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Factors Affecting Anterior Knee Pain in Post-ACLR Comparing Patellar Tendon and Hamstring Tendon Autografts

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FACTORS AFFECTING ANTERIOR KNEE PAIN IN POST-ACLR COMPARING PATELLAR TENDON AND HAMSTRING TENDON AUTOGRAFTS

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Master of Science, Athletic Training

By

Alexandria Annalicia Jauregui-Dusseau

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ABSTRACT

Anterior cruciate ligament (ACL) injuries are frequent athletic and non-athletic injuries that impact a person's functional and athletic capability. ACL injuries generally require surgical reconstruction. The most popular graft types include patellar tendon (PT) and hamstring tendon (HT) autografts. PT autografts have been blamed for chronic anterior knee pain (AKP) and extensor mechanism deficits. This study compared the PT and HT autografts and their impact on AKP in subjects who underwent anterior cruciate ligament reconstruction (ACLR). Data were gathered from existing patient data from rehabilitation therapy records. Additional factors were also analyzed to determine the effect on post-ACLR pain. Post-treatment pain ratings measured by the Numerical Pain Rating Scale (NPRS) were recorded for the patient's first six weeks of therapy visits. A lack of descriptive documentation did not allow for specific pain location. Neither PT nor HT autografts had a significant effect on post-ACLR pain ratings. Rehabilitation type, age, and time from surgery to initial rehabilitation visit were found to have significant effects on pain ratings. This study indicated that multiple variables can affect pain post-ACLR and future studies should focus on additional factors affecting ACLR patients.

KEYWORDS: patient outcomes, accelerated rehabilitation, conservative rehabilitation, Numerical Pain Rating Scale, rehabilitation outcomes

This abstract is approved as to form and content

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I dedicate this thesis to my parents, Tony and Roberta Muff, and my brothers, Timothy and Austin Muff.

TABLE OF CONTENTS

INTRODUCTION

Anterior cruciate ligament (ACL) ruptures of the knee are frequent athletic injuries and have serious implications for return to participation, as well as overall knee function.[1-28] It is difficult to perform high level athletic activities without an ACL due to the ACL's role in controlling anterior translation and rotation of the tibia in respect to the femur.[2-3,10-11,13,15,22-24,28-31] Conservative treatments have been used to treat ACL ruptures, but current literature suggests that only select individuals benefit from this type of management.[3,9,15,20,23,30,32,33] The conservative treatment for ACL ruptures typically is a non-surgical option that utilizes rehabilitation to give stability to the ACL deficient knee. Nandra et al[33] explained that if a patient elects for conservative treatment, consideration of the patient's desired activity level and age must be taken into account. Patients who have goals of returning to a high level of competition are urged to consider surgical management.[1-3,9,16,20,23,30,32,33]

The surgical management of ACL ruptures is ever evolving, and new techniques are studied for long-term outcomes. A major consideration for ACL surgical patients is what type of graft should be utilized. The two most commonly used grafts are the patellar tendon autograft and the hamstring tendon autograft.[1-6,8-17,28,29,33-44,45-48] The grafts are harvested from two different anatomical locations, but both grafts are autografts; meaning the graft is from the patient's own tissue. Widespread debate exists about which graft type results in more favorable outcomes.[1-3,5,8-17,26,28,29,33–46,48] The desired results after an ACL reconstruction include full range of motion, comparable strength and stability, and pain-free with movement or activities.

The hamstring tendon autograft began to be used as an ACL graft option because of the anterior knee pain (AKP) believed to be caused by harvesting the graft from the anterior knee and disruption to the extensor mechanism of the knee.[1-6,8-17,26,28,29,33–46,48] However, factors that contribute to AKP post-surgery are not limited to graft type. Others factors include the surgical approach, individual patient considerations, and the rehabilitation approach.[42,47,49] Individual patient considerations include age, pre-injury activity level based off of metabolic equivalents (METs)[50], mechanism of injury, and history of previous ACL tear.

Rehabilitation of ACLRs varies among clinicians and currently there is not a gold standard protocol that every clinician follows. The rehabilitation of an ACLR has a profound impact on the patient's prognosis, especially if that patient is highly active. Improper rehabilitation can increase risk of injury, can lead to permanent movement asymmetries, can cause a range of motion asymmetry compared to the uninvolved knee, can affect a patient's ability to participate in activities, and can lead to a surgical revision.

Problem Statement

Harvesting of the patellar tendon autograft utilized in ACLR has received considerable blame for AKP and extensor mechanism deficits when compared to hamstring tendon autografts because of the different harvest site location.[1-6,8-17,26,28,29,33–46,48] While there is an abundance of research that indicates that patellar tendon grafts are a reason for AKP and extensor mechanism deficits, little research exists analyzing other factors contributing to AKP, such as surgical approach, individual patient considerations, or the rehabilitation approach. I believe that other factors may be more responsible for

AKP and more research is needed to investigate current trends in rehabilitation, surgical approach, and individual patient factors to determine whether or not graft type alone can be blamed for AKP. The other factors to consider include time elapsed between surgery and first rehabilitation visit and rehabilitation philosophy utilized.

Purpose of the Study and Specific Research Questions

The purpose of this study was to analyze different factors affecting the resolution of AKP following an ACLR by comparing patellar tendon and hamstring tendon autografts. Pain, especially AKP, is often blamed on the type of graft used because of the harvest site location. This study evaluated other aspects of the rehabilitation process that may contribute to pain resolution in addition to comparing the graft types.

This study will investigate three main questions:

1) What factors contribute to AKP post ACLR?
2) Does the graft type utilized for an ACLR affect AKP?
3) Are other factors more contributive to AKP?

Investigating these main questions will provide answers to the following sub-questions:

a. Does amount of elapsed time between the surgical operation to the first rehabilitation visit affect AKP?
b. Does rehabilitation approach affect AKP?
c. Do factors such as, age, gender, pre-injury activity level, or surgeons affect AKP?

Significance of Study

In order to improve the ACLR process as a whole, as well as specific patient outcomes, it is imperative to investigate and understand the variety of factors that contribute to AKP after an ACLR. AKP is most commonly experienced with kneeling and is a position people will have increased difficulty with if they have significant AKP.[1-6,8-17,26,28,29,33–46,48,49] Knowing what contributes to AKP will not only impact the ACLR process, but impact the quality of life of the patient. Data analysis of ACLR patient files will show underlying factors that could contribute to AKP post-ACLR and common trends between ACLR patients. The post-treatment pain ratings collected in the study are subjective variables, and although pain is very consistent for a given person, it is still a subjective factor that could vary from one patient to the next. However, if trends are noted in the data concerning pain and the other analyzed variables, it will help identify best practices and areas of needed improvement in the management of an ACLR.

