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Tailoring ACL injury prevention programs to match age appropriate motor skill proficiency in early adolescent females

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Thesis

TAILORING ACL INJURY PREVENTION PROGRAMS TO MATCH AGE APPROPRIATE MOTOR SKILL PROFICIENCY IN EARLY ADOLESCENT FEMALES

by

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DEDICATION

I would like to dedicate this work to my partner, Casey McGuire, my PA partner, Maddy Hess, and my family. All have been there for me through life's ups and downs and their support is cherished.

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ABSTRACT

The anterior cruciate ligament (ACL) is essential for knee stability, connecting the femur to the tibia and preventing excessive forward movement and rotation of the tibia. ACL injuries are notably more prevalent in females, due to a combination of anatomical, hormonal, and biomechanical factors. Nonmodifiable risk factors include anatomical characteristics and hormonal fluctuations. Modifiable risk factors encompass neuromuscular and biomechanical elements Addressing these modifiable factors through targeted injury prevention programs (IPPs) can significantly reduce the incidence of ACL injuries in females.

However, a literature review revealed that younger females often struggle with the exercises prescribed in existing IPPs. This led to the development of a novel IPP tailored to the neuromuscular capabilities of this specific age group. The new IPP will be evaluated using a movement model designed for pre-adolescent movement patterns (TGMD-2) and include ACL-specific assessments such as muscle dynamometry and LESS scoring. The results of this study will enhance understanding of the practical implementation of ACL IPPs, contributing to a more effective and comprehensive prevention strategy for the future.

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LIST OF ABBREVIATIONS

ACL..Anterior Cruciate Ligament

AE .... Athlete Exposure

AMB...Anteromedial Bundle

H/Q... Hamstring to Quadricep

IPP...Injury Prevention Program

KICKSTART........Kids' Injury Control and Knee Stability Through ACL Reinforcement Training

LESS ....Landing Error Score System

NBA ....National Basketball Association

NHANES ....National Health and Nutrition Examination Survey

NMT... Neuromuscular Training

OA..Osteoarthritis

pKAM ....Probability of Knee Abduction Moment

PLB ....Posterolateral Bundle

Q...Quadricep

TGMD-2.. Test of Gross Motor Development, Second Edition

WNBA .... Women's National Basketball Association

INTRODUCTION

Background

An anterior cruciate ligament (ACL) injury is one of the most prominent and career altering injuries to an athlete, predominantly affecting women. Female athletes are experiencing injury at an increased rate due to hormonal, anatomical, neuromuscular, and social risk factors that increase risk to suffer an ACL injury. The incidence of ACL injuries fluctuates with time but is most pronounced between 16-18 years of age. However, the risk factors leading to this peak begin to appear in early adolescence. They are then exacerbated by pubertal changes including growth spurt and hormonal fluctuations.

These risk factors include nonmodifiable physiologic differences that predispose females to an ACL injury. However, there are several modifiable risk factors that are currently targeted by ACL injury prevention programs to reduce the incidence of rupture.

Statement of Problem

ACL injury prevention is currently aimed at modifying neuromuscular maladaptation in mid-to-late adolescence, but little has been done to implement programs targeting the unique neuromuscular deficiencies of pre-adolescents. Currently, children aged 8-12 have difficulty performing the ACL prevention programs on the market with the correct form to achieve maximal injury prevention.

Hypothesis

If a tailored injury prevention program is implemented for preadolescents, specifically addressing their unique neuromuscular deficiencies, then preadolescents will exhibit improved neuromuscular performance and engagement in the program. Furthermore, this early intervention will contribute to a more effective reduction of neuromuscular risk factors associated with ACL injuries in preadolescents compared to the currently available ACL prevention programs designed for mid to late adolescents.

Objective and Specific Aims

This thesis will investigate ACL injury prevention programing for early adolescent females by first delving into the current history, etiology, and risk factors associated with ACL injury. Specifically, this thesis aims to: evaluate existing literature on the efficacy of current prevention programs in this vulnerable population; and propose a study to evaluate the success of implementing an IPP designed specifically for preadolescent movement patterns in comparison to a current IPP that is currently widely implemented.

REVIEW OF LITERATURE

Overview

The anterior cruciate ligament (ACL) is one of the key ligaments of the knee joint that provides stability and support during various physical activities. It is located deep within the knee joint (Figure 1), connecting the femur to the tibia. Specifically, it originates from the medial wall of the lateral femoral condyle and inserts into intercondylar area of the tibia. The primary function of the ACL is to prevent excess forward movement of the tibia relative to the femur. Secondarily, it acts to resist rotational forces that could otherwise damage the knee joint[1]. It is vital during activities involving cutting, pivoting, jumping, and deceleration, where excess forward motion and rotation commonly occur.

There are three components of the ACL: the anteromedial bundle (AMB), the posterolateral bundle (PLB) and intermediate bundle. These bundles work in tandem to stabilize the knee during flexion and extension, while participating in the previously mentioned activities. For example, the AMB lengthens during flexion, while the PLB shortens.

The composition of the ACL is primarily collagen, which gives the ligament its strength and integrity to properly support the knee joint. Type 1 collagen is the most abundant collagen type found in the ACL, accounting for about 90% of its composition. The parallel arrangement of these collagen fibers is especially important for its function. This allows for transmission and distribution of force throughout the knee. Apart from collagen, the ACL also contains elastin, proteoglycans, and water. Elastin provides a tensile property to the ligament that allows it to stretch and return to original shape after stress[1]. Proteoglycans help retain water and therefore help the ligament absorb any shock and resist any damage. Despite its structural integrity, the ACL is still vulnerable to injury, especially during movements like cutting, pivoting, jumping or deceleration.

Each year approximately 150,000 to 250,000 ACL injuries occur annually in the United States. Although these injuries can occur in the general population, they are prominent among athletes who participate in high-risk movements. Those in high impact and contact sports that include soccer, basketball, football, skiing, and gymnastics are most affected. This is due to the dynamic and unpredictable movements these sports require, which increase the likelihood of ACL injuries. For example, soccer and basketball involve frequent pivoting and cutting movements that put athletes in positions that result in high rate of ACL tears. Similarly, football requires unpredictable directional changes combined with high impact collisions that also increase this risk. Currently, ACL injuries are highest in both soccer and football[2] but there is a significant gender discrepancy in these populations.

In recent years, there has been growing concern about incidence of ACL injuries among females. Females are playing contact sports at an even greater rate than they were previously, ever since the passage of Title IX in 1972.[3] There has also been an increase in visibility of women in sports within the last 10 years, and thus even more of an increase in adolescent female sports participation. With this potential growth, ACL injuries could continue to trend upward, especially for females.

