and no research proven techniques to reduce ACL injuries after long lay-off periods, such as during COVID-19.*

COVID-19

Clinicians/Practitioners

- After a shortened preseason or preparation athletes are at a higher risk for injury.
- Longer, or a second, preseasons helping athletes rebuild their chronic load, and avoiding congested match schedules, may help in reducing athletes' risk.
- Clinicians and practitioners must use their clinical reasoning and best judgement to interpret and extrapolate from the existing literature in building evidence-informed return to play plans for their athletes.

Researchers

- To-date there are no research-backed protocols or programs for returning to sport after long lay-offs, such as lockdown. Post-COVID-19 return to play case-studies and case-series will be valuable for sharing successes and failures.
    - Although sometimes harder to publish, unsuccessful programs or protocols, may be as valuable to the sports medicine community as successful programs.

Future Directions

Beyond the areas already discussed, there are other gaps in the ACL IPP literature related to sports, sex, geographical region, race/ethnicity, as well as now the impact of COVID-19.

Much of the ACL IPP research is in soccer.[42] Some research exists in handball, as well as basketball and volleyball, however there are other high risk sports which need attention.[115] Approximately 20 million people play netball wordwide.[116] Predominantly a women's sport, the sport has a very high ACL injury rate[117] likely due to the rapid decelerations and pivoting required. To date, there is only one netball knee injury IPP published.[117] Smaller, somewhat more regional, sports with high ACL injury risks but little research also include lacrosse[118] and Australian rules football.[118; 119] *Coaches, athletes, and parents should use established programs in similar sports until sport-specific programs are designed and researched.*

Individual sports have also gotten less attention than team sports. Due to its extremely high ACL injury risk, skiing has had the most ACL IPP research of individual sports.[120-122] However, sports such as gymnastics[123] and wrestling[123; 124] also carry high risk for ACL injury and require further prevention work due to their unique demands. There is a sparsity of injury surveillance data on smaller “extreme” sports such as skateboarding, BMX, break dancing, or parkour. Information on the incidence of ACL injuries in such sports will help inform whether prevention programs are needed.

The higher risk for ACL injuries in women[42; 125] has garnered both more attention and research funding. In total numbers, however, more men experience ACL injuries.[125] One of the first ACL IPPs published was in men exclusively,[71] however, since then there have been comparatively fewer studies of ACL IPPs in men than women.[11; 12; 126; 127] Thus, more research on programs effective in men as well as if there are differences that tailor programs to each sex is needed.

Sport specialization in young athletes is common. Talented young athletes may play on multiple teams, increasing their training time, match exposure, and injury risk.[128] While sport specialization research is sometimes focused on overuse injuries,[129] acute injuries such as ACL injuries, and the long term impact of prevention strategies requires further investigation.

Owoeye et al.[11] examined the efficacy of the 11+ program in young Nigerian men. To date, their study remains one of the few ACL IPP studies not to be conducted in North America, Europe, or Australia.[87; 130; 131] Multiple meta-analyses of ACL-IPPs have included only studies from the US and Europe. [130; 131] Such lack of diversity in study location would suggest also a lack of ethnic diversity in the study populations, however given a lack of reporting guidelines/requirements for publication it is impossible to know. Recently, Dr. Tracy Blake wrote a powerful article[132] calling on researchers worldwide to use culturally competent research practices and both reporting and discussing the relevant biases and generalizability. ACL IPP research must heed these calls as well as improve regional investigations on knowledge, behavior, implementation, such as Owoeye et al (2).[133] in Nigeria.

Future Directions

Clinicians/Practitioners

- Clinicians, coaches, parents, and athletes in under-researched high ACL risk sports with similar movement patterns should use established ACL IPPs until sport-specific programs can be established and researched.
    - For example, given the similarities between women's lacrosse and soccer, the 11+ program may be beneficial for lacrosse players until lacrosse-specific programs are available.
- Clinicians, coaches, parents, and athletes working in under-researched areas should work with their communities to identify the unique ACL IPP barriers and facilitators strategizing community-oriented solutions and sharing successes and failures with the wider sports medicine community.
- Clinicians/practitioners should take the time to investigate the disparities in health care, sports medicine, and injury prevention access in their own communities. Becoming an ally[134] is a powerful step in reducing disadvantages.