Limitations

A limitation for this study includes analyzing self-reported pain, a subjective variable, as a main measure of analysis. Pain is individualized and reliability of self-reported pain scores can be questionable. However, numeric and visual pain analogs have been validated and found to be reliable measures of pain.[51,52] The patients must also have an understanding of what pain is and be able to communicate what their level of pain is when given the numeric pain scale. Another limitation for this study is relying solely on previously documented files for data collection. Documentation is done by humans and is subject to error. It is possible some patient files were incomplete, did not provide detail as to the specific location of pain, and/or were incorrectly documented. A significant limitation is if the patient file did not include the specific site of pain that the pain rating corresponds to, I was not able to determine if the pain is in fact AKP.

Assumptions

Several assumptions were made about the information collected. I assumed it contained a properly taken pain scale rating before and after treatment and that all other information was properly documented. Another assumption is that the patients gave an honest rating of their pain level at the time of treatment. Finally, I assumed that the documentation was entered into the electronic medical record correctly.

Definitions of Terms

The following principal definitions are provided for the purpose of this study.

1. Anterior cruciate ligament: a primary ligament of the knee that prevents anterior translation of the tibia relative to the femur.[2,3,10]

2. Anterior cruciate ligament reconstruction (ACLR): surgical repair of the disrupted anterior cruciate ligament.[1-4]

3. Patellar tendon autograft: a graft option used for the reconstruction of the ACL that is harvested from the patient's middle 1/3 of the patellar tendon on the anterior aspect of the knee.[2,3,6,8,9]

4. Hamstring tendon autograft: a graft option used for the reconstruction of the ACL that is harvested from the patient's tendon of the medial hamstring.[2,3,6,9]

5. Numeric Pain Rating Scale: a scale using numeric values (0 – 10) to depict severity of pain, the lowest value being "no pain present" and the highest value, "most severe pain".[51,52]

6. Rehabilitation program: formal rehabilitation consisting of various techniques and exercises aimed at restoring pre-injury function.[2,3]

7. Allograft: a graft option that is not a patient's native tissue, but instead comes from a cadaver and eliminates a harvest site.[2,3,6]

8. Co-morbidities: concomitant injuries that occur in addition to a more catastrophic injury.[2,3,11]

9. Activity level: the activities subjects were involved in at the time of injury found through analysis of treatment records; measured using Metabolic Equivalents.[50]

10. Functional: the ability to perform basic functions such as walking, without limitation, as well as extracurricular activities.[53]

11. Anterior knee pain: pain in the anterior region of the knee that is not located on the medial or lateral aspect of the tibiofemoral joint.[42]

LITERATURE REVIEW

Introduction

This chapter reviews several topics including 1) the existing literature on the anatomy of the ACL, 2) injury to the ACL and ACL reconstruction, 3) comparison of the patellar tendon autograft to the hamstring tendon autograft, 4) the healing process of soft tissue, 5) current trends in rehabilitation and philosophies, and 6) the Numerical Pain Rating Scale (NPRS). Literature on these topics is examined and specific findings are outlined.

The Anatomy of the Knee

The tibio-femoral joint (knee), is a primary hinge joint necessary for efficient locomotion. Varying amounts of stress are transmitted through the joint whenever the body is in motion. The tibio-femoral joint includes the femur, tibia, patella, local neurovasculature, and supporting connective tissue. Each structure is capable of sustaining an injury, with some structures more susceptible than others. The tibio-femoral joint is affected by natural deterioration more than other weight bearing joints because it has a dynamic role in movement.

Ligaments do not have the ability to contract or cause movement, but are responsible for providing the static stability of this joint. The main ligaments of the knee include the anterior and posterior cruciate ligament (ACL and PCL), and the medial and lateral collateral ligaments (MCL and LCL). The cruciate and collateral ligaments emerge from the femur and connect to a corresponding point on the tibia and fibula. In comparison to muscles, ligaments receive less blood supply and nervous supply. When a ligament is injured, the ligament's limited blood supply is a hindering factor as the ligament heals.[9,17] Increased blood flow allows more nutrients to be taken to the injured area and the more blood a structure receives improves its ability to heal.

The ACL is the main restraint against anterior translation of the tibia, relative to the position of the femur.[1-3,10-11,15,13,22-24,28-31] It is a ligament that is commonly injured among the athletic and non-athletic population.[1-28] Many studies have been performed regarding the ACL, and range from epidemiological in nature, to best treatment, and management of an injury.

Anterior Cruciate Ligament Injury and Reconstruction

Many studies have produced data about the mechanism of an ACL tear.[1-7,12-15,17,19,20,23-26,28,29,31,38,54] Previous research has documented that over two-thirds of ACL tears have resulted from non-contact situations and one-third result from contact.[3,23] The non-contact injuries generally result from a combination of planting the foot with a rapid change of direction.[2,15] The current literature explains that treatment of an ACL tear is generally determined by the severity of the injury.[2-4,6,7,9,11,15,20,23,30] The variety of ways to manage an ACL tear include conservative intervention, such as conservative rehabilitation aiming to provide stability to an ACL deficient knee by strengthening surrounding structures, and pharmaceutical treatments aimed at controlling pain and inflammation. The non-conservative approach includes surgical intervention. The need for surgery is dependent on several factors. While the ACL has a primary role in knee stability, not every individual with a diagnosed ACL tear elects to have surgery.[3,9,15,20,23,30,32,33] Participating in rehabilitation before undergoing surgery is considered to be a conservative approach to ACL tear management and has been shown to be successful depending on the person's lifestyle.[3,9,15,20,23,30,32,33] Patients that do not desire to participate in activities requiring pivoting and quick change of direction can be functional and successful without having a surgical reconstruction. If a person can perform activities of daily living without limitation, undergoing an invasive surgery may be counterproductive. However, if a reconstruction is decided as being the best option, Melikoglu et al[21] suggested the surgery take place within 12 months after the initial injury to combat muscle atrophy as much as possible.

Another factor to consider is the person's age.[4,5,7] Age can determine which graft material is an option and can further dictate the appropriate time to perform the surgery. Because the patellar tendon graft is partly harvested from bone, this is not an acceptable option for a patient whose growth plates have not yet closed.[4,5] Depending on surgeon and patient preference, the surgery could be delayed until the growth plates in the tibia have fully closed. However, if the patient is highly active and involved in competitive sports, waiting to have the procedure would not be preferable.[1-3,7,9,16,20,23,30,32,33] In the case that a surgical patient’s growth plates were not closed, the hamstring tendon graft could be utilized.

When an ACL injury occurs, it is rarely an isolated event and it is common for co-morbidities to occur similtaneously.[1-3,11] It has been reported that less than 10% percent of ACL tears occur as an isolated event.[1] Possible co-morbidities include, but are not necessarily limited to: meniscal tears, local ligament tears, and avulsion fractures. These additional injuries can affect the surgical decisions, as well as the rehabilitation process.