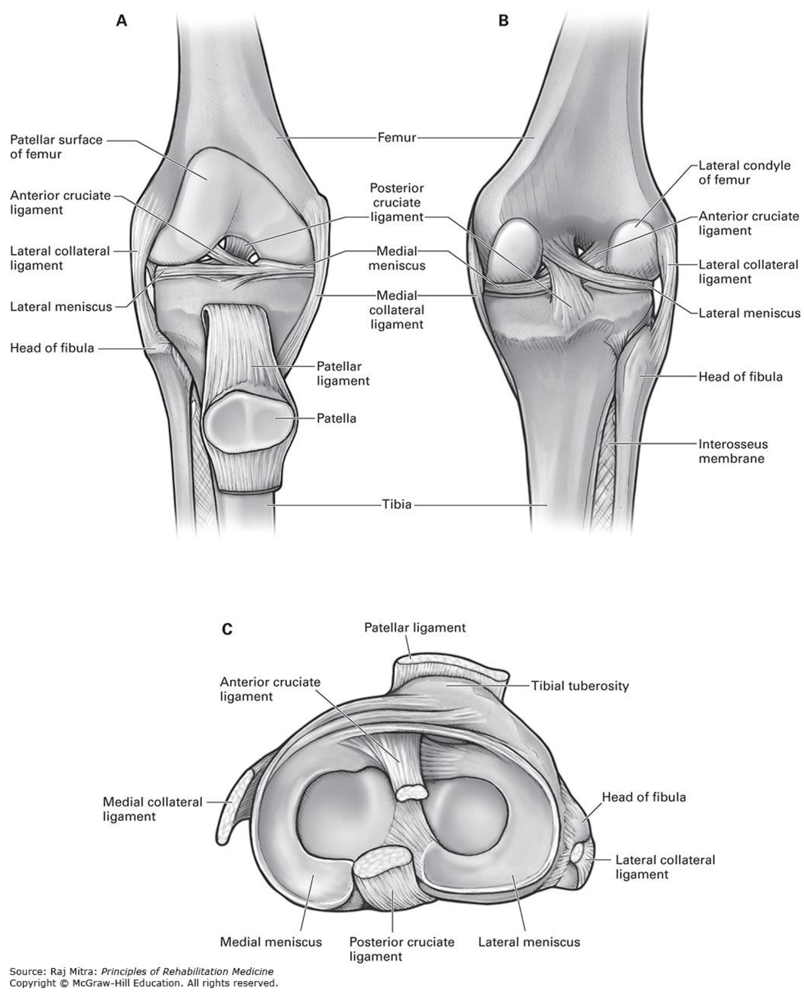

Figure 1: Knee Joint Anatomy. (A) Anterior view of the right knee joint with joint capsule open showing the patella reflected inferiorly. Posterior (B) and superior (C) views of the right knee joint.[4]

Currently, ACL injuries occur 1.51 per 10,000 athlete exposures (AE) in contact sports for both male and female. Unfortunately, this occurs at 1.88 per 10,000 AE for females, a threefold higher rate than the 0.87 per 10,000 AE for males.[5] Furthermore, specific subsets of females are even more vulnerable to ACL injury. ACL injuries start occurring at around age 10, steadily rising [6] until they peak at around 16-18 years of age[7], making adolescent girls specifically at risk. It has been found that 18.3% of current collegiate and professional women's soccer players have a history of at least one ACL injury[8] and most of those occur in their adolescent years, impacting their athletic career for years to come.

Race, ethnicity, insurance status, and socioeconomic status are all risk factors for delay in access to care post injury, which may result in increased injury severity and worse outcomes. Specifically, those of black race, Hispanic ethnicity, public health insurance users, or a low socioeconomic status encounter more obstacles to timely access to care.[9]

The high incidence rates of ACL injury in these populations are important due to the public health consequences of ACL injuries in such a young population. ACL injuries in adolescents can result in long term health implications. Those who have suffered an ACL injury are more likely to develop early osteoarthritis (OA)[10]; up to 90% of the older population who have suffered an ACL injury in the past experience OA[11] and up to 50% show evidence of OA within 10 to 20 years of their injury [12]. Further, with ACL injuries associated meniscal damage is common, which can cause its own set of problems, including further increased future incidence of OA [10] [11]. Osteoarthritis is not the only major sequelae following injury. There have also been instances of growth disturbances following ACL reconstruction in the pediatric population[13] . Risk of reinjury is also high with around 24% of adolescents experiencing subsequent tear at least 2 years post primary injury [14]. Reinjury rates are also female predominant, especially involving the contralateral knee[15].

Unfortunately, ACL injuries are not solely a musculoskeletal problem. In addition to physical impairments, there are major psychological impacts injury can have on the adolescent population. The recovery process, including surgery, rehabilitation, and high potential for reinjury, can lead to psychological distress in vulnerable population. In a systematic review of the effects on return to sport following an ACL injury, of the 36.6% of patients who could not return to sport, the majority cited psychological impacts on their health as the reason. These reasons included lack of confidence, depression, lack of motivation, and psychosocial factors[16]. There is additional evidence that injury can trigger depression, apathy, alienation, and other maladaptive behaviors[17]. All these public health factors ultimately adversely affect the patient's quality of life. [18]

Addressing and preventing these public health concerns is pertinent for keeping young girls in sports, as significant variation exists among return to sport data in the adolescent population; 55% to 97% of those who injure their ACL return to sport[14]. It also will improve the negative economic impact associated with the injury, including treatment, rehabilitation, and potential long-term consequences. ACL injuries are associated with high immediate medical costs that include imaging, orthopedic and surgical costs, and rehabilitation expenses. This can not only affect the patient directly but institutions as well. Elite athletes playing for their school or professional league who suffer an injury will cost these institutions. In the National Basketball Association (NBA) alone, the cost of recovery for a single player was $2.9 million with a cumulative economic loss from 2000-2015 for the league due to ACL injury of $99 million[19]. There is significantly less research on the economic impact of injury in women sports, which historically have been underfunded and athletes underpaid. Assuming the lack of cash flow to these individuals and organizations, the economic impact could be even more significant. In the Women's National Basketball Association (WNBA), those with a history of an ACL injury had significantly shorter careers[20], resulting in loss of income and need to pivot careers. Conversely, in the NBA, ACL reconstruction has been shown not to impact the athlete's career earnings [21].

In conclusion, the economic burden of ACL injuries is substantial and disproportionately affects female athletes. There are significant medical expenses, rehabilitation costs, and potential long-term impacts on productivity and earning potential. As female athletes continue to participate and excel in various sports, it is imperative to address the issue by investing in injury prevention programs to alleviate any possible future financial strain. To begin to create and implement these programs, one needs to understand the interplay of risk factors associated with ACL injury, especially in females, to ensure a healthier and more sustainable future for them in the sports sector.

Nonmodifiable Risk Factors

Many aspects of the anatomical differences between male and female contribute to an increased risk of female ACL injury (Figure 2). Musculoskeletal differences have been the most extensively studies. A larger quadriceps (Q) angle -- commonly found in females to due increased hip width -- has been found to increase the risk of ACL injury, especially for noncontact injuries [22], [23]. However, some studies have observed a relationship between the two [24],[25]. A smaller intercondylar notch width has also been identified as a predictor of ACL injury and is more common in females[22],[26],[25],[6]. There is speculation to mechanism by which the smaller notch contributes to an ACL injury.

Indirectly, it may house a smaller ACL which could be easier to rupture. Directly, a smaller notch could impinge the ligament under loading[1,25]. More investigation is still needed, as some studies only show a weak association between females having smaller notch width[23, 6]. Further, an increased medial posterior tibial slope has been shown as a predictor for ACL injury, as it increases the load the ACL is under[22]. Females generally have a greater posterior tibial slopes and, therefore, are at a higher risk of injury [1,23].

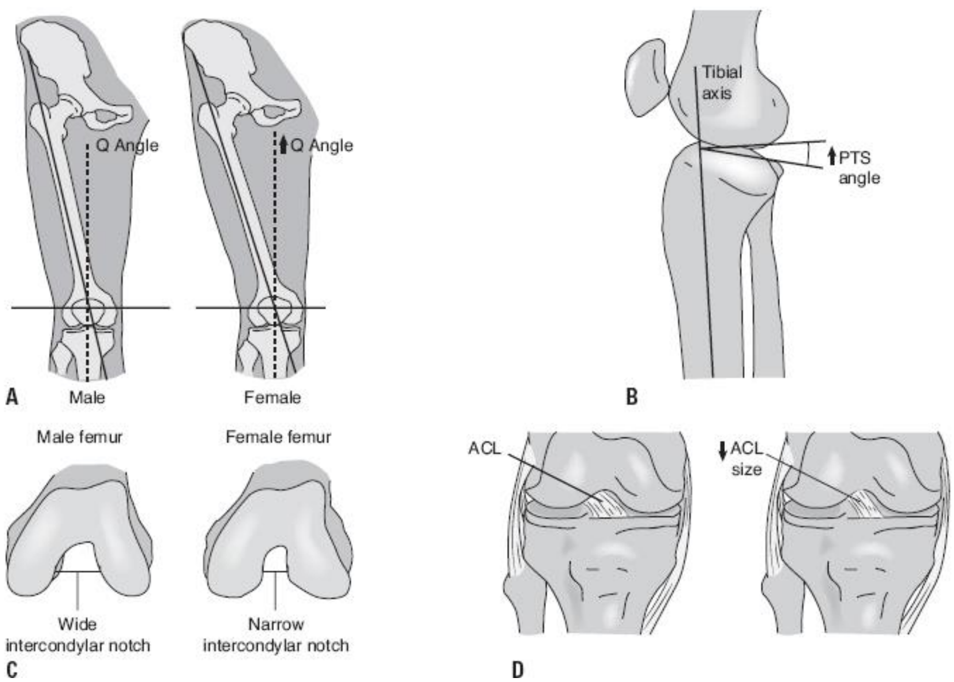

Figure 2: Anatomical factors associated with increased risk of ACL injury in females. (A) Q angle (B) Posterior inferior tibial slope (C) Intercondylar notch width (D) ACL size.[15]

