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A systematic review: The effect of prophylactic braces on reducing risk factors related to ACL injury in athletes

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A systematic review: The effect of prophylactic braces on reducing risk factors related to ACL injury in athletes

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ABSTRACT

A SYSTEMATIC REVIEW: THE EFFECT OF PROPHYLACTIC BRACES ON REDUCING RISK FACTORS RELATED TO ACL INJURY IN ATHLETES

By

Zak Linczeski

Purpose: Anterior cruciate ligament (ACL) injuries are one of the most common sports-related injuries as they account for around 100,000 injuries per year. This study sought to review research on prophylactic knee bracing (PKB) for the reduction of the risk factors related to injury of the ACL.

Methods: An extensive search of articles from 1990-2021 was performed with inclusion criteria of no previous ACL injury, no knee injury or surgery in the past 6 months, the use of a hinged knee brace, and use of kinetic, kinematic, and proprioceptive variables. All studies underwent a PEDro score evaluation to determine article quality. All relevant variables were then compared on a braced vs unbraced basis with further evaluation via two brace categories of fit and type.

Results: Four selected articles were included in the review where kinematic, kinetic, and proprioceptive data were assessed. The custom braces led to greater improvements in mechanisms of injury than the generic counterparts. The other category, type, saw the hinged braces perform better with most kinematic and proprioceptive variables. The primary exception was knee flexion which saw one hinged brace have increased knee flexion while one saw a decrease. Additionally, the non-hinged brace saw an increase in knee flexion.

Conclusion: The analysis of the results allowed for the recommendation that the current research shows the most effective bracing protocol to involve custom, hinged braces. These types of braces allowed for the greatest improvement of the factors related to mechanisms of injury for the ACL. Future research should evaluate different types of braces, varied athlete populations of different ages, and usage of consistent variables to allow a more direct comparison of braces.

Keywords: knee brace, kinetics, kinematics, prophylactic brace

DEDICATION

This thesis is dedicated to my wife, Molly, who has always helped to shake the frost off of my bones.

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Chapter One

Introduction

Trauma to the anterior cruciate ligament (ACL) is one of the most common sports-related injuries with an estimated 100,000-200,000 occurring each year [15, 39]. A study analyzing the National Collegiate Athletic Association Injury Surveillance Program demonstrated the highest rates of ACL injury in women's gymnastics (0.34%), women's lacrosse (0.44%), men's lacrosse (0.42%), and football (1.52%) [15]. Collegiate injury rates were analogous to high school where most injuries occurred in men's football (0.33) and women's sports including soccer (0.28%), basketball (0.23%), and gymnastics (0.33%) [31]. The incidence rate was reported as events per 10,000-athlete exposure. The majority of high school injuries happened in women's soccer and football while in college, football and women's gymnastics were the most common. The incidence rate peaks around age 18 for women while remaining high for adult males between the ages of 16-30 [31]. The high incidence rate is demonstrated further by the evidence that in some sports such as football, handball, and jiu-jitsu, injuries to the ACL account for approximately 50% of all lower leg injuries [45]. Due to the high incidence of ACL injuries, it is imperative to determine effective methods to reduce injury incidence. Current research varies on the effectiveness of bracing in reducing ACL injuries and is limited in how they can reduce injuries in high-risk athletes [4, 12, 16, 25, 36, 54, 55].

There is a need to determine if prophylactic braces can effectively reduce injuries in high-risk athletes. Conflicting results exist that support and refute bracing efficacy making it controversial [4, 12, 16–18, 25, 33, 36, 51, 54]. Limited research exists on the brace's ability to reduce injury incidence in high-risk individuals [12, 16, 18, 25, 36, 55]. Preventative modalities, especially bracing, are important due to the high rate of ACL injury and the subsequent effects following injury. To help assess the effect of bracing, two different categories of bracing will be evaluated in the current study. The two categories of bracing are custom vs generic braces and hinged vs non-hinged. Custom braces refer to those that are fit based on exact specifications for an individual while generic or off-the-shelf refers to a brace that is fit based on a range of sizes. Hinged braces refer to those with a flexible metal bar while non-hinged are braces without a flexible bar. The hip is an important factor in how well the ACL functions and subsequently affect the rate of injury due to the impact of braces on the hip joint.

The hip joint plays a pivotal role in the proper functioning of the ACL due to being proximally located to the knee as well as the function of the lower extremity as a kinetic chain [30]. Due to the interaction of this joint through the kinetic chain, it helps to stabilize the lower extremity during dynamic movements. Abnormalities in hip kinematics including increased hip adduction and internal rotation as well as decreased hip flexion increase the likelihood of ACL rupture [30, 47]. Multiple risk factors are associated with an ACL injury, including intrinsic and extrinsic elements.

Two intrinsic factor categories, modifiable and non-modifiable, exist. Modifiable factors include biomechanical abnormalities, body mass index, neuromuscular deficits, and hormonal status while non-modifiable factors include sex, anatomy, previous injury, and genetic predisposition [1, 18, 40, 42]. Extrinsic factors include the sports equipment, type of sport, weather, playing surface, and playing field conditions [44]. Etiologies of ACL ruptures differ as they can be due to contact or non-contact mechanisms. Rates of each mechanism of injury may vary by sport and within specific sports due to differences in position and physical demands [26]. Non-contact injuries are a common mechanism of injury across all sports.