For example, in the event of a meniscus tear, some surgeons and patients may decide to repair the meniscus tear and then proceed to reconstruct the ACL - two separate processes. Surgical intervention of repairing the meniscus does depend on the severity of the meniscus tear. The meniscus' limited blood supply affects its ability to heal and will determine if a surgical repair is the best option for that patient. The age and activity level of the patient are also considered before a meniscus repair is completed. In the case of a meniscus repair, the surgeon may add restrictions to range of motion and other aspects of rehabilitation to reduce stress on the repaired meniscus. This procedure may in turn prolong the rehabilitation process for the ACL.

Patellar Tendon Autograft and Hamstring Tendon Autograft

Graft choice in ACL reconstructions has been debated for years.[1,5,8,12-16,33-35,37-39,42,45] There are two main types of grafts, bone-patellar tendon-bone autograft and hamstring tendon autograft. The bone-patellar tendon-bone graft is taken from the middle third of the patellar tendon.[9,17,29,38] An incision is made from the inferior pole of the patella to the tibial tuberosity. The tissue is dissected down to expose the patellar tendon. Surgical tools are used to remove the middle third of the tendon, with the bone plugs from the tibia and patella left intact. Bone plugs are sections of bone from the tibial tuberosity and the inferior pole of the patella that are located at the ends of the graft.[9,28,29] The bone plugs are used as anchors during the reconstruction process and contribute to fixation strength.[2,3,9,13,15,36]

The hamstring tendon autograft is made from the semitendinosus and gracilis tendons.[36] To harvest the graft, an incision is made over the anatomical landmark, the pes anserine.[37] The pes anserine is the tendon insertion site of the sartorius, gracilis, and semitendinosus muscles.[41] In addition to having a different anatomical location from the patellar tendon autograft, the hamstring tendon autograft does not include bone plugs. The bone plugs on the patellar tendon graft allow bone to bone healing to occur, but in the case of a hamstring tendon graft two different tissues, tendon and bone, are attempting to heal together.[17,28,29,42,48]

The hamstring tendon autograft was developed due to the effect the patellar tendon graft could have on the extensor mechanism of the knee, as well as the harvest site morbidity.[11-16,32,34-38,40,45,46,55] During the surgery, the middle third of the patellar tendon is harvested and subsequently can lead to extension deficits because of the connection to the quadriceps muscle group. The quadriceps muscle group, responsible for knee extension, converges to form the patellar tendon which inserts on the tibial tuberosity and is used to reconstruct the ACL. The literature also suggests that usage of the patellar tendon graft is a cause of AKP, especially in a deep, flexed knee position.[11-16,32,34-36,40,45,55] AKP is thought to result from the incision made over the patellar tendon and the procedure performed to harvest the new graft material. However, these two possible outcomes are not consistent among all ACLR patients with patellar tendon autografts.[46] More research is needed to assess early rehabilitation interventions that may be critical to restoring mobility to the harvest site, as well as other factors contributing to prolonged AKP at the harvest site and dysfunction in the extensor mechanism.

The hamstring tendon graft also does not go without criticism. By harvesting this graft from the hamstring muscle group that is responsible for knee flexion, the flexor mechanism of the knee is violated and could be the cause for decreased flexion motion and strength.[12-16,33-39,42,45] Similar to the patellar tendon, the hamstring tendon harvest site is also prone to tenderness and pain. However, there are other reasons patients decide to use the hamstring tendon auto graft instead of the patellar tendon autograft. Some patients consider the cosmetic factor and prefer a less visible scar, therefore choose the hamstring tendon autograft. Another external factor is surgeon preference, which can influence a patient to pick one graft over the other. Surgeons may have their own bias formed from years of experience and the outcomes of their patient population.

A meta-analysis by Mohtadi[15] showed that the grafts are equal in respect to overall function and tensile strength, but the patellar tendon graft fixation was found to be more stable. The combined data from 14 studies, whose subjects tested positive for a pivot shift at their post-surgical follow-up appointment, favored the patellar tendon graft.[15] In consideration of return to participation (RTP) timeframes, Gobbi et al[44] found there are not significant differences between the two graft types. Both the patellar tendon and hamstring tendon groups had patients who did not RTP for various reasons.[44] The reasons why patients did not RTP include: fear of re-injury, chondropathy pain in both groups, pain at tibial fixation in the hamstring group, and an extension deficit in the patellar tendon group.[44] These findings in literature show that the patellar tendon and hamstring tendon grafts have their pros and cons, and the selection of graft type used to reconstruct the ACL must be carefully considered.

Healing Process of Soft Tissue

Tissue healing within the body has three distinct phases; the inflammatory phase, proliferation phase, and the maturation or remodeling phase.[17,56,57] The amount of time each phase lasts varies, and it is not uncommon for one phase to be unfinished when another begins.[56] The inflammatory phase is an important component of the healing process and should not be disrupted, except in the case of chronic inflammation. Redness, pain, swelling, increased temperature, and loss of function are signs designating that inflammation is occurring.[56,57] The inflammatory phase is an integral part of tissue healing because of the reactions taking place metabolically, chemically, and within the vascular system.[56,57] As cell metabolism increases, a plethora of cells and mediators infiltrate the area to begin clearing cellular debris.[56] The pain associated with this phase acts as a protective mechanism, signaling that area is injured, and results in "guarding" of that particular area.[56] The inflammation phase lays the groundwork for all the phases to follow and essentially the healing process as a whole. If this phase is unable to be completed or is unnaturally prolonged, it can have serious implications on the prognosis as a whole.[57] These implications include chronic swelling, redness, pain, and loss of motion or overall function.

The inflammation phase is followed by the proliferation phase. The proliferation phase begins about three days after the initial injury and could last up to three weeks.[57] It is during this time that new tissues and vessels are introduced at the injury site. Once the immature tissue is synthesized, the remodeling phase begins. The remodeling phase takes the longest amount of time, lasting up to a year. The remodeling phase is also when the tissue matures and takes its permanent shape.[57] These three phases of healing best describe what occurs at the graft harvest site and lays the foundation to explain what is happening internally with the reconstructed ACL.

A ruptured ACL is not capable of repairing itself because of its limited blood supply therefore surgical reconstruction is often necessary to restore full function.[2,6,13,17,29,33] The new graft will go through the same phases of healing, but will differ slightly depending on the type of graft used.[29] Patellar tendon autografts include a bone plug on each end, one from the distal pole of the patella and the other from the tibial tuberosity, where the patellar tendon inserts. The incision made to harvest the graft is done longitudinally between those two points. Because of the bone plugs and how the ACL is reconstructed, this graft incorporates differently than the hamstring tendon autograft. The bone plugs are anchored into the pre-drilled femoral and tibial tunnels respectively, where bone-to-bone healing can take place.[2,3,9,13,15,17,33,36] Researchers argue that because of the bone-to-bone healing, the patellar tendon graft is incorporated faster compared to the quadrupled hamstring autograft.[2,3,9,13,15,33,36] When the patellar tendon graft is healing, the bone plugs are healing into the tibial and femoral tunnels, therefore the same type of tissue is forming a union. However, it is the opposite for the hamstring tendon autograft. The hamstring tendon autograft is also anchored into the pre-drilled tibial and femoral tunnels, but because it lacks bone plugs, the healing will not be the same. According to Lui et al[17], the healing process of tendon to bone graft involves four phases of healing compared to the three previously discussed. The phases Lui et al[17] described are the inflammatory, proliferation, matrix synthesis, and matrix remodeling phases. If the tendon graft is to incorporate into the bone tunnels, bone growth must occur and envelop the new tissue.[17] The substance of both grafts ultimately determines how it will heal and incorporate into the bone tunnels. Regardless of their different healing properties and outcomes, both grafts are initially highly vulnerable at their fixation sites. Bowditch[2] indicated that patellar tendon bone plugs can incorporate as early as sixteen weeks, while hamstring tendon grafts take longer. Fixation sites are considered the weakest point of the repair and improper healing and management can lead to graft failure, and pullout from the bone tunnels, leading to a revision surgery. The healing properties of both types of grafts must be kept in mind during the rehabilitation process.