Researchers

- More research is needed in high risk team sports, such as Netball, lacrosse, and Australian rules football, as well as individual sports, such as gymnastics and wrestling.
- There are indications that men and women may respond to ACL IPPs differently. Thus, research into tailored programmatic differences for each sex as well as effective programs for men is needed.
- Research on ACL IPPs should not be limited to the US, Australia, and Europe. Greater diversity in both the study locations and populations is necessary. Further, culturally competent research methods must be followed in ACL IPP publications.

Conclusion

There has been significant progress in ACL IPP research over the past 30 years. ACL injuries can be reduced across sports, particularly in young women.[42] Exercise-based programs, often used as warm-ups, are effective but their success depends on implementation and compliance.[19; 76; 89] Thus, researchers and clinicians must collaborate with coaches, athletes, parents and other stakeholders to help identify barriers and strategies. Sports that lack researched ACL IPPs, particularly sports with movement patterns similar to soccer or handball, can use existing ACL IPPs until sport-specific research is available. Further research is needed into understanding both the risk factors that contribute to ACL injuries and the mechanism by which ACL IPPs are effective. Newer evidence indicates that the mechanism of ACL IPPs could be in changing brain-behavior using motor learning principles.[52; 53; 135] However, the future holds a need for further research. Be that research into understudied sports and geographical regions, or subtleties between how men and women respond to ACL IPPs, the next 30 years of ACL injury prevention research will be enlightening and exciting.

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References

1. Kaeding CC, Léger-St-Jean B, Magnussen RA. 2017. Epidemiology and Diagnosis of Anterior Cruciate Ligament Injuries. Clin Sports Med 36:1-8.
2. Yu B, Garrett WE. 2007. Mechanisms of non-contact ACL injuries. Br J Sports Med 41:i47-i51.
3. Herzog MM, Marshall SW, Lund JL, et al. 2017. Cost of Outpatient Arthroscopic Anterior Cruciate Ligament Reconstruction Among Commercially Insured Patients in the United States, 2005-2013. Orthop J Sports Med 5.
4. Ardern CL, Ekås G, Grindem H, et al. 2018. 2018 International Olympic Committee consensus statement on prevention, diagnosis and management of paediatric anterior cruciate ligament (ACL) injuries. Knee Surg Sports Traumatol Arthrosc 26:989-1010.
5. Dingel A, Aoyama J, Ganley T, et al. 2019. Pediatric ACL Tears: Natural History. J Pediatr Orthop 39:S47-S49.
6. Montalvo AM, Schneider DK, Yut L, et al. 2019. “What’s my risk of sustaining an ACL injury while playing sports?” A systematic review with meta-analysis. Br J Sports Med 53:1003-1012.
7. Mandelbaum BR, Silvers HJ, Watanabe DS, et al. 2005. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. Am J Sports Med 33:1003-1010.
8. Gilchrist J, Mandelbaum BR, Melancon H, et al. 2008. A randomized controlled trial to prevent noncontact anterior cruciate ligament injury in female collegiate soccer players. Am J Sports Med 36:1476-1483.

9. Soligard T, Myklebust G, Steffen K, et al. 2008. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. Br Med J 337.

10. Walden M, Atroshi I, Magnusson H, et al. 2012. Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. Br Med J 344:e3042.

11. Owoeye OB, Akinbo SR, Tella BA, et al. 2014. Efficacy of the FIFA 11+ Warm-Up Programme in Male Youth Football: A Cluster Randomised Controlled Trial. J Sports Sci Med 13:321-328.

12. Silvers-Granelli H, Mandelbaum B, Adeniji O, et al. 2015. Efficacy of the FIFA 11+ Injury Prevention Program in the Collegiate Male Soccer Player. Am J Sports Med 43:2628-2637.

13. Hewett TE LT, Riccobene JV, Noyes FR. . 1999. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. Am J Sports Med 1999 27:699-706.

14. Hewett TE, Myer GD, Ford KR. 2005. Reducing knee and anterior cruciate ligament injuries among female athletes: a systematic review of neuromuscular training interventions. J Knee Surg 18:82-89.