Non-contact injuries involve the tibiofemoral articulation in all three anatomical planes of motion. More than 70% of ACL injuries are non-contact as the result of a jump landing or lateral cutting movement common in sports [28]. Primary mechanisms of injury include anterior tibial translation (ATT), knee valgus, and internal tibial rotation [28]. Additionally, poor knee proprioception can lead to greater joint instability, which can increase further the likelihood of the knee being placed into the injurious states of increased ATT, knee valgus, and internal tibial rotation [18, 42]. Injury primarily occurs during lower limb deceleration as the quadriceps contract fully and the knee is at 0 ° of extension. ACL rupture occurs due to the athlete generating immense force overloading the ACL [60]. Forces that overload the ACL include anterior shear force on the proximal tibia in conjunction with a valgus moment, which causes significant ligament strain [60].

Contact injuries result from a direct blow to the knee via a person or an object. This injury requires a fixed lower extremity in contact with the ground and the generation of enough torque to cause a rupture [8]. Additionally, the knee is internally rotated with an inverted foot contacting the ground [8]. The toe-in position of the foot further influences the kinematics of the knee and hip due to increases in the knee abduction and hip adduction angles. This foot position increases the internal tibial rotation [56]. A direct contact injury occurs in two ways. The first mechanism involves limb hyperextension while the second entails the knee being forced medially [8]. In addition to initial injuries, ACL re-injury is common.

Due to the incidence and effects of ACL injuries, there is interest for coaches, athletes, and researchers to determine effective prevention strategies and plans to help reduce the number of injuries. Countless studies have investigated and concluded effective injury prevention methods [2, 4, 8, 12, 16, 25, 36, 50]. Varied evidence exists regarding the efficacy of bracing for injury prevention. Several studies showed braces could decrease kinematic and biomechanical risk factors linked to increased injury risk [12, 15, 16, 36, 50, 52, 55]. However, these studies have demonstrated no correlation between braces and decreased risk factors with a negative impact or no change on biomechanics and proprioception. [4, 49, 54, 58]. Negative effects include an inability to reduce ground reactive forces (GRF) and ATT, decreased proprioception and reaction times, and decreased hamstring muscle activation the diminishing the ability to control ATT [5, 49, 54, 58]. The two methods studied were knee bracing (prophylactic and functional) and exercise programs.

The current study's primary focus is to review primary peer-reviewed research on prophylactic knee bracing (PKB) for the reduction of the risk factors related to injury of the ACL. This study sought to examine the effects that prophylactic braces had on the biomechanics and proprioception of the lower extremity to determine whether there are areas of design and use that can be improved upon to better protect against ACL injury. The purpose of this study is to conduct a systematic review of several studies on the effectiveness of prophylactic braces in the reduction of mechanisms of injury related to an ACL injury during athletic events. This will allow for recommendations to be made regarding the most effective categories of braces based on the currently available biomechanical evidence. Specifically, two different hypotheses will be explored in this study:

1. Custom braces will more effectively reduce mechanisms of ACL injury compared to generic braces.
2. Hinged braces will be more effective at reducing the mechanisms of ACL injury than non-hinged braces.

Methods

Search Strategies

An extensive search for pertinent articles occurred via the NMU OneSearch tool along with the PubMed databases with articles used from the years 1990 through 2021. Searches involved the following keywords: knee brace, prophylactic knee brace, joint kinetics, joint angle, joint kinematics, and ACL bracing. The language was limited to papers originally published in English. The initial search identified 1,081 articles. Further refinement of the search involved using the keyword of contact sport, which pared results down to 198 articles. Searches were further limited to include articles with participants who have not had any knee injury or surgery in the past six months, no previous history of ACL injury, and the use of a hinged, prophylactic knee brace. These studies were required to have variables related to kinetics, kinematics, and proprioception. Relevant studies were cross-referenced to discover articles that may have met inclusion criteria but were unidentified during the initial search. This process involved investigating if there were any articles cited by authors found in the original database search. The cross-referencing occurred via the use of the Google Scholar "cited by" feature. The four selected studies all involved a sports-specific dynamic type movement.

Furthermore, studies were also required to include participant details to allow for usage of the Physiotherapy Evidence Database (PEDro) scale to better evaluate the articles [9]. The PEDro scale is a system that scores studies on a 0-10 scale based on the quality of the methods [9]. The two reviewers (one male, one female, age =26 ±0 years) did not have prior experience with this scale. Each evaluator first reviewed each study individually before discussing and rating each of the studies as a group. All included studies were able to be rated via the PEDro scale with the majority of scores being seven while one was four to missing components of blinding and point measures (see table 1).