Rehabilitation Philosophies and Current Practices

There are many components in an ACLR, and many factors influence the outcome. If an individual has the desire to return to a high level of activity, participating in a rehabilitation program is highly recommended. This quote by Hen et al[19] states the importance of quality rehabilitation, "a good surgery can still have a poor outcome if rehabilitation is inadequate." The rehabilitation of ACL injuries has evolved since the inception of modern day reconstructions, and new philosophies are constantly emerging. In general, rehabilitation approaches are viewed as either being conservative or accelerated. Current literature shows a trend toward the accelerated approach and being more aggressive post-surgery.[2,20-23,25,26,58,59] In addition to the conservative and accelerated rehabilitation approaches, a pre-rehabilitation approach is used by some healthcare providers. Pre-habilitation is another well researched rehabilitation approach that happens before the surgery takes place, and focuses on resolving swelling, and range of motion deficits.[1-3,5,30,33] Pre-habilitation is meant to prepare the patient's body so it will better tolerate the surgery and will hopefully be more functional after surgery.[30] However, not every patient with an ACL deficient knee is able to participate in formal therapy before surgery. In these cases, the surgeon may give them home exercises to do prior to surgery, and the surgery may be delayed until acute symptoms have resolved. According to Klinge et al[3] post-surgical rehabilitation visits, under the accelerated and conservative approach, should be started within one to two days after surgery. The rehabilitation process is an outpatient procedure, given that no complications occurred. Best practice thirty years ago after surgery consisted of keeping the patients overnight, a delay in beginning therapy, and having range of motion and weight-bearing restrictions.[47]

The conservative method of ACLR rehabilitation is not widely used since the development of accelerated rehabilitation programs. In a systematic review by van Grinsven et al[26], they stated that the general time frame for RTP under a conservative program is 9-12 months, in contrast to an accelerated protocol which is 6 months. The review findings included an in-depth comparison between the two rehabilitation protocols and emphasizes evidence-based practice in conjunction with developing rehabilitation programs.[26] The accelerated protocol is characterized by early tissue and joint mobilization, early weight bearing, early range of motion, and limited bracing utilized if at all.[25,26] In contrast, the conservative rehabilitation approach is just the opposite of an accelerated approach. Conservative rehabilitation is designated by restricted or delayed weight bearing, limited range of motion activities, a delay in strength training, post-operative bracing, and return to participation 9-12 months after surgery.[25,26] Silva et al[25] studied the outcomes of an accelerated protocol in ACLR patients. The results suggested that clinicians should be conservative when progressing patients back into dynamic activities because of the strength and proprioception deficits that remained.[25] However, this article failed to go into detail of exact rehabilitation activities and return to play criteria utilized. The review by van Grinsven et al[26] lists the hallmarks of the accelerated program as having no post-operative bracing and emphasis on decreasing pain, swelling, inflammation, and increasing range of motion, strength, and neuromuscular control. Gaining range of motion and mobility are primary goals during the first few therapy visits. The post-operative swelling and edema impact range of motion and mobility, and initiating early motion will promote blood flow and lymphatic drainage. If swelling and edema is allowed to remain stagnant, the process of restoring equal bilateral motion will be prolonged.   However, due to early concerns about comprising the integrity of the graft, early mobilization was not always supported by healthcare professionals.[25,26] Terminal knee extension (TKE), with at least 90 degrees of flexion are the typical ranges of motion that therapists strive to reach within one to two visits. Implications of inadequate mobility include, but are not limited to, pain, scar tissue adhesions, decreased motion, and decreased function.

The accelerated approach also includes neuromuscular and proprioceptive training and is discussed by several sources.[24-26,59] In 2007, Risberg et al[59] compared strength training to neuromuscular training with ACLR patients. The neuromuscular training activities in this study included balance exercise, plyometric exercises, dynamic joint stability exercises, agility drills, and sport-specific drills. In contrast, the strength training group involved exercises that targeted specific muscle groups. Outcomes measured included pain and overall knee function, and results indicated increased function in the neuromuscular training group. Ultimately, they suggested that neuromuscular training as more beneficial than strength training for improving overall knee function and for patients returning to competitive sports. Strength training and neuromuscular function are also related to motor control, and core stability in the ACLR rehabilitation process. Shi et al[24] found core stability to be a poorly integrated component of ACLR rehabilitation programs and hypothesized that a window of opportunity exists to affect motor learning after ACL injury.[24] Shi et al described core stability as the "ability to control the position and motion of the trunk over the pelvis," and core stability was "negatively correlated with an incidence of anterior cruciate ligament injuries."[24] Roos et al[60] studied motor control strategies between ACLR, ACL deficient, and healthy patients while they performed a double-legged squat. Researchers noted significant differences between the ACLR and ACL deficient groups in how they compensated while performing the squat. They concluded that motor control deficits in a movement must not be overlooked and need to be addressed before that patient can progress to more advanced movements. Roos et al also determined that individualized programs are necessary for each patient.

Another much debated component of accelerated rehabilitation programs is the introduction of closed (CKC) and open kinetic chain (OKC) exercises. A closed kinetic chain exercise is characterized as having the distal body segment fixed, and open kinetic chain exercises are just the opposite. Open kinetic chain exercises have been criticized for distressing the extensor mechanism, the quadriceps, and increasing pressure in the knee joint.[55] In a 2002 study, Morrissey et al[55] found no difference between CKC and OKC exercises and their effect on pain in post-surgical ACLRs. They suggested that other factors were responsible for the pain, particularly AKP, elicited while performing OKC or CKC exercises. In another study, Gerber et al[43] examined the effects of eccentric exercise beginning three weeks out of surgery. They found a greater increase in muscle volume one year out of surgery in the experimental group, who began an eccentric exercise program three weeks post-surgery in addition to the general rehabilitation activities. In comparison, the control group only progressed through the latter.