15. Alentorn-Geli E, Myer GD, Silvers HJ, et al. 2009. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 2: a review of prevention programs aimed to modify risk factors and to reduce injury rates. Knee Surg Sports Traumatol Arthrosc 17:859-879.

16. Bizzini M, Dvorak J. 2015. FIFA 11+: an effective programme to prevent football injuries in various player groups worldwide—a narrative review. Br J Sports Med 49:577-579.

17. Bizzini M, Junge A, Dvorak J. 2006. The 11+ Manual: A Complete Warm-Up Programme to Prevention Injuries. Zurich, Switzerland: Fédération Internationale de Football Association (FIFA);

18. Mandelbaum B, Silvers H, Watanabe D, et al. 2005. Effectiveness of a neuromuscular and proprioceptive training program in preventing the incidence of ACL injuries in female athletes: two-year follow up. Am J Sports Med 33:1003-1010.

19. Hägglund M, Atroshi I, Wagner P, et al. 2013. Superior compliance with a neuromuscular training programme is associated with fewer ACL injuries and fewer acute knee injuries in female adolescent football players: secondary analysis of an RCT. Br J Sports Med 47:974-979.

20. Waldén M, Hägglund M, Ekstrand J. 2006. High risk of new knee injury in elite footballers with previous anterior cruciate ligament injury. Br J Sports Med 40:158-162.

21. Salgado E, Ribeiro F, Oliveira J. 2015. Joint-position sense is altered by football pre-participation warm-up exercise and match induced fatigue. Knee 22:243-248.

22. Soligard T, Nilstad A, Steffen K, et al. 2010. Compliance with a comprehensive warm-up programme to prevent injuries in youth football. Br J Sports Med 44:787-793.

23. Hewett T, Lindenfeld T, Riccobene J, et al. 1999. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. Am J Sports Med 27:699-706.

24. Donaldson A, Finch CF. 2013. Applying implementation science to sports injury prevention. Br J Sports Med 47:473-475.

25. Finch CF, Donaldson A. 2010. A sports setting matrix for understanding the implementation context for community sport. Br J Sports Med 44:973-978.

26. O'Brien J, Donaldson A, Barbery G, et al. 2014. The three must-do's of intervention reporting: enhancing sports injury prevention research. Br J Sports Med 48:1267-1269.

27. Griffin LY, Agel J, Albohm MJ, et al. 2000. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. J Am Acad Orthop Surg 8:141-150.

28. Griffin LY, Albohm MJ, Arendt EA, et al. 2006. Understanding and preventing noncontact anterior cruciate ligament injuries - A review of the Hunt Valley II Meeting, January 2005. Am J Sports Med 34:1512-1532.

29. Bates NA, Hewett TE. 2015. Motion Analysis and the Anterior Cruciate Ligament: Classification of Injury Risk. J Knee Surg 29:117-125.

30. Hewett TE, Ford, K. R., Hoogenboom, B. J., & Myer, G. D. . 2010. Understanding and preventing acl injuries: Current biomechanical and epidemiologic considerations – update 2010. North Am J Sport Phys Ther 5:234-251.

31. Pappas E, Nightingale EJ, Simic M, et al. 2015. Do exercises used in injury prevention programmes modify cutting task biomechanics? A systematic review with meta-analysis. Br J Sports Med 49:673-680.

32. Faude O, Rossler R, Petushek EJ, et al. 2017. Neuromuscular Adaptations to Multimodal Injury Prevention Programs in Youth Sports: A Systematic Review with Meta-Analysis of Randomized Controlled Trials. Front Physiol 8:791.

33. Thompson JA, Tran AA, Gatewood CT, et al. 2017. Biomechanical Effects of an Injury Prevention Program in Preadolescent Female Soccer Athletes. Am J Sports Med 45:294-301.

34. Caraffa A, Cerulli G, Projetti M, et al. 1996. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. Knee Surg Sports Traumatol Arthrosc 4:19-21.

35. Grooms DR, Palmer T, Onate JA, et al. 2013. Soccer-specific warm-up and lower extremity injury rates in collegiate male soccer players. J Athl Train 48:782-789.

36. Myklebust G, Engebretsen L, Braekken IH, et al. 2007. Prevention of noncontact anterior cruciate ligament injuries in elite and adolescent female team handball athletes. Instructional course lectures 56:407-418.