Data synthesis

Biomechanical variables including kinetic and kinematic variables were analyzed from the studies that were assessed during this systematic review. The variables included in the analysis were peak vertical ground reaction force (PVGRF), hip flexion, hip internal rotation (IR), knee flexion, knee frontal plane abduction (FPA), and proprioception. These variables were then compared using braced vs non-braced conditions to evaluate the effectiveness of bracing. For further evaluation, braces were divided into two categories based on the fit and type of the different braces utilized in the studies. These two categories are custom vs generic braces and hinged vs non-hinged braces. To enable comparison between values, the p-value was set a priori at $p < 0.05$.

Results

Included Studies and Quality Assessment

Four studies met the required criteria. All of the included articles provided the consensus that bracing is effective in improving various biomechanical factors that are related to an ACL injury as they lead to better proprioceptive control and better management of forces through the ligament [3, 6, 11, 31]. Bodendorfer et al. noted a decrease in knee flexion, however, the authors concluded the remaining reduction of factors outweighed the negative influence of decreased knee flexion [6]. See table 1 to observe the details of the included studies.

Effect of braces

An array of kinetic, kinematic, and injury variables were measured in the studies that were included in this systematic review. The effect of the different braces tested on the various variables is summarized in tables 2-4.

Table 4. Details of the selected research studies. Abbreviations used in this table include peak vertical ground reaction force (PVGRF), internal rotation (IR), and frontal plane abduction (FPA)

Study details	**PEDro score**	**Study design**	**Population**	**Brace used**	**Variable(s) measured**
Rishiraj et al., 2012	7; Is missing blinding components	Repeated-measures design	Male basketball and field hockey athletes	Ossur Extreme Ligament Brace	1. Peak vertical ground reaction force (PVGRF)
Baltaci et al., 2011	7; is missing blinding components	Repeated-measures design	Men and women aged 18-22	*Brace 1*: Hinged Trupull Advanced System *Brace 2*: Hinged 'H' Buttress Knee Brace *Brace 3*: Buttress for Support Patella *Brace 4*: Drytex Lat Pat Knee for Support of Knee *Brace 5*: Drytex Economy Hinged Knee	1.Proprioception
Bodendorfer et al.,2019	7; Is missing blinding components	Repeated-measures design	Male and female recreational athletes	*Brace 1*: Breg Neoprene Knee Support *Brace 2*: Breg Roadrunner Hinged Knee Brace	1. Knee flexion 2. Hip IR 3. FPA
Ewing et al., 2016	4; is missing blinding components and point measures	Controlled laboratory study	Male and female recreational athletes	POD MX K300 knee brace	1. Hip flexion angle at PVGRF 2. Knee flexion angle at PVGRF

Table 5. Effect of bracing on PVGRF compared to the control unbraced condition.

Brace name	Study	Type of fit	Type of brace	Effect
Ossur Extreme Ligament Knee Brace	Rishiraj et al., 2012	Custom	Hinged	↓

↔ denotes no significant change, ↓ indicates a significant decrease, ↑ indicates significant increase, and – indicates variable was not measured. Significance indicated when $p < 0.05$

Table 6. Effect of braces on proprioception leg compared to unbraced control.

Condition	Study	Type of fit	Type of brace	Effect
Drytex Economy Hinged Knee	Baltaci et al., 2011	Generic	Hinged	↑

Table 4. Effect of braces on kinematic variables

Brace name	Study	Type of fit	Type of brace	Effect Knee Flexion	Effect hip flexion	Effect FPA	Effect Hip IR
POD MX K300 knee brace	Ewing et al., 2016	Generic	Hinged	↑	↑	-	-
Breg Neoprene Knee Support	Bodendorfer et al.,2019	Custom	Non-hinged	↓	-	↔	↓
Breg Roadrunner Hinged Knee Brace	Bodendorfer et al.,2019	Custom	Hinged	↓	-	↓	↓

↔ denotes no significant change, ↓ indicates a significant decrease, ↑ indicates significant increase, and – indicates variable was not measured. Significance indicated when $p < 0.05$

Discussion

The purpose of this study was to review the current research on the use of prophylactic bracing on reducing the mechanisms of injury associated with injury to the ACL. This occurred through the review of four different articles related to ACL bracing. The findings of each of the different studies can be found in table 6. Through this thorough review, two different hypotheses were analyzed and assessed allowing for a greater understanding of current knowledge of bracing. These hypotheses were:

1. Custom braces will more effectively reduce mechanisms of ACL injury compared to generic braces.
2. Hinged braces will be more effective at reducing the mechanisms of ACL injury than non-hinged braces.

Effects of braces

Two different categories of braces were able to be evaluated through this systematic review. The first category, type of fit, also directly corresponds with the first hypothesis. The main area that this hypothesis that can be directly assessed is the effect on kinematic variables (see table 4). With these variables, we can directly observe the contrast between custom and generic. The primary observation that was able to be made was that the generic brace led to an increase in knee flexion while the custom braces led to a decrease in knee flexion. Other observations were that the generic brace increased hip flexion while the custom braces led to decreased hip IR, knee FPA, and PVGRF. The findings (see tables 2 and 4) do support the first hypothesis despite some minor negative effects of decreased knee flexion seen with custom bracing.