Pain and the Numerical Pain Rating Scale

A primary complaint and symptom of injuries and post-surgical healing is pain. Pain is a highly subjective variable that can be difficult to measure.[51,52] Each individual has their own interpretation of pain intensity, which translates into different ratings for that intensity. Kahl et al[51] explained that although pain is subjective, it can be turned into an objective measure. Since many therapists use pain as an outcome measure and indicator to progress with exercises, it is necessary to have a reliable tool to measure patient's pain level. The Numeric Pain Rating Scale (NPRS) is commonly used in the clinical setting and is convenient to administer and interpret.[51,52] The NPRS is a numbered scale that begins with zero and ends at ten. Zero indicates no pain, while ten is the worst intensity of pain that individual can imagine.[51,52] There is also a visual component to the pain scale, the visual analogue scale (VAS), and is administered the same as the NPRS, and may be preferred by some patients.

Because the NPRS is an interval, it can be utilized for statistical analysis.[51,52] The NPRS has been found by several researchers to have favorable sensitivity, meaning that it can be used to identify changes.[51,52] The NPRS has been supported in accurately measuring pain intensity and has been found to be reliable, which indicated that it consistently measures the same variable.[51,52] Kahl et al[51] reported the test-retest reliability of the NPRS to 0.67 to 0.96, which has a moderate to high rating. While neither the NPRS nor the VAS is the gold standard for pain measurement, validity analysis shows both measures result in similar outcomes, and the NPRS has convergent validity of 0.79 to 0.95.[51]

Pain has a large influence on the therapy process of an ACLR, as well as the overall attitude of the patient. The patient's response to the ACLR and overall demeanor at the initial therapy visit can vary greatly from person to person. The patient could also be apprehensive about the first therapy session and have increased anxiety due to the anticipation of experiencing pain. This psychological component cannot be overlooked, and the therapist must reduce any anxiety and fear the patient may have through proper education about the surgical and rehabilitation process, as well as give the patient an opportunity to ask relevant questions. Chmielewski et al[18] explained that the initial attitudes a patient may have immediately post-surgery did not necessarily determine future pain levels and overall function. Another finding included an association between a decreased pain level and the patient's ability to complete tasks during the therapy session.[18] The study also found that if fear of movement and re-injury is not addressed early in the rehabilitation process, knee function suffers.[18] This finding indicated the importance of addressing the psychological needs of the patient. Researchers also determined that as function of the knee increases, the fear level of a subsequent knee injury decreases.[18] Returning to the prior level of activity will be dependent on the patient's fear of re-injury, as well as their functional status.[18]

Chapter Summary

A tear to the ACL is a serious injury that generally requires surgical reconstruction in order for the patients to return to their previous level of activity. The ACL is a main stabilizer of dynamic knee motion and its reconstruction is necessary for that dynamic movement to occur optimally. The ACL injury and surgical process is well researched, and surgical approaches have been well refined since their initial development. Many studies exist on the use of different graft types and patient outcomes.[1,5,8,12-16,33-35,37-39,42,45] The hamstring tendon and patellar tendon autografts are the most common grafts used for reconstruction and both have their advantages, as well as disadvantages. Regardless, of the graft type used, ACLR patients experience varying degrees of pain after surgery, especially during the rehabilitation process. This study aims to explore the variables that contribute to AKP after surgery such as the amount of time elapsed between the date of surgery and the first rehabilitation visit, surgeon, injury history, rehabilitation philosophies utilized, activity level, specific pain location, and age and gender demographics. If ACLRs are to be managed in the most effective way possible, it is imperative to analyze the multiple factors that would contribute to the overall outcome and the initial six weeks post-surgery.

METHODS AND PROCEDURES

Introduction

This chapter provides a detailed look into the methodology employed in this study. The specific topics discussed are 1) subject population, 2) analyzed variables, 3) research design, and 4) statistical analysis. This study conformed to the requirements of Missouri State University and received approval from the institutional review board (696063-1: January 6, 2015). Prior to beginning this study HIPPA training was completed. This study was a retrospective data analysis of medical documents, therefore consent forms were not applicable.

Subject Population

Subject and data collection were gathered from a local hospital's electronic medical records. The subject files ranged from January 1, 2008 to December 31, 2014. The data was existing patient information, and patient notification was not applicable to this study because identifying information was not utilized. Inclusion criteria for data included patients who had undergone an ACLR and participated in a formal rehabilitation process for at least six weeks. Patient records were obtained from six separate rehabilitation clinic locations within one hospital system. The locations were determined by the volume of ACL patients rehabilitated at the locations. The locations included: Mercy Sports Medicine Clinic-Fremont, Mercy Sports Medicine - Health Tracks, Physical Therapy Clinic-Fremont, E. Kearney Rehabilitation Clinic, W. Kearney Rehabilitation Clinic, and Nixa Rehabilitation Clinic. Medical records were excluded from the data set for patients that had additional structures, local ligaments and the menisci, repaired at the time of the ACLR. Patients were not excluded on basis of age, gender, or activity level. Demographics collected for statistical analysis, and comparison included age at the time of surgery, gender, surgeon, activity level, mechanism of injury (contact or non-contact), and injury history of the ACL tear. Sixty out of 144 original subject files were omitted for the following reasons: 1) co-morbidities, such as those involving other surgical procedures done to the knee at the time of the ACLR (7); 2) did not complete six weeks' worth of rehabilitation (4); 3) patients who utilized allograft tendons (31); 4) the clinic location was not one of the six selected for analysis (16); and 5) the ACLR was done too recently for sufficient data collection (2).

Analyzed Variables

This study assessed multiple variables in order to determine the factors that affect AKP post ACLR, comparing the patellar tendon autograft and the hamstring tendon autograft. The following data were collected: 1) patient demographics (gender, age at the time of surgery, and previous history of ACL injury); 2) surgery date; 3) graft type (hamstring tendon or patellar tendon autograft); 4) surgeon; 5) contact or non-contact mechanism of initial injury; 6) post therapy session pain ratings over six weeks, at six months and one year post-surgery if available; 7) time elapsed between surgery date to first therapy visit; 8) co-morbidities related to the ACL tear that were not a part of exclusion criteria; 9) conservative or accelerated rehabilitation approach; 10) location of reported pain; and 11) activity level at the time of injury. No identifying variables such as name, date of birth, or social security number were reported for this study. I sorted the clinic locations into either an accelerated or conservative rehabilitation approach based off criteria found in the literature.[25,26] The therapy notes were reviewed for content and the clinic location was categorized to the rehabilitation approach it best aligned with. A majority of the criteria had to be met in order for the clinic location to be assigned to a particular category. Out of the 84 patient files analyzed, 40 completed rehabilitation that utilized the accelerated approach, and the remaining 44 patients underwent a conservative rehabilitation approach. The criteria for the accelerated approach included: early joint and tissue mobilization, early weight bearing (the goal of having full and uncompensated weight bearing in 10 days), early restoration of range of motion, and no post-operative bracing.[25,26] The criteria for the conservative rehabilitation approach included: restricted or delayed weight bearing, a delay in neuromuscular or strength training, limited range of motion activities, and post-operative bracing.[25,26]