37. Alentorn-Geli E MJ, Samuelsson K, Musahl V, Karlsson J, Cugat R, Myer GD. 2014. Prevention of anterior cruciate ligament injuries in sports. Part I: systematic review of risk factors in male athletes. Knee Surg Sports Traumatol Arthrosc 22:3-15.

38. Alentorn-Geli E MJ, Samuelsson K, Musahl V, Karlsson J, Cugat R, Myer GD. 2014. Prevention of non-contact anterior cruciate ligament injuries in sports. Part II: systematic review of the effectiveness of prevention programmes in male athletes. Knee Surg Sports Traumatol Arthrosc 22:16-25.

39. Shultz SJ, Schmitz RJ, Benjaminse A, et al. 2015. ACL Research Retreat VII: An Update on Anterior Cruciate Ligament Injury Risk Factor Identification, Screening, and Prevention: March 19–21, 2015; Greensboro, NC. J Athlet Train 50:1076-1093.

40. Taylor JB, Waxman JP, Richter SJ, et al. 2015. Evaluation of the effectiveness of anterior cruciate ligament injury prevention programme training components: a systematic review and meta-analysis. Br J Sports Med 49:79-87.

41. Sugimoto D, Myer GD, Foss KDB, et al. 2016. Critical components of neuromuscular training to reduce ACL injury risk in female athletes: meta-regression analysis. Br J Sports Med 50:1259-1266.

42. Arundale A, Bizzini M, Giordano A, et al. 2018. Exercise-Based Knee and Anterior Cruciate Ligament Injury Prevention. J Orthop Sports Phys Ther 48:A1-A42.

43. Sugimoto D, Myer GD, Foss KDB, et al. 2015. Specific exercise effects of preventive neuromuscular training intervention on anterior cruciate ligament injury risk reduction in young females: Meta-analysis and subgroup analysis. Br J Sports Med 49:282-289.

44. McLean S, Huang X, Su A, et al. 2004. Sagittal plane biomechanics cannot injure the ACL during sidestep cutting. Clin Biomech 19:828-838.

45. Krosshaug T, Steffen K, Kristianslund E, et al. 2016. The Vertical Drop Jump Is a Poor Screening Test for ACL Injuries in Female Elite Soccer and Handball Players: A Prospective Cohort Study of 710 Athletes. Am J Sports Med 44:874-883.

46. Della Villa F, Buckthorpe M, Grassi A, et al. 2020. Systematic video analysis of ACL injuries in professional male football (soccer): injury mechanisms, situational patterns and biomechanics study on 134 consecutive cases. Br J Sports Med 54:1423-1432.

47. Hewett TE, Myer GD, Ford KR, et al. 2005. Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes: A Prospective Study. Am J Sports Med 33:492-501.

48. Lopes TJA, Simic M, Myer GD, et al. 2018. The effects of injury prevention programs on the biomechanics of landing tasks: a systematic review with meta-analysis. Am J Sports Med 46:1492-1499.

49. Padua DA, DiStefano LJ, Marshall SW, et al. 2012. Retention of Movement Pattern Changes After a Lower Extremity Injury Prevention Program Is Affected by Program Duration. Am J Sports Med 40:300-306.

50. Arundale AJH, Silvers-Granelli HJ, Marmon A, et al. 2018. Changes in biomechanical knee injury risk factors across two collegiate soccer seasons using the 11+ prevention program. Scan J Med Sci Sport 28:2592-2603.

51. Schubert M, Beck S, Taube W, et al. 2008. Balance training and ballistic strength training are associated with task-specific corticospinal adaptations. Eur J Neurosci 27:2007-2018.

52. Grooms DR, Kiefer AW, Riley MA, et al. 2018. Brain-Behavior Mechanisms for the Transfer of Neuromuscular Training Adaptions to Simulated Sport: Initial Findings From the Train the Brain Project. J Sport Rehabil 27:1-5.

53. Diekfuss JA, Bonnette S, Hogg JA, et al. 2020. Practical training strategies to apply neuro-mechanistic motor learning principles to facilitate adaptations towards injury-resistant movement in youth. J Sci Sport Exer:1-14.