A decrease in knee flexion is a negative effect of bracing due to the effect of knee flexion increasing the amount of force transferred to the ACL [37]. Previous studies have shown that when the knee is in a more extended position, ground reaction forces are greater causing a greater amount of force to be transmitted through the ACL due to the decreased force absorption capacity [34, 46, 60]. While there is a decrease in knee flexion (from approximately 50 to 46 degrees), it is still much greater than 20 degrees which is a level that can allow for dangerous levels of GRF to be distributed through the ACL. High levels of knee flexion are still observed with the brace even if they are slightly decreased indicating that it is still well within a safe range of knee flexion [11, 32, 35, 46]. Multiple positive changes were observed as well. The positive aspects of custom bracing are related to minimizing knee valgus which is one of the primary mechanisms of ACL injury [28, 37]. A decrease in knee FPA also helps to minimize the degree of valgus that occurs at the knee [7, 21, 22]. The final important factor is a decreased PVGRF which could help to further minimize the force transmitted through the ACL helping to reduce the impact of the knee flexion [48, 57]. Based on all of these factors, it is of this author's opinion that custom braces are more effective at reducing the mechanisms associated with an ACL injury.

The second category, type of brace, compares hinged and non-hinged braces. Multiple comparisons can be drawn between hinged and non-hinged braces. The first of these is the effect on proprioception as there was not a definitive difference noted in proprioception for the braces although all the braces led to improved proprioception (see table 3). It is important to note the Drytex Economy Hinged Knee was the only brace that was able to be fully compared to the unbraced condition. The other braces included in the

Baltaci et al. study were not able to be directly compared to the unbraced condition due to the absence of p-value or effect size measures. The next factor evaluated was PVGRF which was decreased with a hinged brace (see table 2). The final kinematic variables are more complex due to conflicting data (see table 4). The hinged brace used in Ewing et al., 2016 showed an increase in knee and hip flexion while both of the braces (hinged and non-hinged) in Bodendorfer et al., 2019 showed decreases in knee flexion, hip flexion, and knee FPA. Based on the results of these studies, the second hypothesis is partially supported.

Multiple benefits of the hinged brace support the second hypothesis. The first is due to the braces leading to increased proprioception which is believed to increase the protection of the knee joint as the knee is less likely to be placed in an injurious position [19, 29, 43]. This is an important component in both managing and preventing ACL injuries [43]. Additionally, the hinged braces led to decreased knee FPA which is important due to minimizing the amount of knee valgus experienced [7, 22, 22]. The decrease of hip IR with the hinged brace may also help with neuromuscular control and minimizing knee valgus [59]. A decrease in the movement from the hip in the transverse plane (IR) is important as excessive motion in this plane is believed to contribute to greater valgus and increased loading [35]. The last aspect of kinematic interaction is the effect on knee flexion which had conflicting results as one hinged brace had an increase while the other hinged and non-hinged braces had a slight decrease (see table 4). While this is contradicting, it is of this author's opinion that the other positive influences on the hinged braces far outweigh this possible negative influence as the knee flexion was still well within a safe range. As mentioned while talking about hypothesis one, the effect of decreased knee flexion can be minimized by the other improvements seen with the brace while an increase in knee flexion may have a positive influence. Due to all of the interactions of the brace with the various factors, the hinged brace is likely to provide a greater degree of prophylactic protection to the knee.

Recommendations

The recommendations of the individual studies are summarized in table 5. Through careful analysis of the data found in the included studies, a few different recommendations can be made by this author regarding the usage of braces. The first recommendation is that custom braces should be utilized whenever possible due to improvements observed with kinematics, kinetics, and proprioception. It is worth noting that while custom braces did function better at reducing factors associated with mechanisms of injury to the ACL and brace migration, they are significantly more expensive than their off-the-shelf counterparts. Athletes, clinicians, and coaches will have to weigh the benefits of this type of brace vs the cost to make their final bracing decision. The other primary recommendation is regarding the type of brace. While there were some conflicting results across the studies, the evidence supports the use of hinged braces due to the significant positive impact on factors associated with mechanisms of injury. The hinged brace was more effective at reducing the negative factors associated with injury. Based on the categories investigated in this study, a custom and hinged prophylactic brace would be the most effective way to reduce the factors related to mechanisms of injury of the ACL.

Limitations and future research

The limitations of the included studies are summarized in table 5. There were also a few limitations of this systematic review. One main limitation of this study was many of the included studies did not investigate the same variables causing direct comparison to be difficult at times. Interpolation of the results of the different studies was required as each study evaluated different kinematic and kinetic variables. A second limitation of this study was only one functional knee brace (FKB) was utilized in the studies which limited the ability of this author to compare FKBs to prophylactic braces to evaluate the differences in effectiveness at reducing mechanisms of injury. Another limitation of this study was different braces were used in each of the studies meaning that the conclusions drawn regarding braces were not specific to one specific brace. This could mean multiple factors were in play that could lead to the reduction of some of the factors related to mechanisms of injury. The last major limitation was none of the studies measured distal brace migration during activity. This is a substantial factor that can decrease the effectiveness of a knee brace when it is not corrected [41].