Delimitations

This study is a retrospective analysis of ACLRs during the first six weeks of rehabilitation. Data was gathered from electronic medical records and further analyzed for significant correlations between the patellar tendon and hamstring tendon autograft groups and the previously mentioned variables. The two main variables analyzed were the post-treatment pain rating taken at every treatment visit and the prevalence of AKP. While pain is a subjective measure, it is major component to any surgery and rehabilitation process, and should be studied and analyzed for variables that significantly contribute to increased or prolonged pain during the rehabilitation process. In addition, not every subject had a six month or one year follow-up with their doctor and therefore is inconsistent among the subject population. Fifty-five subjects out of eighty-four had a six month follow-up and only three subjects had a one year follow-up visit. The hierarchal-linear model analysis used in this study accounts for this variance and allows for missing data points. The absence of an outside reviewer for sorting the clinic locations to a specific rehabilitation approach is another delimitation of this study. However, the criteria utilized were supported by literature.

Research Design

A retrospective study design was conducted by analyzing existing patient files in the hospital electronic medical record system. A request for electronic health data was requested through Mercy Research Services for ACLR patient files who completed rehabilitation at the following locations: Mercy Sports Medicine Clinic-Fremont, Mercy Sports Medicine - Health Tracks, Physical Therapy Clinic-Fremont, E. Kearney Rehabilitation Clinic W. Kearney Rehabilitation Clinic, and Nixa Rehabilitation Clinic. The main variable assessed was the patient's reported pain rating taken by the NPRS at the beginning and end of each rehabilitation visit. However, for this study only the post-treatment pain measurement was analyzed. The NPRS used by the contributing locations ranges from 0 to 10, with 10 being the highest amount of pain being experienced and 0 being no pain at all. Data was gathered on each patient for the first six weeks post ACL reconstruction. Generally, therapy sessions are scheduled two to three times a week, therefore a sufficient amount of data was gathered for each patient. Typically patients have increased their functional capabilities by the six week mark and at that point post-operative pain should be subsiding.[19,26,43] If available the six month and one year follow-up visit were also analyzed for pain ratings pertaining to their ACLR.

Chapter Summary

In order to determine if a particular graft type has a greater effect on AKP or if other factors contribute more to AKP, the following selected variables were analyzed: amount of time elapsed between the date of surgery and the first rehabilitation visit, surgeon, injury history, rehabilitation philosophies utilized, activity level, specific pain location, and age and gender demographics. If ACLRs are to be managed in the most effective way possible, it is imperative to analyze the multiple factors that would contribute to AKP and affect the overall outcome. To be able to determine the rate of pain resolution and better understand the factors contributing to post-ACLR pain, while comparing two main graft types, a retrospective study utilizing a hierarchal-linear model was conducted. Data was gathered from the six clinic locations that rehabilitate the most ACLRs via the hospital's electronic medical record system. The purpose of the data analysis was to identify trends and correlations to aid in addressing the original research questions: 1) What factors contribute to AKP post ACLR?, 2) Does the graft type utilized for an ACLR affect AKP?, and 3) Are other factors more contributive to AKP? Investigating these main questions will provide answers to the following sub-questions: 1) Does amount of elapsed time between the surgical operation to the first rehabilitation visit affect AKP; 2) Does rehabilitation approach affect AKP; and 3) Do factors such as, age, gender, activity, or surgeons affect AKP?

RESULTS

Introduction

The purpose of this study was to analyze different factors affecting the resolution of AKP following an ACLR by comparing patellar tendon and hamstring tendon autografts. Often, pain (especially AKP) is blamed on the type of graft used because of the harvest site location, but this study evaluates other aspects of the rehabilitation process that may contribute to pain resolution in addition to comparing the graft types. In order to determine what factors affect AKP, a variety of variables were analyzed.

Participants

Eighty-four subjects out of 144 patient files met all set criteria; $N = 84$. Sixty subjects out of the original 144 patient files analyzed were omitted for the following reasons: 1) co-morbidities, such as those involving other surgical procedures done to the knee at the time of the ACLR (7); 2) did not complete six continuous weeks of rehabilitation (4); 3) patients who utilized allograft tendons (31); 4) the clinic location was not one of the six selected for analysis, these particular files were included in the subject pool because the initial evaluation was conducted at one of the selected clinics, but these patients transferred their rehabilitation to a clinic not included in analysis (16); and 5) the ACLR was done too recently for sufficient data collection (2). Demographics collected for statistical analysis and comparison included age at the time of surgery, gender, surgeon, activity level, mechanism of injury (contact or non-contact), and injury history of the ACL tear. The demographics of the subjects includes: $M = 29.44$ years old;

SD = 9.43; females *n* = 46; males *n* = 38. The age of the subjects ranged from 13–46 years old. The average number of visits was *M* = 14.02; *SD* = 2.84. The patient files were sorted by clinic location and the first twenty patient files that met inclusion criteria were included in the analysis. A maximum of twenty patient files were collected from each clinic location. Each clinic had a varying number of patient files utilized: Mercy Sports Medicine Clinic-Fremont (20), Mercy Sports Medicine - Health Tracks (20), Physical Therapy Clinic-Fremont (19), E. Kearney Rehabilitation Clinic (6), W. Kearney Rehabilitation Clinic (11), and Nixa Rehabilitation Clinic (8).

Statistical Analysis

Hierarchal-linear modeling (HLM) was the primary analysis method utilized and was calculated using the Statistical Package for Social Sciences, version 22 (SPSS). This type of analysis can be calculated even if subjects are starting rehabilitation at different times. By taking into consideration that patients will have varying injury dates, surgery dates, and demographics, error variance can be equated for multiple time measurements and these factors. Furthermore, HLM allows regression data analysis over repeated time points by controlling for the fact that subjects do appear multiple times in the data set. The dependent variable analyzed was a post-therapy pain rating using the NPRS. The average pain rating over the course of the first six weeks of rehabilitation was *M* = 1.58 with a range of 0-10. The independent continuous variables of this study included: age, activity level, and time elapsed from surgery to first therapy visit. The independent categorical variables included: graft type, rehabilitation type, surgeon, gender, side of ACL tear (right/left), mechanism of injury (contact v. non-contact), co-morbidities, pre-habilitation, side of previous ACL tear, ACL history, and additional surgical procedures performed at the time of the ACLR. Due to an inadequate amount of pain location description in therapy notes, I could not definitively state what anatomical location the pain rating was corresponding to. Pain location was reported with over 22 different descriptors for the lower extremity region in therapy notes reviewed. Therefore, pain location variable was excluded from analysis due to a small sample size and large variance in pain location descriptors. The categorical variables, clinic location and previous history of ACL tear, were also excluded from analysis because of multicollinearity with rehabilitation type and side of previous ACL tear.