54. Powers CM, Fisher B. 2010. Mechanisms underlying ACL injury-prevention training: the brain-behavior relationship. J Athlet Train 45:513-515.

55. Pascua LA, Wulf G, Lewthwaite R. 2015. Additive benefits of external focus and enhanced performance expectancy for motor learning. J Sports Sci 33:58-66.

56. Gokeler A, Neuhaus D, Benjaminse A, et al. 2019. Principles of Motor Learning to Support Neuroplasticity After ACL Injury: Implications for Optimizing Performance and Reducing Risk of Second ACL Injury. Sports Med 49:853-865.

57. Hewett T, Stroupe A, Nance T, et al. 1996. Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. Am J Sports Med 24:765-773.

58. Liao C-M, Masters RS. 2001. Analogy learning: A means to implicit motor learning. J Sports Sci 19:307-319.

59. Benjaminse A, Gokeler A, Dowling AV, et al. 2015. Optimization of the Anterior Cruciate Ligament Injury Prevention Paradigm: Novel Feedback Techniques to Enhance Motor Learning and Reduce Injury Risk. J Orthop Sports Phys Ther 45:170-182.

60. Benjaminse A, Otten E. 2011. ACL injury prevention, more effective with a different way of motor learning? Knee Surg Sports Traumatol Arthrosc 19:622-627.

61. Benjaminse A, Otten B, Gokeler A, et al. 2017. Motor learning strategies in basketball players and its implications for ACL injury prevention: a randomized controlled trial. Knee Surg Sports Traumatol Arthrosc 25:2365-2376.

62. Harris M, Casey LB, Meindl JN, et al. 2020. Using Behavioral Skills Training With Video Feedback to Prevent Risk of Injury in Youth Female Soccer Athletes. Behav Anal Prac 13:811-819.

63. Bahr R. 2016. Why screening tests to predict injury do not work—and probably never will…: a critical review. Br J Sports Med 50:776-780.

64. Hewett TE. 2016. The Vertical Drop Jump Is a Poor Screening Test for ACL Injuries: Letter to the Editor. Am J Sports Med 44.

65. Hewett TE, Myer GD, Ford KR, et al. 2016. Mechanisms, prediction, and prevention of ACL injuries: Cut risk with three sharpened and validated tools. J Orthop Res 34:1843-1855.

66. Lewis DA, Kirkbride B, Vertullo CJ, et al. 2016. Comparison of four alternative national universal anterior cruciate ligament injury prevention programme implementation strategies to reduce secondary future medical costs. Br J Sports Med 52:277-282.

67. Swart E, Redler L, Fabricant PD, et al. 2014. Prevention and screening programs for anterior cruciate ligament injuries in young athletes: a cost-effectiveness analysis. J Bone Joint Surg 96:705.

68. Pfile K, Curioz B. 2017. Coach-led prevention programs are effective in reducing anterior cruciate ligament injury risk in female athletes: A number-needed-to-treat analysis. Scan J Med Sci Sport 27:1950-1958.

69. Taylor JB, Nguyen A-D, Shultz SJ, et al. 2020. Hip biomechanics differ in responders and non-responders to an ACL injury prevention program. Knee Surg Sports Traumatol Arthrosc 28:1236-1245.

70. Chow JY. 2013. Nonlinear learning underpinning pedagogy: evidence, challenges, and implications. Quest 65:469-484.

71. Caraffa A, Cerulli G, Projetti M, et al. 1996. Prevention of anterior cruciate ligament injuries in soccer. Knee Surg Sports Traumatol Arthrosc 4:19-21.

72. Waldén M, Atroshi I, Magnusson H, et al. 2012. Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. Br Med J 344:e3042.

73. Myklebust G, Engebretsen L, Braekken I, et al. 2003. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. Clin J Sports Med 13:71 - 78.

74. Morrissey MC, Seto JL, Brewster CE, et al. 1987. Conditioning for Skiing and Ski Injury Prevention. J Orthop Sports Phys Ther 8:428-437.

75. Morris ZS, Wooding S, Grant J. 2011. The answer is 17 years, what is the question: understanding time lags in translational research. J R Soc Med 104:510-520.