There are certain properties of an individual's ACL that also contribute to risk of injury. Variations in size and length occur throughout the population but the male ACL is usually longer, wider, and thicker[26 6] after the developmental growth spurt [1] and those with smaller ACL sizes are more likely to suffer an injury. Even after accounting for these size differences, the female ACL has different mechanical properties leading to increased ligament laxity[25]. For example, the female ACL was found to have lower fibril concentrations in comparison to that of males[1], possibly resulting in increased injury risk[26]. However, there are multiple studies refuting that laxity is associated with injury risk[25].

The increased risk for ACL injuries for females emerges during ages 11 to 17, while prior there is little to no risk to injury. [6] This coincides with the age of puberty onset, which massively affects female body anatomy, muscle strength, and neuromuscular control. Increases in estrogen could be contributing to these musculoskeletal changes during puberty. Estrogen receptors have been located on the female ACL, suggesting it could have a possible direct effect on the ligament[23]. Estrogen has also been found to decrease fibroblast production, causing a decrease in tensile strength and creating making the ACL more vulnerable to tears[25,27,28]. There are also known associations between menstrual cycle fluctuation and ACL injury. During the ovulatory phase, when estrogen is the highest, there is an increased incidence of ACL injuries[29,30,31,32].

Neuromuscular changes that coincide with the menstrual cycle have also been discovered. For example, strength measurements of flexion and extension of the knee joint are lower in early follicular phases of the menstrual cycle [31]. Also, knee valgus and knee external rotation moments increase during the preovulatory phase, which can contribute to ACL injury [30] Finally, a recent study found different motor unit recruitment between vastus medialis and vastus medialis oblique muscles during the ovulatory and midluteal menstrual cycle phases[33]. Despite the nonmodifiable nature of the menstrual cycle, the neuromuscular changes that coincide with it are modifiable.

High relaxin concentrations have also been implicated as a risk factor. Relaxin is a hormone produced by the corpus luteum in both pregnant and non-pregnant individuals. While concentrations are highest during pregnancy, due to production by the placenta, concentrations are still notable in nonpregnant individuals. Relaxin regulates collagen and fibroblast metabolism to relax the myometrium, widen the pubic symphysis, and soften the cervix in preparation for delivery. However, it has also been found to affect the musculoskeletal system in other ways. Relaxin receptors have been identified on female ACLs and those that tore their ACL had higher serum relaxin concentrations than those who did not [34]. Further, it was found that relaxin contributed to negative neuromuscular movements, like valgus, that further increased risk to the ACL risk[34].

Overall, studies have found that after puberty there is increased ligament laxity[28] and neuromuscular changes[23] attributable to hormonal changes. More research is needed on the effects of gonadal hormones on injury risk in terms of direct ligament laxity and neuromuscular effects to fully understand its effects on the female anatomy.

Puberty not only comes with hormonal changes but also a growth spurt that massively affects the body. At the start of peak growth velocity, there is a rapid increase in body mass, tibia and femur length, and a change in the center of mass. In females, this is accompanied with a delay in muscular strength compensation in comparison to males, which increases their risk for ACL injury. [23] Female quadricep strength significantly increases during this time without development of hamstring strength [28]. Boys have greater knee extensor strength than girls during pubertal and post pubertal phases after having remained similar during ages 9-10[6]. Similarly, single leg hop distances, representing lower extremity power, were found to be similar for both genders during Tanner stages I and II (Table 1) but differentiated after that[6], coinciding with increased ACL risk. These growth spurts also affect lower extremity alignment more significantly in girls in comparison to boys throughout their development. Valgus knee angulation is similar in boys and girls until the age of 12, when girls begin to veer into significantly more valgus[6]. Q angle also increases in girls, while decreasing in boys throughout development[6].

Pubertal neuromuscular changes ultimately affect the biomechanics of female athletes during competition. Girls consistently have more knee abduction moments, an indicator of ACL tear risk, starting as early as age 10.[6] Finally, females reach their peak growth velocity at an earlier age than males, accounting for their earlier peak of ACL injury incidence[23],[28]. However, some areas of the body grow differently in comparison to peak growth velocity that further affect biomechanics. In girls, peak lower limb growth occurs before the time of peak height velocity and peak torso growth occurs after peak height velocity[28]. All of these growth spurt changes have been shown to occur in the absence of increasing estradiol concentrations[28], suggesting that the growth spurt on its own affects ACL risk. Although growth spurts during puberty are nonmodifiable, the strength changes and neuromuscular maladaptation to rapid growth are not.

Tanner Stage	Testes Development	Penis Development	Pubic Hair Development
I	Prepubertal (<4 mL)	Prepubertal	None
II	Enlarge (>4 mL)	Slight enlargement	Sparse, short, straight, at base of penis

III	Larger	Longer	Darker, longer, coarser, curlier, pubic bone distribution
IV	Scrotum darkens	Larger, wider, glans development	Coarse, curly, distribution spares thighs
V	Adult size	Adult size	Adult distribution (inverse triangle with spread to medial thigh)

Table 1: Tanner Staging in (A) Males and (B) Females

Finally, previous ACL injury or even a different injury has been shown to increase ACL risk[35]. Those who have previously torn their ACL are at an increased risk of re-injury with up to 33% reporting a subsequent ACL tear after return to sport[35].

Modifiable Risk Factors

Neuromuscular risk factors are the main modifiable entities that affect an individual's chance of sustaining an ACL injury.

Quadricep dominance is a common neuromuscular factor that contributes to the higher ACL injury risk in females. Compared to males, female athletes often exhibit greater quadriceps-to-hamstring strength imbalances, leading to reduced knee joint stability, as the force is shifted more onto the toes. This may be due to altered quad and hamstring activation strategies or altered hip musculature recruitment [35], which would present as a stiff knee during jumping, load contact landing, and increased knee extension during cutting.

Leg dominance is another key neuromuscular factor that may elevate ACL injury risk in female athletes. Like males, females can also display differences in strength, control, and coordination between their dominant and non-dominant legs. However, this has been found to occur at a higher rate in females [35]. Women demonstrate a great difference in strength, flexibility, and muscle recruitment patterns. Asymmetries in lower limb loading, especially during landing, are associated with an increased risk of ACL injury (Figure 2-C).

Trunk displacement is another significant neuromuscular factor linked to ACL injury risk in females. Female athletes tend to exhibit greater lateral trunk movement during dynamic activities[35] with increased trunk range of motion, which can lead to increased loads on the knee joint. Excessive trunk displacement can disrupt the alignment of the lower limbs, potentially affecting ACL stability. Incorporating exercises that promote core stability and proprioceptive control can help reduce lateral trunk displacement[35].

Valgus knee collapse is one of the primary neuromuscular factors associated with increased risk in females. Female athletes often demonstrate a higher prevalence of valgus during landing and cutting movements compared to males[35]. This inward angling of the knee places excessive stress on the ACL, making it more vulnerable to injury. As previously mentioned, the Q angle and narrow intercondylar notch found in females affects how the knee joint is loaded, leading to valgus. Further, there are hormonal influences that increase the tendency for females to go into valgus during dynamic movement.