Effects of Continuous Variables

The continuous variables of this study included: age, activity level, and time elapsed from surgery to the first therapy visit. Age was found to be significant, and indicated that as age increased so did the pain rating, $F(1, 809.61) = 25.40$, $P<0.001$, $b = 0.04$, $SE = 0.01$. The activity level of the patient at the time of their injury did not have a significant effect on pain rating, $F(1, 907.96) = 0.95$, $P = 0.33$, $b = 0.03$, $SE = 0.03$. However, the analysis did reveal that the time elapsed from surgery to the first therapy visit, measured in days, was a significant predictor, $F(1, 1017.09) = 7.25$, $P = 0.007$, $b = 1.00$, $SE = 0.04$. This outcome showed that the longer a patient waits to initiate therapy after ACLR, the higher their pain rating was. See Appendix A and B for fixed effects of continuous and categorical variables.

Effects of Categorical Variables

A variety of categorical variables were analyzed in this study to determine their effect on AKP on post-ACLRs comparing a patellar tendon and hamstring tendon autograft. Sixty-three ACLR patients utilized a patellar tendon autograft and the remaining 21 patients utilized a hamstring tendon autograft. Graft type is a main variable in this study, but it was not found to be significant through data analysis, $F(1, 810.28) = 1.80$, $P = 0.18$. Therefore, it cannot be stated that one graft type significantly affects pain post-ACLR. Analysis showed that rehabilitation type was significant, $F(1, 625.76) = 42.06$, $P<0.001$; accelerated rehabilitation, $M = 0.24$, $SE = 0.27$; conservative rehabilitation, $M = 1.19$, $SE = 0.24$. The lower mean of the accelerated rehabilitation approach indicated that patients experience less pain post-ACLR when undergoing this rehabilitation approach in contrast to the conservative approach which may be due to having an increased number of visits. Under the accelerated approach the average number of visits was $M = 15.21$, $SD = 2.14$; the conservative approach, $M = 12.84$, $SD = 2.83$. Forty patients were at a clinic location where the accelerated rehabilitation approach was utilized and the remaining 44 patients completed therapy at clinic location that utilized a conservative rehabilitation approach. In addition, surgeon, was also found to be significant, $F(7, 886.24) = 4.46$, $P<0.001$. The variable was controlled for in the analysis to account for the effects of different surgeons but was not analyzed in a post hoc. The remaining categorical variables (gender, side of ACL tear, mechanism of injury, co-morbidities, pre-habilitation, side of previous ACL tear, ACL history, and additional surgical procedures performed at the time of the ACLR) were not found to be significant. See Appendix A and B for complete summary of fixed effects.

Chapter Summary

To determine what factors contribute to AKP post-ACLR and if the graft type utilized significantly affects AKP, a statistical analysis was performed. Overall, the data provided evidence that the graft type does not have a significant effect on AKP post-ACLR. Due to an inadequate amount of pain location description in therapy notes, I also could not determine the specific location of the given pain rating. However, significant findings were found for several factors analyzed. The factors include age, rehabilitation type, surgeon, and the time elapsed from surgery to the first therapy visit.

DISCUSSION AND CONCLUSION

Introduction

The purpose of this study was to analyze different factors affecting the resolution of AKP following an ACLR by comparing patellar tendon and hamstring tendon autografts. Often pain, especially AKP, is blamed on the type of graft used because of the harvest site location, but this study showed that other aspects of the rehabilitation process contribute to pain resolution.

Many studies analyze the variety of factors that impact ACL injuries. A majority of these studies compare the patellar tendon autograft to the hamstring tendon, and show that harvesting the patellar tendon causes long-term AKP and extensor mechanism deficits.[1-6,8-17,26,28,29,33–46,48] When comparing which graft is more stable, a meta-analysis by Mohtadi[15] found the patellar tendon autograft to be more stable and may be better for patients wishing to return to dynamic activities. However, the grafts were found to be similar in function and overall tensile strength.[15]

The main rehabilitation categories are conservative rehabilitation and accelerated rehabilitation approaches. The conservative rehabilitation approach does not involve aggressive post-surgical range of motion and weight bearing is generally more limited.[25,26] The primary goals of the accelerated and conservative approaches during the initial rehabilitation visits are gaining range of motion and mobility. However, the execution of those goals might be different. An accelerated approach involves early weight bearing, assuming there are not any restrictions per the surgeon, early range of motion, early mobilization, and no post-operative bracing.[25,26] Other components of an accelerated rehabilitation approach include, but are not limited to, strength training, neuromuscular training, core stability, eccentric exercises, and closed and open kinetic chain exercises.[24-26,43,55] The general RTP time frame utilizing a conservative rehabilitation protocol is 9-12 months, in comparison to a 6 month return in an accelerated approach.[26]

Pain is a hallmark of any injury or post-surgical healing. In the aftermath of an ACLR, the patient experiences swelling, edema, pain, and the psychological components of being injured and having undergone surgical trauma. Often times, this leaves the patient feeling somewhat helpless. While the pain can be controlled post-operatively by medication, every patient will react to pain differently. On some level, the patient will have some form of discomfort. In the clinical setting pain is generally measured by the NPRS.[51,52] The NPRS is a numbered scale, zero to ten, which is representative of pain intensity. Zero indicates no pain, while ten is the worst intensity of pain that individual can imagine.[51,52] There is also a visual component to the pain scale, the visual analogue scale (VAS), and is administered the same as the NPRS, and may be preferred by some patients. Both of these scales are utilized to gain some idea of how that patient is feeling and this can direct the approach a clinician may take with the patient. Some patients may feel like they are experiencing a great deal of pain and may not be able to tolerate as much as another patient who does not feel as much pain. Although pain is highly subjective, the NPRS allows clinicians to turn pain into an objective measure.

Discussion of Data

The objective of this study was to compare the patellar tendon autograft to the hamstring tendon autograft and determine their effect on AKP in post-ACLR patients. This study also strived to find other factors that may contribute to post-ACLR AKP, such as rehabilitation approach and the time elapsed from surgery to the initial therapy visit.

The main variable of graft type was not significant and did not affect the pain rating during therapy visits. This finding is consistent with a meta-analysis by Mohtadi[15], which indicated that while each graft type has its pros and cons, both are acceptable for an ACLR. Although the patellar tendon autograft is associated with AKP and extensor mechanism deficits in some patients, literature does show that these two outcomes are not consistent among all ACLR patients.[46,56] Also, due to a lack of descriptive documentation in therapy notes, it cannot determined if the pain rating relates to AKP or general knee pain. Although this study did not conclude that one graft type is more beneficial for reduced post-ACLR pain, this study did identify other contributing variables to post-operative pain. Statistical analysis showed significant effects of age, rehabilitation type, surgeon, and time elapsed from surgery to the first therapy visit.