The final major limitation can be divided into three parts and is related to the methodology of this review. The first part is two people conducted the article search and it is possible the inclusion of a third person, could have led to more articles being included in the study since it would have been more objective. Secondly, due to limited research matching the criteria, only four studies were included in this review which limits further the data available to evaluate and make recommendations on the efficacy of bracing strategies. The third component is this study did not allow for the inclusion of studies originally published in a foreign language due to the issues and expenses that can arise when translating an article from its native language to English. This means some studies would have otherwise met the inclusion criteria and enhanced the results of this study, which may have been excluded.

The recommendations from each of the individual studies regarding future research are summarized and can be seen in table 5. Future research in the area of ACL bracing should focus on several different concepts. The first is focusing on consistent kinematic and kinetic variables allowing for comparisons of the different braces. Additionally, by using consistent brands of braces, more comparisons can be made with a few variables at play that could change results. Another area of study that would be useful is to include a wider assortment of types of braces. Different types of braces should include FKBs, hinged, non-hinged, and neoprene sleeves. The inclusion of these different types of braces would allow for more recommendations to be made for more effective brace prescriptions. The final recommendation for future research would be for a more diverse participant population to include athletes from a wider variety of sports to enable recommendations to be more specific to different sports and the athletes in those populations.

A few recommendations can also be made regarding a future systematic review. The first is having a three-member panel to search and review articles will remove much of the subjective components. Secondly, having an effective and cost-efficient method to translate and include foreign language articles in the search would increase the likelihood that a true comprehensive article search was conducted. Finally, expanding the inclusion criteria could lead to more articles being included which would allow for more data available for interpretation.

Table 5. Summary of the limitations and recommendations in the included studies

Study	Limitations	Recommendations
Rishiraj et al., 2012	• Performance ability of the athlete • The short duration of brace accommodation • Limited evaluation of brace migration • Didn't evaluate game conditions	• Future research should evaluate lower extremity kinematics/NMS control • Investigate the efficacy of FKB in reducing injury incidence and severity • Braces may reduce PVGRF limiting traumatic forces
Baltaci et al., 2011	• Didn't show that brace usage doesn't hinder performance • Didn't have evidence for a proper technique of brace application • Small sample size/a large number of conditions • Did not report p-value or effect size for proprioception limiting comparisons	• Bracing in healthy subjects can be used to enhance performance • Add subjects who have had knee injuries to evaluate better the effect of braces • Evaluate braces based on fitness level
Bodendorfer et al.,2019	• Small sample size • Some measurements are not validated • The study was not specifically designed to determine the role of braces in limiting injurious mechanisms	• Bracing may protect against non-contact ACL injury • Future studies should specifically measure tibial rotation • Studies should utilize a larger sample size and a more diverse population • Need to evaluate long-term effects of bracing on joints
Ewing et al., 2016	• Only studied biomechanics in the sagittal plane • No prior experience of participants wearing braces • Did not account for muscular changes possible due to bracing	• Future studies should evaluate different types of braces • Evaluate the effectiveness of braces with training • Investigate long-term training effects • Evaluate if bracing is indicated for high-risk athletes

Table 6. Summary of the findings of the included studies

Study	Findings
Rishiraj et al., 2012	• Lower PVGRF in braced conditions may limit traumatic force to the ACL allowing neuromuscular (NMS) • Greater NMS helps to control to protect ligament reducing injury risk
Baltaci et al., 2011	• Bracing was shown to provide coordination and maximal force while enhancing proprioception. • Sports performance may be diminished in unfamiliar individuals

Bodendorfer et al.,2019	• Bracing was shown to decrease hip IR, knee flexion, and knee FPA which may decrease dynamic knee valgus. • The benefit of reducing knee FPA may outweigh the risk of decreased knee flexion due to improved NMS control.
Ewing et al., 2016	• Bracing increased hip and knee flexion angles which may diminish forces transmitted through ACL and decrease knee valgus • Increased peak hip extension moment that decelerates the knee

Chapter Two

Literature review

The high incidence of ACL injury in high-risk athletes produces significant interest for researchers, athletes, and coaches to determine effective injury prevention strategies. This systematic review sought to evaluate the effectiveness of prophylactic bracing based on two different categories. The two categories of bracing assessed were custom vs off-the-shelf (generic) and hinged vs non-hinged. The anterior cruciate ligament is a crucial structure fulfilling a pivotal role during static and dynamic movements of the knee. The function of the ACL is highly dependent upon the interaction of the kinetic chain. An injury to the ACL is common during competition due to intrinsic and extrinsic risk factors. Two primary etiologies, contact and non-contact mechanisms, exist, although re-injury is common as well. Numerous consequences occur involving short and long-term effects. Due to many adverse outcomes, it is imperative to determine appropriate preventative measures to reduce the incidence of ACL injuries. Preventative modalities include exercise programs and bracing protocols. This literature review evaluates the anatomy and biomechanics of the ACL as well as the etiology and injury incidence. Additionally, it discusses the short and long-term consequences of ACL injuries. Finally, this review will evaluate the current preventative modalities being used for ACL injuries and will include prophylactic bracing, functional bracing, and exercise programs.