Neuromuscular fatigue has been identified as a significant factor affecting ACL injury risk in females. Fatigue alters neuromuscular control and coordination, making the knee joint more susceptible to injury during high-intensity movements. Female athletes may experience neuromuscular fatigue differently than males due to variations in muscle architecture and hormonal profiles. Adequate recovery strategies and well-structured training programs that account for fatigue management can help minimize ACL injury risk in female athletes.

Inadequate warm up prior to performance has been identified as a risk factor for ACL tears[36]. Warm up has long been understood to prepare the body for athletic activity through priming neuromuscular coordination, increasing blood flow to muscles, and ensuring flexibility. Without it, there is a risk that the athletes' movements during sport may unnecessarily strain the ACL.

Training load plays a critical role in influencing ACL injury risk. For example, a rapid increase in the volume or intensity of training without progression can place excessive strain on the knee joint without the body being able to adapt[35]. These elements ultimately lead to diminished neuromuscular control, leaving the ACL susceptible to injury. Similarly, insufficient recovery periods between exercise or training sessions can also contribute to neuromuscular fatigue in combination with lack of tissue repair, again contributing to an increased risk of tear. Recently, training monotony has become more common in adolescent ages, as children become specialized in sport earlier. Repetitive movement patterns limit the knee's ability to overcome different athletic demands it encounters in real world situations.

Playing surface variability affects the rate of ACL tears, especially in soccer where both natural grass and artificial turf are popular. As artificial turf gains popularity in the

United States, it is beginning to be used more often in youth sports. However, artificial turf has been shown to increase frictional forces that lead to increased ACL injury[37],[38]. Interestingly, further studies have found that artificial turf fields increase the ACL injury risk for women soccer players but the association is less clear for men. While have found no increase in ACL risk men on turf[8], another identified an increased injury risk[39]. Further research is needed on the exact mechanics of why artificial turf would disproportionately affects female soccer players, as the reasons may be multifactorial. However, the increased risk remains as artificial turf continues to be used. Environmental factors could also impact the playing surface. High rainfall can help lower the risk of ACL injuries, most likely due to the softening of the natural grass surface[40]. Ground watering and softening helps decrease the risk of ACL injuries. However, this practice is not possible on artificial turf, again increasing its association with injury risk.
Cold weather has also been found to increase ACL injury risk due to its negative effects on muscular strength activation[41].

Footwear has also been recently proven to affect ACL injury risk. Improper fit or poor ankle support leads to athletes' experiencing even more instability during movements that stress the ACL, like cutting and landing. This may be due to the shoe not providing enough traction but also due to improper alignment or force distribution. This is particularly troublesome for female athletes, as they usually wear shoes that are designed for men with different biomechanical risk factors. Female feet have a wider forefoot and a narrower heel in comparison to men, which means that shoes designed for men may not fit them properly. This leads to instability during cutting or landing and, thus, increased susceptibility to injury. A cleat designed for females ensuring the proper support may help mitigate the risk for ACL tears. Outsole-surface interface also affects injury rates. Researchers have explored the relationship between the outsole of soccer boots and the playing surface as a potential contributor to ACL injuries by evaluating friction in terms of translation traction and axial rotation. There are a variety of outsole types one could choose based on the playing surface that include soft ground, firm ground, artificial ground, and turf. Each outsole type has a different material and stud length to better accommodate the turf type. Further, different cleat companies have different stud shapes that can affect biomechanics. Soft ground cleats on artificial turf or cold season natural grass were the only stud type to have shown ineffective traction resulting in an increase in ACL injury[42]. Further experiments have also found that the lowest strain force exerted on the ACL during rotational movements was natural turf cleats. In contrast, artificial turf cleats produced the highest average strain force on the ACL[38].

Nonmodifiable risk factors (anatomy, gonadal hormones, ACL properties, age, previous injury) compound with modifiable risk factors to contribute to the increased susceptibility of females to ACL injuries. The majority of these injuries occur due to noncontact mechanisms [12], opposed to direct knee trauma, due to neuromuscular maladaptation like knee valgus, quad dominance, and lateral trunk displacement that place excess stress on the ligament. Certain dynamic movements exacerbate these neuromuscular deficiencies, including change of direction and improper landing technique. Change of direction during sports causes rotational force at the knee joint with simultaneous rapid deceleration and tendency for valgus. If the knee is not properly stabilized the ACL can be overstretched or ruptured. Landing without proper force absorption and alignment can also cause ACL injury from excessive ground reaction forces that increase stress on the ligament. One mechanism that disproportionately affects females during landing includes simultaneous extension of the hip and knee, knee valgus, internally rotated tibia, and foot pronation[12] (Figure 3).

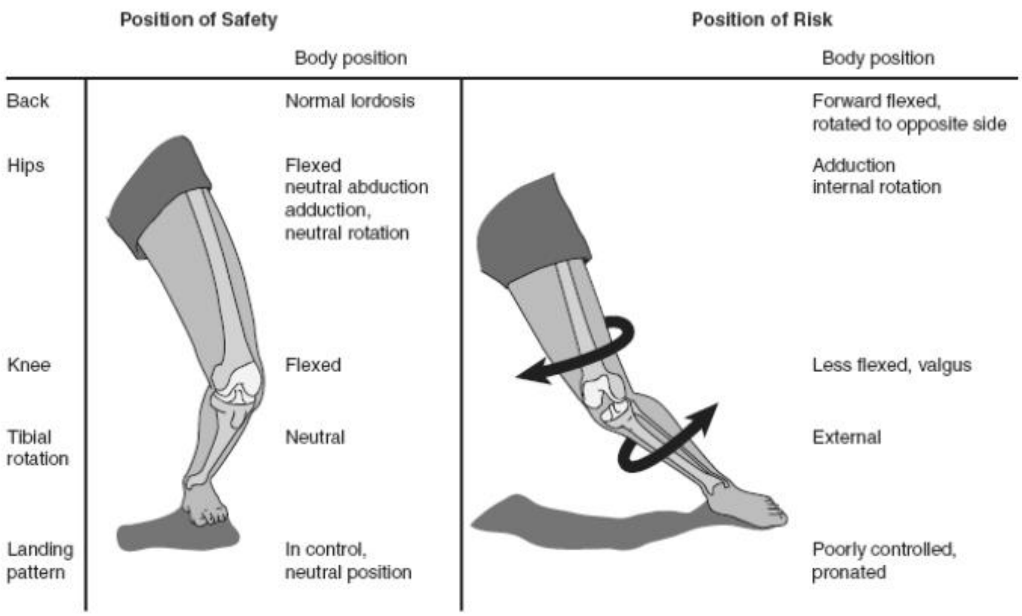

Figure 3: Correct cutting technique in comparison to common mechanism of noncontact female ACL injuries[15]

Prevention

Current prevention techniques target neuromuscular risk factors that affect dynamic movement deficiencies. Neuromuscular training programs are designed to improve communication and coordination between the nervous system and the muscles to improve movement patterns, thus decreasing ACL injury risk. All neuromuscular training programs include proprioception training and dynamic stability work to focus on the proper movement mechanics, thus correcting neuromuscular deficiencies. In older populations, these deficiencies are identified with screening tools that include hop tests, drop jump tests, landing error scoring system (LESS), and isokinetic strength testing (BioDex) that can identify risk factors to target in prevention programs. In younger populations with less developed motion literacy, there are limited screening tools that can differentiate normal neuromuscular deficiencies for their age from potential risk factors for future ACL injury to incorporate age-appropriate drills into the prevention programs. However, a current tool being used is the Test of Gross Motor Development 2 (TGMD-2). This test is divided into two subsets of motion - locomotor and object control. The locomotor assessment analyzes run, gallop, leap, horizontal jump, and slide, while the object control section assesses striking a stationary ball, stationary dribble, kick, catch, overhand throw, and underhand roll (Table 2). Each subset thoroughly analyzes the movement abilities of those in this age group in terms of quality and the subject is given a score based on their performance.