Early initiation of rehabilitation, within a couple days post-surgery showed a reduced amount of pain. Beginning rehabilitation promptly will ensure tissue mobilization, early range of motion, and weight bearing, which are all characteristics of the accelerated rehabilitation approach.[25,26] Since the post-operative swelling contributes to reduced movement and range of motion, it is advantageous to initiate therapy as soon as possible to ensure motion is restored and overall function is improved. During the first 1-3 days post-ACLR, the patient is in the inflammation phase of healing and cellular metabolism is increased to introduce cells and mediators to the area in order to begin clearing cellular debris resulting from the surgical procedure.[56] The early initiation of motion may positively affect the inflammation phase of healing through the manual and exercise interventions utilized during the therapy visits. If the inflammation phase is positively affected, the following phases of healing will be optimized as well.

The age of the patient, as well as the surgeon who performed the surgery had an effect on post-ACLR pain ratings. A total of 8 different surgeons were identified during data collection, and each had varying numbers of patients. With some surgeons having a greater number of patients, that could have affected the results. Each surgeon is unique in years of experience, overall technique, and the frequency of performing ACLR surgeries, while this is an important variable it is not the focus of this study. The finding does suggest specific techniques may be affecting pain post-surgically and is a recommendation for a future study. Older patients reported greater amounts of pain during therapy visits. Pain is highly individualized and each individual will have their own interpretation of what pain is and the intensity of it. In my opinion, with increased age comes more experiences and older patients may have more life experiences to draw from that affects their reported pain rating. Additional ailments an older person may experience that are separate from the ACLR should be analyzed as they could affect the overall pain rating. This outcome is something to consider when a clinician is working with an older patient and how their age could be affecting the reported pain rating.

Conclusion

This study shows that a variety of variables can affect the post-ACLR pain and the process as a whole and are not limited to graft type alone. The findings suggested that there was less pain post-ACLR associated with earlier initiation of rehabilitation. In addition to the initiation of rehabilitation, the type of rehabilitation significantly affected pain resolution. An accelerated rehabilitation approach yielded less pain when compared to a conservative rehabilitation program. Also, the younger the patient is, the less pain they experienced post-ACLR. If the patient's goal is to return to a high level of function after their ACLR, the accelerated rehabilitation approach should be utilized and the patient should advocate starting rehabilitation within 1-3 days after surgery. Although this study showed that graft type is not a significant predictor of pain post-ACLR, it is still an integral component of the process and the patient should consider their selection carefully.

Recommendations for Future Studies

Understanding the multitude of factors that could contribute to post-ACLR pain can provide clinicians additional knowledge on the treatment of ACLR patients. Having the ability to reduce the post-operative pain an ACLR patient experiences can greatly impact the quality of the initial therapy visits and may enable the patient to do more during their therapy sessions. Examining in further detail, other variables that impact the ACLR and rehabilitation outcomes would increase the body of research that in turn guides the treatment of ACLRs. The following recommendations should be considered.

1. Future research could set more parameters on the demographics of patient data being collected. An age range of younger individuals could be specified due to

the greater frequency of ACL injuries experienced by young, active people. Studying specific age groups would also indicate that results would not need to be generalized to the entire population.

2. Future studies need to increase the overall sample size and collect from a larger population. Increasing the sample size could affect the overall results and tease out more variables that were underpowered in this study.

3. In order to determine if AKP or any other anatomical location is affected by graft type, thorough analysis of therapy notes and records would be necessary. This study would be challenging due to the assumption that clinicians are providing adequate details in their documentation.

4. Future research should attempt to look at individual therapy visits and specific rehabilitation activities, specifically manual therapy techniques. Currently, there is not a gold standard protocol for treating ACLR patients that includes a detailing of manual interventions and studying the specific rehabilitation interventions would greatly add to the existing body of research.

5. This study did not analyze the average number of visits for subjects who experienced less pain or in those who began rehabilitation within a few days after surgery. By knowing the average number of visits in this particular group a recommendation could be made to healthcare providers and insurance companies on the number of visits necessary to decrease pain in the first six weeks post-ACLR and the urgency in beginning a rehabilitation program.

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APPENDICES

Appendix A. Statistics for Continuous Variables from the HLM analysis

Variable	df_{num}	df_{denom}	F	P	b	SE
Age	1	809.61	25.40	P<0.01	0.04	0.01
Activity Level	1	907.96	0.95	0.33	0.03	0.03
Time Elapsed from surgery to therapy	1	1017.09	7.25	P<0.01	1.00	0.04

APPENDICES

Appendix B. Statistics for the Categorical Variables from the HLM Analysis

Variable	df_{num}	df_{denom}	F	P	M	SE
Rehabilitation type:	1	625.76	42.06	$P<0.01$	-	-
Accelerated	-	-	-	-	0.24	0.27
Conservative	-	-	-	-	1.19	0.24
Surgeon:	7	886.24	4.46	$P<0.01$	-	-
A	-	-	-	-	1.19	0.20
B	-	-	-	-	1.21	0.24
C	-	-	-	-	1.13	0.56
D	-	-	-	-	1.93	0.26
E	-	-	-	-	1.05	0.37
F	-	-	-	-	-0.61	0.57
G	-	-	-	-	1.29	0.30
H	-	-	-	-	-1.50	0.74
Gender:	1	962.84	1.15	0.28	-	-
Female	-	-	-	-	0.78	0.26
Male	-	-	-	-	0.65	0.24
Graft Type:	1	810.28	1.80	0.18	-	-
Patellar Tendon Autograft	-	-	-	-	0.61	0.25
Hamstring Tendon Autograft	-	-	-	-	0.81	0.26
Mechanism of Injury:	1	955.23	0.00	0.97	-	-
Contact Mechanism		-	-	-	0.71	0.28
Non-contact Mechanism		-	-	-	0.71	0.23
Side of Injury:	1	889.95	0.04	0.84	-	-
Right	-	-	-	-	0.72	0.24
Left	-	-	-	-	0.71	0.26
Co-morbidities:	3	836.03	1.70	0.17	-	-
None	-	-	-	-	0.96	0.25
Lateral Meniscus Tear	-	-	-	-	0.61	0.28
Medial Meniscus Tear	-	-	-	-	0.73	0.25
Lateral and Medial Meniscus Tear	-	-	-	-	0.55	0.30
Pre-habilitation	1	801.10	1.66	0.10	-	-
Yes	-	-	-	-	0.83	0.27
No	-	-	-	-	0.59	0.23
Side of Previous ACL Tear	3	835.14	0.91	0.45	-	-
None	-	-	-	-	0.87	0.24
Right	-	-	-	-	0.62	0.30
Left	-	-	-	-	0.57	0.26
Both	-	-	-	-	0.79	0.48
Additional Surgery	1	904.26	0.66	0.51	-	-
Yes	-	-	-	-	0.76	0.26
No	-	-	-	-	0.66	0.26
ACL History:	1	927.02	0.28	0.78	-	-
Re-tear	-	-	-	-	0.76	0.35
1st Tear	-	-	-	-	0.66	0.22