Structure of the ACL

Anatomy

The ACL, an intracapsular ligament, is a primary knee stabilizer originating on the posterolateral femoral condyle and inserting anteriorly to the intercondylar eminence of the tibia [8]. It is composed of two different bundles, the anteromedial (AM) and posterolateral (PL) bundles. The naming utilizes their insertion points on the tibial plateau [10]. The location and anatomy of the different facets of the ACL enable the pivotal role of knee stability.

Function

The ACL is vital in knee stabilization during dynamic movements. The primary function of this ligament is to prevent the anterior translation of the tibia on the femur. Additionally, it aids in the prevention of ATT, excess knee extension, and varus and valgus movements [31]. The two bundles have distinct functions. The AM bundle functions when the knee is in a flexed position while the PL bundle is active when the knee is in an extended position [10]. The proper functioning of the ACL is dependent upon the kinetic chain and the interaction between the different components (hip, knee, and ankle/foot).

Influence of the hip and foot

The connection between the foot, knee, and hip is important in the lower extremity kinetic chain. The knee is affected by the kinematics of the proximal (hip) and distal (ankle/foot) aspects of the kinetic chain [30]. This enables increased stabilization of the lower extremity during weight-bearing activities, allowing for increased support, neuromuscular control, and proprioceptive feedback during dynamic activities [27]. Alterations in the kinematics at the ankle and hip can lead to changes in the biomechanics of the knee. Changes include increased hip adduction and internal rotation, decreased hip flexion, increased foot pronation**,** and reduced plantarflexion [30, 47]. All of these deviations from normal kinematics result in an increased injury risk due to decreased abilities to absorb forces during landing and increased valgus and anterior translation of the tibia [47]. The role of the ACL and abnormalities due to deviations from the proper functioning of the kinetic chain causes the ligamentous structure to have a high injury incidence.

Injuries to the ACL

Incidence

ACL ruptures are common sports injuries with an estimated 100,000-200,000 cases per year [39]. The injury rate at the collegiate level varies by sport with the highest incidence occurring in men's football, women's gymnastics, and women's soccer [15]. The incidence in high school athletes is lower than in collegiate athletes; however, there is a similar injury distribution by sport. In high school, ACL injuries are most common in girls' soccer, boys' football, and girls' basketball [31]. Additionally, injuries were more common in female sports than male sports as they represented a more substantial percentage of total injuries. Studies showed females injure their ACL three to four times more often than males participating in the same sport. The increased incidence is attributed to differences in biomechanics, anatomical structures, and hormonal status [28]. Injury to the ACL involves various risk factors, which include extrinsic and intrinsic elements.

Intrinsic risk factors

There are many underlying intrinsic, non-modifiable risk factors for an ACL injury that exist and with disparities between genders. Anatomical variation is apparent in both sexes. In males, changes leading to injury include a significantly narrower intercondylar notch and an increased slope of the posterior tibia [2]. Additional, less significant factors that differ in males include increased body mass index (BMI), laxity of the ligaments of the knee, decreased hip range of motion, and a greater distance from the base of support and the center of mass [2]. Variation in anatomical structures is evident in the female athletic population as well.

Females tend to have specific anatomical variations that may predispose them to a greater incidence of ACL injuries. Female athletes are more likely to have more significant ATT than males [23]. A considerable difference in anatomy is related to an increase in the flexibility of the hamstrings in females compared to men, which will affect dynamic control of the knee [23]. Additionally, women tend to have a higher overall joint laxity, which can increase knee hyperextension, and valgus, both predisposing them to injury. Increased knee laxity in the frontal plane can lead to more significant ATT [44]. Less substantial factors include age, BMI, hormonal effects of estrogen and contraceptives, and increased foot pronation and navicular drop. Hormonal effects vary throughout the menstrual cycle with a higher injury incidence during the luteal phase [23, 40]. In addition to the intrinsic non-modifiable risk factors, modifiable intrinsic risk factors are essential in understanding how injuries to the ACL occur.

Several modifiable risk factors for ACL injury exist. Neuromuscular and biomechanical deficits are two of the more important risk factors due to their significant influence on the mechanisms of injury of knee flexion, ATT, internal tibial rotation, and valgus as a result of poor landing technique [1, 42]. BMI and hormonal status are two other modifiable factors, however, depending on the sport, it may be very difficult to alter BMI while maintaining a high level of performance while hormonal status often cannot be changed without medical intervention which violates most competitive guidelines [1]. The final factor, fatigue, is important as when the body is fatigued, there is an increased likelihood the joints are positioned in disadvantageous positions amplifying the injury risk [1]. In addition to the modifiable intrinsic risk factors, extrinsic factors are essential in studying ACL injuries

Extrinsic risk factors

Extrinsic, modifiable risk factors rarely differ by gender. Certain elements are easier to control while others may be somewhat beyond control. Difficult to control aspects include weather conditions (wet vs. dry fields), playing surface or type of grass, and the state of the playing surface [44]. The factors that are easier to control include the kind of footwear and the function and number of cleats. Additionally, the interaction between the shoe and the surface can play a pivotal role in the incidence of ACL injury. This interaction can increase the amount of torsional resistance between the foot and the ground leading to an elevated injury incidence [53]. These various factors may all contribute to ligament injury in athletes. These intrinsic and extrinsic risk factors can lead to two different mechanisms of injury that can occur via contact or non-contact mechanisms.