The screening tools are utilized to identify at risk individuals for ACL injury and direct them to a proper prevention program for their current state of motion literacy. These prevention programs, as advised by the International Olympic Committee in 2008, should include strength and power training, neuromuscular training, plyometric work, agility exercises, perfecting cutting and landing techniques, and a proper warm up. One such prevention program is FIFA 11+ (Table 3). Other prevention programs include Harmoknee and the Prevent Injury and Enhance Performance (PEP) program.

Subset	Exercise	Performance Criteria	Score
Locomotor	Run	Arms move in opposition to legs. Elbows bent. Brief period where both feet are off ground. Narrow foot placement. Landing on heel or toe. Nonsupport leg bent 90 degrees.	0 = incorrect 1 = correct
Locomotor	Gallop	Arms bend and lifted to waist level at takeoff. Step forward with lead foot followed by step with other foot adjacent/behind lead foot. Rhythmic pattern for 4 consecutive gallops.	0 = incorrect 1 = correct
Locomotor	Hop	Nonsupport leg swings forward to produce force. Foot of nonsupport leg behind body. Arms swing forward to produce force. Takes off and lands 3 consecutive times on nonpreferred foot.	0 = incorrect 1 = correct
Locomotor	Leap	Take off on 1 foot and land on opposite food. Period where both feet are off the ground. Forward reach with arm opposite lead foot.	0 = incorrect 1 = correct
Locomotor	Horizontal Jump	Prior to jump, flexion of both knees and arms extended behind body. During jump, arms extend forward and upward with full extension. Take off and land on both feet simultaneously. During landing, arms thrust down.	0 = incorrect 1 = correct
Locomotor	Slide	Body sideways with shoulders aligned to line on floor. Step sideways with lead foot followed by slide of trail foot. 4 continuous step-slides to both right and left.	0 = incorrect 1 = correct
Object Control	Stationary ball strike	Dominant hand grips bat above nondominant hand. Nonpreferred side of body faces imaginary tosser with feet parallel. Hip and shoulder rotation during swing. Transfer body weight to front foot. Bat contacts ball.	0 = incorrect 1 = correct
Object Control	Stationary dribble	Contacts ball with one hand at about belt level. Pushes ball with fingertips. Ball contact surface in front of or to the outside of foot on the preferred side. Maintains control of ball for 4 consecutive bounces without having to move feet to retrieve it.	0 = incorrect 1 = correct
Object Control	Catch	Prep phase where hands are in front of body and elbows are flexed. Arms extend while reaching ball as it arrives. Ball is caught by hands only.	0 = incorrect 1 = correct

Object Control	Kick	Rapid continuous approach to ball. Elongated stride or leap prior to ball contact. Nonkick foot placed even with ball. Kick ball with instep or toe.	0 = incorrect 1 = correct
Object Control	Overhand Throw	Windup is initiated with downward movement of hand/arm. Rotate hip and shoulder to a point where nonthrowing side faces wall. Weight transferred by stepping foot opposite throwing hand. Follow through beyond ball release diagonally across the body toward the nonpreferred side.	0 = incorrect 1 = correct
Object Control	Underhand Roll	Preferred hand swings down and back, reaching behind trunk while chest faces cones. Bend knee to lower body. Release ball close to floor so ball does not bounce more than 4 inches	0 = incorrect 1 = correct

Table 2: TGMD-2 Protocol and Scoring [43]

These injury prevention programs (IPP) target the strength deficiencies and biomechanical movement patterns that could lead to an ACL injury. Neuromuscular training (NMT) is utilized in most programs to optimize muscle firing patterns to produce the correct movements to provide joint stability. Certain NMT exercises target specific risk factors and are pooled together to create an ideal IPP. For example, an effective single leg squat is utilized to target valgus knee moments. In combination with strength training and early implementation, IPPs have been proven to reduce the risk of ACL injury [44,45]. However, early implementation remains a problem in the early adolescent population. The currently designed IPP's target an older population of athletes, which impacts younger children who are unable to get the most benefits out of the IPPs.

Exercise	Level 1	Level 2	Level 3
Running	Straight, hip out/in, circling partner, shoulder contact, and quick forward/backward		
Plank	Static	Alternate legs	One leg lift and hold
Side plank	Static	Raise and lower hip	Leg lift and hold
Nordic hamstring curl	3-5 reps	7-10 reps	12-15 reps

Single leg balance	Hold ball	Partner throw	Partner perturbation
Squats	Double leg with toe raise	Walking lunges	Single leg
Jumps	Vertical	Lateral	Box
Running	80% maximum pace, bounding, and plant and cut		

Table 3: FIFA 11+ Injury Prevention Protocol[46]

Treatment

Current treatment of adolescent injuries combines acute management with a follow up comprehensive rehabilitation program. Ligament reconstruction is the mainstay of treatment for those who wish to remain in their high demand sport or those with persistent knee instability. There are multiple graft options for reconstruction, an autograft or allograft with multiple options in each category. It is unclear whether autograft or allograft is superior to the other. The decision ultimately is a joint one between surgeon and patient. Autografts increase donor site morbidity and length of recovery time but have a decreased risk of graft failure or rupture, especially in adolescents[47]. The three main autograft choices include bone-patellar tendon-bone, quadrupled hamstring tendon, and quadricep tendon. Each autograft option has specific advantages and weakness that need to be matched to patients' need and surgeon preference. Each graft varies in anatomical properties, biomechanics, and incorporation that may affect recovery. However, there is limited evidence to suggest that any of the autografts are superior to the other in overall stability and patient satisfaction[48],[49].

Nonsurgical treatment is also an option for athletes whose sport does not involve cutting or those who are older and not experiencing significant instability. Adult females are more likely to opt for nonsurgical management in comparison to males, thus making them less likely to return to sport. Specifically, males are 1.5 times more likely to return to sport. However this data is specific to adults as there is limited data on adolescent treatment choices[15].

Existing Research

Current prevention programs are aimed at adolescents; early adolescents have difficulty performing these movements[50] and, thus, aren't getting the full benefits of the program. Even though prevention techniques have been proven to decrease neuromuscular risk factors, especially in women[50], female ACL injury rates continue to remain high, suggesting these programs have yet to be optimized.

Below is research that supports that preadolescent programs are beneficial and that much needed implementation is lacking in the real-world setting, mainly due to lack of ability of kids this age to perform IPP exercises correctly. Further literature is also reviewed regarding neuromuscular skill surveys in preadolescent children that could contribute to identifying movement deficiencies in this age group.

Otsuki et al. 2021[51] identified a gap in ACL prevention programs for females going through early stages of puberty so they investigated whether injury prevention programs (IPP) would be effective in altering knee mechanics in early, late, and post pubertal females. They took a population of female basketball players from Japan and divided them into early, late, or post puberty by their self-reported Tanner stage. The mean age of the early puberty group was around 12 to 13. After categorization, they separated each puberty stage into two separate study arms: those who would participate in an IPP and the control. They then analyzed the effectiveness of the intervention by evaluating medial knee displacement, knee flexion motion, and probability of high knee abduction moment (pKAM) during a multifaceted dynamic movement that included landing, cutting, and sprinting. All which have been proven to be biomechanical risk factors for an ACL injury.

The program was designed based on previous literature, focusing on prevention of valgus and proper knee flexion during cutting and landing (Table 4). It was initially run by athletic trainer, who then followed up every two weeks with guidance. After participating in the program three times a week for six months, they found that, in early puberty training groups (Tanner stage 2 and 3), there was no change in medial knee displacement or pKAM, while it was significantly increased in the control. Similarly, there was no change in knee flexion range of motion for the early puberty training groups but significantly decreased range of motion in those who did not participate in IPP. In the late puberty group (Tanner stage 4), there were no observed changes in any of the variables. However, in late puberty (Tanner stage 5) there was significant decrease in pKAM among those who did the IPP, while there is no difference between the two groups regarding median knee displacement or knee flexion ROM. These findings support the idea that post puberty females showed greater improvement than those in early puberty after completion of a standard ACL IPP. However, they speculated that the reason for this might be the program was not appropriate for younger participants who were at a different stage of motor development. They advised that injury prevention programs should be implemented early because their study did show that as girls aged, their pKAM increased. This showed that there was a natural development of high-risk movements that needed to be prevented earlier on but the injury prevention program was not as efficient for the early puberty age group in comparison to the late puberty group.