76. Myklebust G, Skjølberg A, Bahr R. 2013. ACL injury incidence in female handball 10 years after the Norwegian ACL prevention study: important lessons learned. Br J Sports Med 47:476-479.

77. Wilke J, Niederer D, Vogt L, et al. 2018. Is the message getting through? Awareness and use of the 11+ injury prevention programme in amateur level football clubs. PLOS ONE 13:e0195998.

78. O'Brien J, Finch CF. 2016. Injury prevention exercise programmes in professional youth soccer: understanding the perceptions of programme deliverers. BMJ Open Sport Exer Med 2.

79. O'Brien J, Young W, Finch CF. 2017. The use and modification of injury prevention exercises by professional youth soccer teams. Scan J Med Sci Sport 27:1337-1346.

80. Dix C, Logerstedt D, Arundale A, et al. 2020. Perceived barriers to implementation of injury prevention programs among collegiate women. J Sci Med Sport.

81. Richmond SA, Donaldson A, Macpherson A, et al. 2020. Facilitators and Barriers to the Implementation of iSPRINT: A Sport Injury Prevention Program in Junior High Schools. Clin J Sport Med 30:231-238.

82. Emery CA, van den Berg C, Richmond SA, et al. 2020. Implementing a junior high school-based programme to reduce sports injuries through neuromuscular training (iSPRINT): a cluster randomised controlled trial (RCT). Br J Sports Med 54:913-919.

83. Andersson SH, Bahr R, Olsen MJ, et al. 2019. Attitudes, beliefs, and behavior toward shoulder injury prevention in elite handball: Fertile ground for implementation. Scan J Med Sci Sport 29:1996-2009.

84. Thein-Nissenbaum J, Brooks MA. 2016. Barriers to compliance in a home-based anterior cruciate ligament injury prevention program in female high school athletes. Wisconsin Med J 115:37-42.

85. Owoeye OB, Palacios-Derflingher LM, Emery CA. 2018. Prevention of ankle sprain injuries in youth soccer and basketball: effectiveness of a neuromuscular training program and examining risk factors. Clin J Sports Med 28:325-331.

86. McKay CD, Verhagen E. 2016. 'Compliance' versus 'adherence' in sport injury prevention: why definition matters. Br J Sports Med 50:382-383.

87. Donnell-Fink LA, Klara K, Collins JE, et al. 2015. Effectiveness of Knee Injury and Anterior Cruciate Ligament Tear Prevention Programs: A Meta-Analysis. PLOS ONE 10:e0144063.

88. Grimm NL, Jacobs JC, Kim J, et al. 2015. Anterior Cruciate Ligament and Knee Injury Prevention Programs for Soccer Players. Am J Sports Med 43:2049-2056.

89. Silvers-Granelli HJ, Bizzini M, Arundale A, et al. 2018. Higher compliance to a neuromuscular injury prevention program improves overall injury rate in male football players. Knee Surg Sports Traumatol Arthrosc 26:1975-1983.

90. Steffen K, Emery CA, Romiti M, et al. 2013. High adherence to a neuromuscular injury prevention programme (FIFA 11+) improves functional balance and reduces injury risk in Canadian youth female football players: a cluster randomised trial. Br J Sports Med 47:794-802.

91. O'Brien J, Finch CF. 2017. Injury prevention exercise programs for professional soccer: understanding the perceptions of the end-users. Clin J Sports Med 27:1-9.

92. Hägglund M, Waldén M, Magnusson H, et al. 2013. Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. Br J Sports Med 47:738-742.

93. Finch CF, McCrory P, Ewing MT, et al. 2013. Concussion guidelines need to move from only expert content to also include implementation and dissemination strategies. Br J Sports Med 47:12-14.

94. Whalan M, Lovell R, Steele JR, et al. 2019. Rescheduling Part 2 of the 11+ reduces injury burden and increases compliance in semi-professional football. Scan J Med Sci Sport 29:1941-1951.

95. Faude O, Rößler R, Junge A. 2013. Football injuries in children and adolescent players: are there clues for prevention? Sports Med 43:819-837.

96. Rössler R, Donath L, Bizzini M, et al. 2016. A new injury prevention programme for children's football–FIFA 11+ Kids–can improve motor performance: a cluster-randomised controlled trial. J Sports Sci 34:549-556.