Etiology

Non- contact mechanism

The primary mechanism of injury is non-contact, without a direct blow, occurring in approximately 70% of ACL injuries [28]. This mechanism requires the athlete to generate large amounts of force at the knee that causes the ACL to be excessively loaded. Usually, this includes movements with cutting and jumping [60]. Injuries of this type encompass motions of the tibiofemoral joint in all three planes of motion with loadings such as anterior shear, valgus of the knee, and internal tibial rotation [28]. When these injuries occur, the knee is at full extension with maximal quadriceps contraction, leading to increased force and stress on the ACL [8]. While the primary cause of injury to the ACL is non-contact, it is essential to be conscious of how contact injuries can occur during sport.

Contact mechanisms

The remaining 30% of injuries are the result of a direct blow to the leg. This direct blow can occur via a person or an object with the mechanism including two primary elements. The first is a fixed lower extremity such as planting of the leg or enough torque to cause ACL tearing to occur [8]. While non-contact injuries are the most common mechanisms, the rate of contact injuries can vary from sport to sport as well as within a specific event. Within football, more skill position players (wide receivers, defensive backs, and running backs) incur injury via non-contact mechanisms while offensive and defensive linemen will primarily suffer injury via contact [26]. Injury mechanisms differ mostly due to variations in the physical demands and duties amongst various player positions. In addition to first-time injuries involving contact and non-contact, it is common for re-injury to occur in athletes, as the rate of injury ranges from 4.5% and 10%.

Re-ruptures of the ACL

Research has shown that up to 50% of these injuries may occur within one year after reconstructive surgery [20, 39]. The majority of these cases, 55%, involve non-contact injury to the grafted ACL. These injuries primarily occur because of returning too quickly to competition. Female athletes were observed to rupture their ACL at a higher rate than males due to insufficient neuromuscular control and imbalances in muscle strength, coordination, and flexibility [15]. Regardless of the mechanism, various consequences occur as a result.

Effects of ACL injury

Short-term consequences

Some of the possible short-term effects resulting from ACL injury include joint effusion, diminished muscular strength, alteration of movement patterns, decreased coordination and proprioception, and a reduction in sport-specific functional performance. Alterations in biomechanics can contribute to knee instability and diminished performance [24, 28]. This can substantially impact the ability of athletes to perform at a peak level that is necessary for success. Changes in stability and function of the lower extremity can also result in the loss of an entire sports season or longer. Additionally, there is a substantially increased risk for re-injury of the ACL following an initial injury. Long-term sequelae may also occur because of injury indicating extra emphasis to reduce the risk factors associated with injury.

Long-term consequences

Some long-term effects are evident in conjunction with the array of short-term impacts of ACL injuries. The primary long-term consequence is the increased risk of the development of early-onset osteoarthritis (OA). There is a substantial increase in the risk of early-onset OA [28]. Additionally, individuals who have torn their ACLs are more prone to subsequent injuries to their meniscus and articular cartilage. These injuries lead to functional limitations and increased pain which may necessitate the need for osteotomy or knee arthroplasty before the age of 50 [38]. Due to the various short and long-term consequences of an ACL injury, there is a need to investigate injury prevention methods.

Preventative measures

Prophylactic braces

The use of PKB may target less modifiable risk factors like anatomical and hormonal that lead to injury. Prophylactic bracing can perform a pivotal role in reducing ACL loading due to increased energy absorption, decreased ATT, decreased hip IR, decreased knee valgus, and an increased knee flexion angle during landing [12, 16, 17, 36, 50, 51]. Other studies have shown that bracing can increase the force absorption that occurs when landing from a jump. Minimizing force is correlated with a reduction in injury to the ACL [18, 33]. Bracing of the knee has also been suggested to improve the proprioception of the knee which aids in better joint positioning to avoid injurious states for the ACL [18, 42]

Increasing the knee flexion angle during jumping is pivotal for injury prevention as small knee flexion angles incur high loads on the ACL corresponding to increased injury risk [36]. The reduction of ATT occurs in activities where increased rotational and translation forces are commonplace. It was most prevalent when athletes were landing from a jump and then pivoting [16]. Other studies have shown that prophylactic braces were ineffective at reducing injuries.

While many studies have shown bracing can reduce injury incidence, studies have also demonstrated that bracing does not affect the incidence rate. These studies determined that the slowing of hamstring reaction times, as well as reductions in the speed of running and turning movements, are evident with bracing [4, 31]. Bracing, while often used prophylactically, can also have significant usage following injury.

Functional braces

Functional knee bracing (FKB), used as a substitute for damaged or missing ligaments, is designed for sports participation [14]. Usage of braces occurs in conjunction with surgical intervention or place of surgical operation. The purpose of braces is to protect an injured ACL during healing due to a restoration of normal tibiofemoral kinematics. Bracing reduced ACL strain and ATT while increasing knee flexion and also enabled running and cutting improvements and decreased injury incidence [54].