Exercise	Repetition	Instruction
Two-legged squat	2x10	Maintain alignment of feet, knees, and hips. Avoid allowing the knees to collapse inward. Flex both the knees and hips.
One legged squat	10 x side	Maintain alignment of feet, knee and hips. Avoid allowing knees to collapse inward. Flex the knee and hips. Ensure pelvis remains level.
Squat jump	1x10	Lower into a squat and execute the highest vertical jump possible. After landing, return to the starting stance and repeat the movement. Keep your feet, knees, and hips aligned, and aim for a gentle landing.
Tuck jump	1x10	Jump up, pulling your knees toward your chest. Land gently and quickly spring back up. Ensure your feet, knees, and hips remain aligned.
180-degree jump	10 x side	Leap into the air and turn 180 degrees. Make a soft landing while keeping your feet, knees, and hips aligned. Flex both your knees and hips as you land.
Contact jump	10 x side	Leap towards your partner and make shoulder-to-shoulder contact. Land gently, maintaining alignment of your feet, knees, and hips. Flex your knees and hips upon landing.
Lateral hop	10 x side	Balance on one leg and jump to the side. Land softly on the opposite foot, keeping your feet, knees, and hips aligned. Bend your knees and hips as you land.
Pivoting	20 x side	Stand on the balls of your feet with knees slightly bent. Rotate 45 degrees to the right and left while keeping your knees and feet aligned in the same direction.
Two-legged plant and cut	10 x side	Spring forward with 4-5 steps, planting firmly on both legs. Pivot on your feet to change direction. Ensure your feet, knees, and hips remain aligned.

Table 4: Otsuki et al. 2021[51] IPP

Distefano et al. 2011[52] performed a similar study but focused solely on an early adolescent population with a mean age of 10 years. However, they compared two different types of IPP, a traditional one like the one used in Otsuki et al. 2021 (Table 4) and a newly designed pediatric program. This pediatric program used a greater progression of exercises, taught smaller task components, diversified exercises to keep children attentive, and provided more opportunity for instruction and feedback. However, even this specific pediatric program, based off motor learning literature for this age group, was insufficient in improving significant results, aside from modifying knee rotation in the transverse plane. This suggests that this level of exercise, despite the progression, may still be too advanced for preadolescents. Their program focused on continual feedback and instruction and tried to match tasks for their cognitive age, suggesting that more information is needed on both these topics to thoroughly design an effective IPP for early adolescent females.

It was found by **Ling et al. 2021**[50] that continual feedback and instruction improves IPP performance in children but many could not perform the activities prescribed. They utilized a neuromuscular training program designed by the Sports Safety Program at the Hospital for Special Surgery to evaluate the ability of different age groups to perform the program's exercises. Sports medicine practitioners evaluated each child in the two different age groups (ages 8-11 and 16-17) to determine whether they performed the exercises with appropriate biomechanical alignment. They found that in all exercises for all, less than 50% of the children could accurately perform the IPP with instruction alone. However, when adding feedback cues, that percentage significantly increased. They also noted several exercises in each age group could not be performed properly, even after feedback. Among those in the early adolescent female age group, the exercises most notably lacking are commonly implemented in all ACL IPP's (Table 5). Most notably, after instruction, the lunge, scissor jump, and broad jump were all under 30%

completion, suggesting further reformation needed on matching exercises to cognitive and neuromuscular age to increase compliance for prevention programs in this age group.

Exercise	After Instruction	After Technique Cues
Forward/Backward Jog	35.6%	73.3%
Narrow Figure 8 Run	50%	77.8%
Level 1 Lunge	7.8%	23.3%
Level 1 Double Leg Squat	16.7%	41.1%
Level 1 Broad Jump	13.3%	25.6%
Level 1 Scissor Jump	4.4%	10%
Level 1 Side Plank	22.2%	61.1%

Table 5. Proportion of females age 8-11 who performed exercises with proper alignment.[50]

Root et al. 2022[53] studied the effect of verbal feedback even further, postulating that simplified feedback might be less overwhelming in younger populations and, subsequently, help them improve their outcomes from IPP. They focused on soccer players aged 10-12, comparing those who received a traditional program, a program with simplified verbal feedback, and a warmup of the coaches' choice. There was no difference between the 3 arms of the study with all 3 groups showing improved LESS scores immediately post training program. However, effects were only found in the groups that participated in the IPP with some form of feedback, as evident in the improved LESS scores 12 weeks post program. This suggests that simplified feedback was non-inferior and all could be capable of providing feedback to children. However, this study did not address the limitations of the specific program in terms of ability to properly execute the exercises. Therefore, the reason for lack of ability to complete exercises may not be the direction but neuromuscular maturity.

Thompson-Kolesar et al. 2018[54] also studied the biomechanical effects of IPP using the FIFA 11+ program (Table 3). They compared the muscle co-contraction of knee flexor- extensors and valgus moment in preadolescent and adolescent female soccer players, evaluating how the IPP affects the different age groups. At baseline, the preadolescent players had greater peak knee valgus angles but both groups had similar mean valgus moments. Co-contraction at baseline during weight bearing exercised was higher in preadolescents compared to adolescents. After FIFA 11+ implementation, preadolescents only improved their knee valgus moment during double legged jumping and double legged jump-landing in comparison to controls. However, there was no change in co-contraction for preadolescent for any weight bearing activity. Thus, the FIFA 11+ may be insufficient for preadolescents. Authors also stated a limitation of the study was the inherent differences in ability and skill level between the preadolescent and adolescent athletes. No preadolescents advanced to any level 3 exercises during the program or even level 2 for front plank or side planks. Glaringly, even less than 50% of the population progressed forward on Nordic hamstrings, squats, and jumping. This further supports the need for targeting different exercises to implement in preadolescent ACL prevention programs (Table 6).

Current literature has shown that prevention programs aimed at adolescents are not fully effective, especially for early adolescents. Although these programs reduce neuromuscular risk factors, female ACL injury rates remain high, indicating a need to change. Research shows that preadolescent programs are beneficial but lack real-world implementation, partly because younger children cannot perform the exercises correctly.

Studies by Otsuki et al. (2021) and others indicate that while IPPs can positively alter knee mechanics in post-pubertal females, they are less effective for those in early puberty due to developmental differences. Even programs tailored for younger children, such as those by Distefano et al. (2011) and Ling et al. (2021), often fail to produce significant improvements, suggesting the exercises might still be too advanced. Root et al. (2022) found that simplified verbal feedback helps but does not fully address the ability to execute exercises, pointing to neuromuscular maturity as a key factor. Thompson-Kolesar et al. (2018) also demonstrated that current IPPs, like FIFA 11+, are insufficient for preadolescents due to the inability to progress through exercises.

Exercise	Preadolescents	Adolescents
Front Plank	0%	100%
Side Plank	0%	100%
Nordic Hamstring	46.4%	100%
Single legged stance	100%	45.5%
Squats	42.9%	100%
Jumping	42.9%	45.5%

Table 6. Proportion of females who advanced to level 2 exercises in FIFA 11+[54]

This body of research emphasizes the necessity for IPPs specifically designed for younger children to effectively prevent ACL injuries. Therefore, a new IPP targeted towards early adolescents' neuromuscular movements would be ideal to ultimately reduce ACL injury risk. A study comparing the new IPP to traditionally used IPPs aimed at older age groups would address this gap in the literature.