97. Zarei M, Abbasi H, Daneshjoo A, et al. 2018. Long-term effects of the 11+ warm-up injury prevention programme on physical performance in adolescent male football players: a cluster-randomised controlled trial. J Sports Sci 36:2447-2454.

98. White P, Donaldson A, Finch CF. 2016. But can someone like me do it? The importance of appropriate role modelling for safety behaviours in sports injury prevention. Br J Sports Med 50:569-570.

99. Santos-Ferreira D, Tomas R, Dores H. 2020. TEAM to Defeat COVID-19: A Management Strategy Plan to Address Return to Play in Sports Medicine. Orthop J Sports Med 8:2325967120951453.

100. Colby MJ, Dawson B, Heasman J, et al. 2017. Preseason Workload Volume and High-Risk Periods for Noncontact Injury Across Multiple Australian Football League Seasons. J Strength Cond Res 31:1821-1829.

101. Lee AJ, Garraway WM, Arneil DW. 2001. Influence of preseason training, fitness, and existing injury on subsequent rugby injury. Br J Sports Med 35:412-417.

102. Windt J, Gabbett TJ, Ferris D, et al. 2017. Training load--injury paradox: is greater preseason participation associated with lower in-season injury risk in elite rugby league players? Br J Sports Med 51:645-650.

103. Carling C, McCall A, Le Gall F, et al. 2016. The impact of short periods of match congestion on injury risk and patterns in an elite football club. Br J Sports Med 50:764-768.

104. Bengtsson H, Ekstrand J, Hägglund M. 2013. Muscle injury rates in professional football increase with fixture congestion: an 11-year follow-up of the UEFA Champions League injury study. Br J Sports Med 47:743-747.

105. Bengtsson H, Ekstrand J, Waldén M, et al. 2018. Muscle injury rate in professional football is higher in matches played within 5 days since the previous match: a 14-year

prospective study with more than 130 000 match observations. Br J Sports Med 52:1116-1122.

106. Lodi E, Scavone A, Carollo A, et al. 2020. Return to sport after the COVID-19 pandemic. How to behave? G Ital Cardiol 21:514-522.

107. Bisciotti GN, Eirale C, Corsini A, et al. 2020. Return to football training and competition after lockdown caused by the COVID-19 pandemic: medical recommendations. Biol Sport 37:313-319.

108. Weber-Spickschen TS, Bischoff S, Horstmann H, et al. 2018. Injury prevention in amateur football with FIFA 11+ : What is implemented on the football pitch? Unfallchirurg 121:463-469.

109. Epstein D, Korytny A, Isenberg Y, et al. 2020. Return to training in the COVID-19 era: The physiological effects of face masks during exercise. Scand J Med Sci Sports.

110. Mason J. 2020. The Bundesliga Blueprint: the snapshot becomes a story Trackademic.Available from: https://www.trackademicblog.com/

111. Dodson CC, Secrist ES, Bhat SB, et al. 2016. Anterior Cruciate Ligament Injuries in National Football League Athletes From 2010 to 2013: A Descriptive Epidemiology Study. Orthop J Sports Med 4:2325967116631949.

112. League NF. 2020. Injury Data Since 2012. NFL.Com: National Football League; p. Webpage Available from: https://www.nfl.com/playerhealthandsafety/health-and-wellness/injury-data/injury-data

113. Myer GD, Faigenbaum AD, Cherny CE, et al. 2011. Did the NFL Lockout expose the Achilles heel of competitive sports? J Orthop Sports Phys Ther 41:702-705.

114. Pillay L, Janse van Rensburg DCC, Jansen van Rensburg A, et al. 2020. Nowhere to hide: The significant impact of coronavirus disease 2019 (COVID-19) measures on elite and semi-elite South African athletes. J Sci Med Sport 23:670-679.

115. Michaelidis M, Koumantakis GA. 2014. Effects of knee injury primary prevention programs on anterior cruciate ligament injury rates in female athletes in different sports: A systematic review. Phys Ther Sport 15:200-210.