Utilization of bracing in ACL deficient and injured knees has been found to reduce strain on the ACL with the application of anterior shear loads to weight-bearing and non-weight-bearing legs. Bracing, however, was noted to be unable to decrease external loads and varus and valgus moments in the weight-bearing lower extremity [14]. Differences existed between double-leg and single-leg activities, indicating reduced effectiveness of bracing when subjected to higher loads as seen in single-leg exercises. FKB was also theorized to reduce meniscal strain and minimize the damage to articular cartilage in ACL damaged and deficient knees [55]. Additionally, functional bracing was able to improve performance during cutting and running movement and increase knee flexion during vigorous activities [54]. Other evidence demonstrated the use of ACL bracing does not influence pain, stability, or function following surgery [49].

Other studies have determined functional bracing does not minimize strain on the ACL or ATT during practical-type activities. Additionally, there was limited evidence to suggest a reduction in GRF [54]. Studies showed FKB was unable to restore normal joint kinematics during high-stress activities. There was also evidence of thigh atrophy and decreased joint and muscle stabilization with bracing [49]. While bracing is the focus of this study, exercise programs are an integral component of injury prevention programs.

Exercise programs

While not a primary focus, preventative exercise programs are pivotal in the reduction of ACL injuries. These programs vary in their content; however, it is necessary to include neuromuscular training within the program. The regiments should consist of strength training, plyometrics, dynamic balance, stretching, and improvement in landing patterns [4]. These programs should also highlight hamstring recruitment (minimize quadriceps dominance), dynamic trunk training, and compliance strategies [4].

Due to the high incidence of ACL injuries amongst high-risk athletes, it is imperative to determine prevention strategies. This study sought to determine the effectiveness of two different prophylactic braces on factors related to injury and if pricing influences the level of efficacy. This literature review aimed to provide an overview of the structure and function of the ACL while also examining the mechanisms and incidence rate of injury. Additionally, it investigated the various methods used to reduce the high incidence of ACL injuries within high-risk athletes. These methods include prophylactic bracing, functional bracing, and preventative exercise programs. A systematic review was performed to evaluate the literature to determine the current evidence on prophylactic bracing for ACL injury. This enabled a better understanding of current practices that are being utilized and their efficacy in minimizing risk factors associated with injury.

Chapter Three

Conclusion

Two hypotheses were assessed via this systematic review. The first hypothesis was that custom braces would be more effective at reducing the mechanisms of ACL injury. This hypothesis was fully supported due to the multiple positive benefits observed with the use of a custom vs generic brace. The second hypothesis was that hinged braces would be more effective at reducing the mechanisms associated with an ACL injury. This hypothesis was partially supported as a result of the positive changes observed with most of the kinematic and kinetic variables as well as proprioception. The primary reason that it is not fully supported is due to the somewhat conflicting results observed with knee flexion as some hinged braces decreased knee flexion while others led to an increase. The evidence in the included studies suggests that a custom, hinged brace will have the greatest prophylactic effect at reducing the mechanisms of injury associated with ACL damage.

This study was not without its limitations which could have impacted the results. For future research, reviews should include three or more reviewers to make articles searches as objective as possible. Additionally, the inclusion of foreign language papers could allow for insight into a greater understanding of bracing protocols. The final recommendation for a review would be to possibly expand the inclusion criteria to allow for more articles to be selected and analyzed. Recommendations for future research include the utilization of different types of braces such as FKBs, using consistent kinematic and kinetic variables, and a more diverse population of athletes in different sports and various ages. This would allow for greater applicability of results

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APPENDIX A

IRB approval document

IRB approval-Linczeski NMU Saved ×

Zak Linczeski Mon, Feb 15, 11:01 AM (1 da

Hello Dr. Anderson, My name is Zak Linczeski and I am a MSc. Exercise Science student working with Dr. Sarah

Derek Anderson Mon, Feb 15, 11:52 AM (1 day ago)

to me

Hi Zak,

Your project would not require IRB review. Good luck with your research!

Derek

Dr. Derek L. Anderson

Chair - Institutional Review Board | Professor | School of Education, Leadership, and Public Service

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APPENDIX B

PEDro Scale

1. Eligibility criteria were specified? No ☐ Yes ☐

2. Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received)? No ☐ Yes ☐

3. Allocation was concealed? No ☐ Yes ☐

4. The groups were similar at baseline regarding the most important prognostic indicators? No ☐ Yes ☐

5. There was blinding of all subjects? No ☐ Yes ☐

6. There was blinding of all therapists who administered the therapy? No ☐ Yes ☐

7. There was blinding of all assessors who measured at least one key outcome? No ☐ Yes ☐

8. Measures of at least one key outcome were obtained from >85% of the subjects initially allocated to groups? No ☐ Yes ☐

9. All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome were analyzed by intention to treat? No ☐ Yes ☐

10. The results of between-group statistical comparisons are reported for at least one key outcome? No ☐ Yes ☐

11. The study provides both point measures and measures of variability for at least one key outcome? No ☐ Yes ☐