PROJECT METHODS

Project Design

A 12-week randomized controlled trial will investigate the effectiveness are of a newly designed IPP called Kids' Injury Control and Knee Stability Through ACL Reinforcement Training (KICKSTART) compared to a traditional IPP (FIFA 11+) in reducing ACL injuries in female youth soccer players aged 8-12. KICKSTART will focus on exercises designed for pre-adolescent motor skill proficiency, as it has been shown that little has been done to implement programs that this age group can effectively perform. Each participant will be randomly assigned to KICKSTART or the FIFA 11+, which has historically been used for modifying neuromuscular adaptation in later adolescence.

Project Population and Sampling

Participants in this study will include female soccer players aged 8-12 who will be recruited from Chicago area youth soccer clubs. Inclusion criteria will consist of age less than 13 and those who are willing to commit to a 12-week program. Informed consent will also be granted by parents or legal guardians. Exclusion criteria will consist of those with a prior ACL injury, those who have a history of neuromuscular disorder (muscular dystrophies, spinal muscular atrophy, congenital myopathies, etc.) or injury affecting movement patterns, and those who are currently participating in a structured 12-week IPP.

Sample size for primary outcome was calculated using G*Power given two tailed t test comparing means of independent groups. Type of power analysis used was A priori. Using evidence of a medium effect size of pre-adolescent girls in TGMD- 2[55], Cohen's d was set to 0.5, alpha error of less than 0.05, power set to a standard of 0.8, and allocation ratio set to , a total sample size of 126 is required. Separate power analysis for each secondary outcome (LESS scores, H/Q, and compliance) were completed and they were not larger than the primary outcome, ensuring adequate power for all outcomes.

Intervention

KICKSTART will be tailored towards pre-adolescents and has been modified based on previous studies (Table 7). Exercises which have been shown as too difficult for a majority (>50%) of preadolescents to perform will be modified to simpler movements so that a majority of participants could execute them with the correct form. Progression to higher levels will only occur once a clinician has determined the child has the correct form and is able to do the next exercise safely. Further, verbal feedback from clinicians with provided cue descriptions will be implemented throughout the IPP to ensure proper alignment and form. KICKSTART will consist of 20-minute sessions conducted 3 times a week. The FIFA 11+ program will be used as the traditional ACL IPP, which is commonly implemented throughout the country.

Target	Level 1 Exercise	Level 2 Exercise	Level 3 Exercise
Core weakness	Dead Bug	Bird Dog	Plank
Hamstring weakness	Bridge	SL Bridge	Hamstring walkouts
Hip weakness	Clam	Banded Clam	Side plank

Balance	Heel/Toe raise	Heel/Toe walk	SL Stand
Squat mechanics	Assisted squat	DL squat	Lunge
Landing mechanics	Box to land	DL jump	Broad jump

Table 7: KICKSTART Program

Participants and their coaches will receive comprehensive instruction on the precise execution of KICKSTART exercises and interventions. This training will entail hands-on demonstrations of correct techniques, detailed explanations of the rationale behind each exercise, and guidance on safe progression through the program.

Project Variables

To evaluate the multitude of factors that contribute to an ACL injury, overall movement patterns will be evaluated, along with landing mechanics and strength of significant muscle groups before and after each intervention. Overall movement patterns in adolescents will be evaluated using TGMD-2 scores (Table 2). The TGMD-2 was originally developed as movement assessment tool for children aged 3-10 but has been also found to be effective for use in the adolescent population[56], making it an ideal screening tool for ages 8-12 used in this study. Procedure directions and scoring requirements entailed in supplement were adapted from National Health and Nutrition Examination Survey (NHANES) TGMD-2 procedures manual (Table 2) [43]. Each athlete will receive zero points for a failed attempt and one point for each skill with a total of 12 skills assessed – 6 locomotor and 6 object control. Participants will complete one practice run and 2 trial runs of each skill after instruction by clinician. Each of the 2 trial runs points will be averaged together to get a total skill score of up to 24. The average of both was then taken for each athlete for analysis.

As secondary outcomes, landing error scoring system (LESS) and muscle dynamometry will also be evaluated. LESS scores will be taken before and after both programs to evaluate for 17 neuromuscular risk factors in ACL injury. In youth soccer players, LESS has been proven as a valid and reliable screening tool for neuromuscular risk factors for ACL injuries[57],[58]. The LESS evaluates high-risk movement during a jump landing task, including valgus, trunk displacement, and symmetric foot contact. Athletes will be directed to jump off a 30 cm height box, land just past half their body height marked with a line, and then jump for maximal height after the landing. The athletes will be scored on a total of 3 jump-landing trials with a score of 1 given if the potential risk factor is present and no points given if the risk factor was not identified during their trial based on the definition of error (Table 8). The average of all 3 trials for each athlete will be taken for analysis.

Risk Factor	**Definition of Error**	**Score**
Knee flexion: initial contact	Knee flexed < 30 degrees	0 = absent 1= present
Hip flexion: initial contact	Thigh and trunk aligned	0 = absent 1= present
Trunk flexion: initial contact	Trunk vertical or extended	0 = absent 1= present
Ankle plantar flexion: initial contact	Foot lands heel to toe or flat footed	0 = absent 1= present
Medial knee position: initial contact	Center of patella medial to midfoot	0 = absent 1= present
Lateral trunk flexion: initial contact	Midline of trunk towards right or left	0 = absent 1= present
Wide stance width	Greater than shoulder width apart	0 = absent 1= present
Narrow stance width	Less than shoulder width apart	0 = absent 1= present

Foot external rotation	Externally rotated > 30 degrees at between initial contact and maximum knee flexion	0 = absent 1= present
Foot internal rotation	Internally rotated > 30 degrees between initial contact and maximum knee flexion	0 = absent 1= present
Symmetric foot contact	One foot lands before other foot or one is plantar flexed while other is dorsiflexed	0 = absent 1= present
Knee flexion displacement	Knee flexion < 45 degrees between initial contact and maximum knee flexion	0 = absent 1= present
Hip flexion displacement	Thigh does not move towards trunk more between initial contact and maximum knee flexion	0 = absent 1= present
Trunk flexion displacement	Trunk does not flex more between initial contact and maximum knee flexion	0 = absent 1= present
Medial knee displacement	At point of maximum medial knee position, center of patella is medial to midfoot.	0 = absent 1= present
Joint displacement	Soft = large trunk, hip, and knee displacement Average = Some trunk, hip, and knee displacement Stiff = Little trunk, hip, and knee displacement	0 = soft 1=average 2=stiff
Overall impression	Excellent = soft landing with no transverse or frontal plane motion Poor = Stiff landing with some transverse or frontal plane motion OR large transverse or frontal plane motion	0 = excellent 1 = all other landings 2 = poor

Table 8: LESS Scoring System[58]

Muscle strength comparing quad and hamstring strength will be evaluated using isokinetic dynamometry to assess quad dominance. Peak torque of the hamstrings and quadriceps will be taken. This will be used to evaluate quadricep dominance through a ratio of hamstring to quadricep peak torque.

Recruitment

Female soccer players aged 8-12 will be recruited to participate with parent permission. Youth soccer clubs in the Boston area will be targeted at tournaments and playing institutions throughout the area. The study would set up booths at local soccer tournaments, soccer academies, and training centers where brochures and flyers would be distributed to players and coaches. To ensure parental consent and player understanding, informational sessions would be conducted with interested families. The study will also collaborate with local clubs in the area, providing brochures to these coaches and families as well.

Data Collection

Two video cameras will be placed in front and to the right of the athletes to evaluate frontal and sagittal technique for all trials. Trained research assistants blinded to the assigned IPP will score the digital videos of each athlete taken based on TGMD-2 and LESS scoring systems. For LESS, the athletes will be scored on a total of 3 jump-landing trials with a score of 1 given if the potential risk factor is present and no points given if the risk factor was not identified during their trial based on the definition of error (Table 5). The average of all 3 trials for each athlete will be taken for analysis.

For TGMD-2 procedure directions and scoring requirements entailed in supplement were adapted from NHANES TGMD-2 Procedures manual (Table 2) [43]. Each athlete will receive zero points for a failed attempt, and one points for each skill with a total of 12 skills assessed – 6 locomotor and 6 object control. Participants will complete one practice run and 2 trial runs of each skill after instruction by clinician. The average of both will then be taken for each athlete for analysis.