116. 2011. About IFNA. Online: International Federation of Netball Assocations.Available from: https://web.archive.org/web/20110308132327/http://www.netball.org/IFNA.aspx

117. Hopper AJ, Haff EE, Joyce C, et al. 2017. Neuromuscular Training Improves Lower Extremity Biomechanics Associated with Knee Injury during Landing in 11–13 Year Old Female Netball Athletes: A Randomized Control Study. Front Phys 8:1-13.

118. Stanley LE, Kerr ZY, Dompier TP, et al. 2016. Sex Differences in the Incidence of Anterior Cruciate Ligament, Medial Collateral Ligament, and Meniscal Injuries in Collegiate and High School Sports. Am J Sports Med 44:1565-1572.

119. Fox A, Bonacci J, Hoffmann S, et al. 2020. Anterior cruciate ligament injuries in Australian football: should women and girls be playing? You’re asking the wrong question. BMJ Open Sport Exer Med 6:e000778.

120. Csapo R, Runer A, Hoser C, et al. 2020. Contralateral ACL tears strongly contribute to high rates of secondary ACL injuries in professional ski racers. Knee Surg Sports Traumatol Arthrosc.

121. Posch M, Schranz A, Lener M, et al. 2020. In recreational alpine skiing, the ACL is predominantly injured in all knee injuries needing hospitalisation. Knee Surg Sports Traumatol Arthrosc.

122. Jordan MJ, Aagaard P, Herzog W. 2017. Anterior cruciate ligament injury/reinjury in alpine ski racing: a narrative review. Open J Sports Med 8:71-83.

123. Agel J, Rockwood T, Klossner D. 2016. Collegiate ACL Injury Rates Across 15 Sports: National Collegiate Athletic Association Injury Surveillance System Data Update (2004-2005 Through 2012-2013). Clin J Sports Med 26:518-523.

124. Joseph AM, Collins CL, Henke NM, et al. 2013. A multisport epidemiologic comparison of anterior cruciate ligament injuries in high school athletics. J Athlet Train 48:810-817.

125. Alentorn-Geli E, Mendiguchía J, Samuelsson K, et al. 2014. Prevention of non-contact anterior cruciate ligament injuries in sports. Part II: systematic review of the effectiveness of prevention programmes in male athletes. Knee Surg Sports Traumatol Arthrosc 22:16-25.

126. Silvers-Granelli H, Bizzini M, Arundale A, et al. 2017. Does the FIFA11+ Injury Prevention Program Reduce Incidence of ACL Injury in Male Soccer Players? Clin Orthop Rel Res 475:2447-2455.

127. Grooms D, Palmer T, Onate J, et al. 2013. Soccer-specific warm-up and lower extremity injury rates in collegiate male soccer players. J Athlet Train 48:782-789.

128. Jayanthi NA, LaBella CR, Fischer D, et al. 2015. Sports-Specialized Intensive Training and the Risk of Injury in Young Athletes:A Clinical Case-Control Study. Am J Sports Med 43:794-801.

129. Bell DR, Post EG, Biese K, et al. 2018. Sport Specialization and Risk of Overuse Injuries: A Systematic Review With Meta-analysis. Pediatrics 142:e20180657.

130. Al Attar WSA, Soomro N, Pappas E, et al. 2016. How Effective are F-MARC Injury Prevention Programs for Soccer Players? A Systematic Review and Meta-Analysis. Sports Med 46:205-217.

131. Petushek EJ, Sugimoto D, Stoolmiller M, et al. 2019. Evidence-based best-practice guidelines for preventing anterior cruciate ligament injuries in young female athletes: a systematic review and meta-analysis. Am J Sports Med 47:1744-1753.

132. Blake T. 2020. In the fight for racial justice, the sidelines are no longer an option. Br J Sports Med 54:1245-1246.

133. Owoeye OBA, Akinbo SRA, Olawale OA, et al. 2013. Injury prevention in football: knowledge and behaviour of players and availability of medical care in a Nigerian youth football league. S Africa J Sports Med 25:77-80.

134. Nixon SA. 2019. The coin model of privilege and critical allyship: implications for health. BMC Public Health 19:1637.

135. Diekfuss JA, Grooms DR, Nissen KS, et al. 2020. Alterations in knee sensorimotor brain functional connectivity contributes to ACL injury in male high-school football players: a prospective neuroimaging analysis. Brazil J Phys Ther 24:415-423.