Muscle dynamometry will be evaluated using a BioDex, the participant will be seated with straps to secure torso, thigh, and leg. They will be asked to perform three maximal voluntary contractions of knee extension and knee flexion at both 60 and 180 degrees per second with 60 seconds of rest in between reps. Peak torque of both the hamstrings (knee flexion) and quadriceps (knee flexion) will be recorded. Quad dominance will be evaluated by calculated the hamstring-to-quadricep (H/Q) ratio at each speed.

To safeguard internal validity, a meticulous approach to train evaluators is necessary. Rigorous training sessions will be conducted, focusing on standardized assessment techniques and meticulous data collection procedures. The emphasis will be on fostering consistency and objectivity in evaluating participants' motor skills, ensuring adherence to intervention protocols, and documenting any adverse events or injuries encountered during the study. Moreover, evaluators will be sensitized to recognize and mitigate potential biases that might influence data collection.

Analysis

Mean TGMD2, LESS scores, and the H/Q ratio will be compared between the preadolescent IPP and the traditional IPP using two tailed t-tests. Demographic information including age, ethnicity, and socioeconomic status will also be collected for analysis. T tests will then be performed to identify any difference in outcomes between ages 8-10 and the 11-12 age groups. Ethnicity and socioeconomic status be compared with mean outcomes scores using ANOVA.

Timeline

The clinical trial will begin in the first month with obtaining Institutional Review Board (IRB) approval. In the second month, participants will be recruited for the study. The third month will involve baseline data collection, including preintervention assessments of the Test of Gross Motor Development-2 (TGMD-2), the Landing Error Scoring System (LESS), and BioDex values. In the fourth month, participants will be randomized and assigned to different groups. The intervention period will span from the fifth to the eighth month. In the ninth month, post-intervention assessments of outcomes will be conducted. Data analysis will take place in the tenth month. Finally, in the eleventh month, the results and conclusions of the trial will be presented.

Resources

TGMD-2 supplies will include: 2 cones, 1 4-5" bean bag, 1 soccer ball, 1 tennis ball, 1 4" plastic ball, 1 plastic bat, 1 Nerf ball, 1 batting tee, trained clinician to administer test. LESS evaluation will require 30 cm box, marking tape, measuring tape, trained clinician to administer test. To perform isokinetic dynamometry a BioDex will be utililzed. Finally, for video recording the study will need 2 cameras, 2 tripods, 2 trained research assistants.

Institutional Review Board

This study protocol will be submitted for expedited IRB review to the Boston University Medical Campus IRB under category 4 and child research category 1. This study would be considered minimal risk. The population would already be participating in sports activity, still there is some risk associated with performing an IPP. However, the IPP is ultimately mitigating and chance of injury. As children are considered a vulnerable population, informed consent from the parent and assent from the child will be obtained. Additional protections include ensuring the child fully understands there would be no negative consequences if they do not wish to participate, and they can withdraw from the study at any time. Furthermore, all procedures will be conducted in a safe and controlled environment, with trained personnel present at all times to monitor for any adverse effects.

CONCLUSION

Discussion

The KICKSTART program presents several advantages over existing interventions, particularly through its focus on pre-adolescents, a group often overlooked in ACL injury prevention programs that predominantly target older athletes. KICKSTART is tailored to the developmental needs of children aged 8-12, incorporating exercises that are appropriate for their motor skill level. This specificity enhances motor skill proficiency more effectively than traditional programs like FIFA 11+, which are generally designed for older age groups. The structured progression of exercises, supervised by clinicians, ensures that movements are performed correctly and safely, thereby reducing the risk of injury. Additionally, the use of verbal feedback and cue descriptions improves the educational aspect of the program, fostering better technique and understanding among young participants.

Furthermore, the study's randomized controlled trial design, comparing KICKSTART to FIFA 11+, offers a robust framework for assessing the new program's effectiveness. The application of objective measures, including TGMD-2 scores, LESS, and isokinetic dynamometry for muscle strength assessment, enhances the study's methodological rigor. This comprehensive evaluation allows for a thorough analysis of the intervention's impact on ACL injury risk factors.

Although the study design was carefully curated, there are still limitations that must be acknowledged. While the sample size has been calculated to ensure adequate power to the study, the generalizability of this study could still be limited. There would be limited detection of findings to a broader populations of female youth soccer players. The findings would only be applicable to a specifically targeted population of young female soccer players in the Boston area. Further, generalizing this study's results to different age groups, male soccer players, or athletes from different sports would be inexact. This study also excludes those with a neuromuscular disorder or previous ACL injury to decrease variability among objective measures. However, this does not represent the diversity of the youth soccer population. Although this study specific focus is on youth female soccer players aged 8-12, which has been shown to be an understudied population, its application to different populations may be limited.

As in any real-world setting, there is significant variation among coaches or instructors of IPPs. Although steps were taken to ensure that instructions to the exercise protocols of both IPPs remained consistent, there still may be variability between personnel. This could influence outcomes of the study. In parallel, there could be subjectivity surrounding the scoring of TGMD 2 and LESS evaluations. Evaluators may have inherent unconscious biases that may influence scoring. They also may perceive cues of success or failure differently person to person but vigorous instruction will be provided to decrease this variability.

Those who choose to participate in this study may be inherently more motivated to perform the IPP correctly in hopes of decreasing their chance of sustaining an ACL injury and continue to play their sport. This may affect how the variables are scored and how the children respond to the IPP. Children may also have a fear of disappointing their parents, coaches, or instructors and therefore perform better overall. Therefore, changing the real-world implementation of this IPP.

Summary

The anterior cruciate ligament (ACL) plays a crucial role in knee stability, connecting the femur to the tibia and preventing excessive forward movement and rotation of the tibia relative to the femur. ACL injuries are significantly more common in females, attributed to a mix of anatomical, hormonal, and biomechanical factors. Nonmodifiable risk factors include anatomical features such as a variable posterior tibial slope, narrower intercondylar notch, smaller ACL size, and a greater Q-angle, which affects knee alignment. Hormonal fluctuations also have a multifactorial impact on increasing the risk of injury. Conversely, modifiable risk factors involve neuromuscular and biomechanical elements. Those include improper landing mechanics, insufficient muscle strength, and muscle imbalances, especially between the quadriceps and hamstrings. By addressing these modifiable factors through targeted injury prevention programs, it is possible to significantly reduce the occurrence of ACL injuries in females. Current IPPs have been shown to a have a positive impact on injury rates in an older population. However, the literature review revealed there was a lack of ability for younger females to perform the exercises prescribed in the existing injury prevention programs. This led to a study design to experiment with a newly designed IPP targeted to the neuromuscular movements this specific age group can perform. Further, it will be evaluated using a movement model aimed towards pre-adolescent movement patterns (TGMD-2) with ACL specific evaluations also being performed including muscle dynamometry and LESS scoring. Results from this study will advance knowledge regarding the real-world implementation of ACL IPPs, making for a more comprehensive prevention strategy.

Significance

Effective ACL injury IPPs are pertinent to reduce injury in a vulnerable population where injury could have lifelong ramifications. Ultimately, less injury would reduce OA incidence later in life, decrease health expenses associated with ACL injury, and decrease the impact of these injuries on institutions who employ athletes.

Currently there are multiple investigations into the increasing incidence of female ACL injuries as women professional sports continue to increase in visibility. FIFPRO, in conjunction with Professional Footballers' Association England, Nike, and Leeds Beckett University, recently launched a 3-year study in the Football Association Women's Soccer League due to the lack of existing research in supporting IPPs in professional women's soccer leagues. As research continues to advance in professional leagues, it is important to also expand research into the pre-adolescent population, as ACL injury prevention beginning earlier will only benefit these athletes as they advance their careers into professional sports. This study aims to enhance our understanding of how to best support female athletes in their soccer careers. Ultimately, this will empower young girls to participate in sports with comprehensive injury prevention measures in place.

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