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Sciatic Peripheral Nerve Blockade for Pain Control Following Hamstring Autograft Harvest in Adolescents: A Comparison of Two Techniques

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University.

by

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Abstract

SCIATIC PERIPHERAL NERVE BLOCKADE FOR PAIN CONTROL FOLLOWING HAMSTRING AUTOGRAFT HARVEST IN ADOLESCENTS: A COMPARISON OF TWO TECHNIQUES

By James Scott Furstein, DNAP, CRNA, CPNP-AC

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University.

Virginia Commonwealth University, 2016

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Anterior cruciate ligament reconstruction utilizing a hamstring autograft is a surgical technique that has gained popularity among orthopedic surgeons caring for adolescent patients. While utilization of a hamstring autograft is a revered technique, harvest of the hamstring yields significant pain. Sciatic peripheral nerve blockade has proven to reliably provide analgesia at the hamstring donor site. Single-injection sciatic peripheral nerve blockade is considered a basic and effective technique, making its use following anterior cruciate ligament reconstruction standard practice in many institutions. The duration of action of a single-injection sciatic peripheral nerve blockade may fail to

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outlast the pain arising from the hamstring donor site, prompting some clinicians to employ continuous sciatic peripheral nerve blockade via an indwelling catheter. A lack of comparative effectiveness studies exists in the literature regarding the duration of action of peripheral nerve blockade necessary to adequately provide pain control following hamstring autograft harvest, resulting in disagreement among clinicians as to best pain control practices. Proponents of continuous sciatic peripheral nerve blockade assert that while more costly, the extended duration of analgesia afforded by this technique improves pain control postoperatively and decreases the use of other pain medications. Advocates of single-injection sciatic peripheral nerve blockade cite concerns associated with continuous sciatic peripheral nerve blockade known to be detrimental to rehabilitation, such as decreased active knee flexion and increased risk of falls. The purpose of this research is to compare the effect of single-injection sciatic PNB to continuous sciatic PNB on 1) postoperative pain control as measured by self-reported pain scores, pain medication use, and unplanned hospital admission due to poor pain control, 2) active knee flexion, and 3) patient satisfaction with pain control following ACL reconstruction with a hamstring autograft. The findings of this study have the potential to guide informed clinical reasoning and decision making regarding sciatic peripheral nerve blockade techniques following hamstring autograft harvest in adolescents undergoing anterior cruciate ligament reconstruction.

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Chapter One: Introduction

In 1980, Rosenblatt first reported the use of a continuous femoral nerve catheter as the sole means of providing postoperative analgesia following knee surgery for patella alta, or high riding patella, in an adolescent (Rosenblatt, 1980). With the patient under general anesthesia, a small incision was made below the inguinal ligament, just lateral to the femoral artery. An 18-gauge Teflon-coated intravenous (IV) catheter was then threaded over a 22-gauge spinal needle through the incision at a 30-degree angle to the skin, leaving the tip of the catheter adjacent to the femoral nerve in the neurovascular sheath. The spinal needle was then withdrawn and the IV catheter was connected to extension tubing and sutured in place. Bupivacaine, a local anesthetic, was infused through the catheter for the next 24 hours. At the time, the duration for infusion of the local anesthetic was chosen arbitrarily as the uptake and distribution of drugs from the femoral space was unknown.

While likely unaware of the impact of this procedure on the future of clinical practice, Rosenblatt provided the foundation for what would soon become the gold standard in providing postoperative analgesia following knee surgery: continuous peripheral nerve blockade. Much has changed since Rosenblatt first introduced the use of a continuous femoral nerve catheter for postoperative analgesia. Local anesthetics utilized today offer a safer side-effect profile compared to their predecessors. Additionally, modern purpose-specific equipment, such as continuous perineural

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infusion (CPI) catheters, allows clinicians to provide effective site-specific analgesia over an extended period in a more reliable fashion.

Background

Anterior cruciate ligament (ACL) injury is the most prevalent injury treated in orthopedic sports medicine. The incidence of ACL injuries continues to increase with approximately 250,000 now occurring annually in the United States (Gagnier, Morgenstern, & Chess, 2012). As such, ACL reconstruction has become a common surgical procedure and is frequently performed on an outpatient basis. ACL reconstruction has historically been avoided in skeletally immature patients due to concerns of injuring the immature physes, resulting in growth deformities. Advances in surgical techniques, however, now allow ACL reconstruction to be performed safely and effectively in skeletally immature patients. Given the decreasing age of patients now undergoing this surgical procedure, orthopedic surgeons are charged with ensuring optimal ACL longevity following reconstruction. Subsequently, there has been a marked increased in the use of hamstring autografts for reconstruction of the injured ACL in adolescents due to the favorable long-term outcome profile of this surgical technique when compared to other available graft reconstruction options. The harvesting of a hamstring autograft, however, yields significant postoperative pain for which no consensus exists among clinicians as to how to best treat.

Statement of the Problem

Several options exist for replacement of the damaged ligament during ACL reconstruction in adolescents, yet the use of a hamstring autograft has emerged as the technique of choice due to the overall decreased morbidity and proven long-term

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stability when compared to other ligament reconstruction options (Mehta, Mandala, Foster, & Petsche, 2010; Pallis, Svoboda, Cameron, & Owens 2012). The growing trend to use a hamstring autograft for ligament reconstruction is a departure from the technique typically employed in the adult population, where use of an allograft tendon, or transplant tendon from another individual, has been the predominant technique employed. The use of hamstring autograft creates new concerns for surgeons and anesthetists alike.

A hamstring autograft is commonly comprised of both semitendinosus and gracilis muscles harvested via an anterior approach from the ipsilateral leg during ACL reconstruction (Figure 1). Once harvested, the two harvested muscles are sutured into a unified graft in an effort to replicate the size and strength of the native ACL. Despite the benefits of using a hamstring autograft, it is not without its drawbacks. One of the biggest disadvantages related to the use of hamstring autograft is significant pain at the hamstring donor site during the postoperative period. Accordingly, pain control accounting for pain arising from the donor site is of the utmost importance when developing an analgesic plan (Bushnell, Sakryd, & Noonan, 2010).

Pain control can be operationalized a multitudes of ways. For the purposes of this study, pain control will be measured via self-reported pain scores, the frequency of oral pain medicine use following discharge from the hospital after surgery, and the incidence of unplanned hospital admission due to poor pain control. While it is acknowledged that hamstring harvest leads to considerable pain during the immediate postoperative period, the significance of this pain beyond the initial 24 hours postoperatively remains undetermined as it has yet to be fully investigated (Bushnell,

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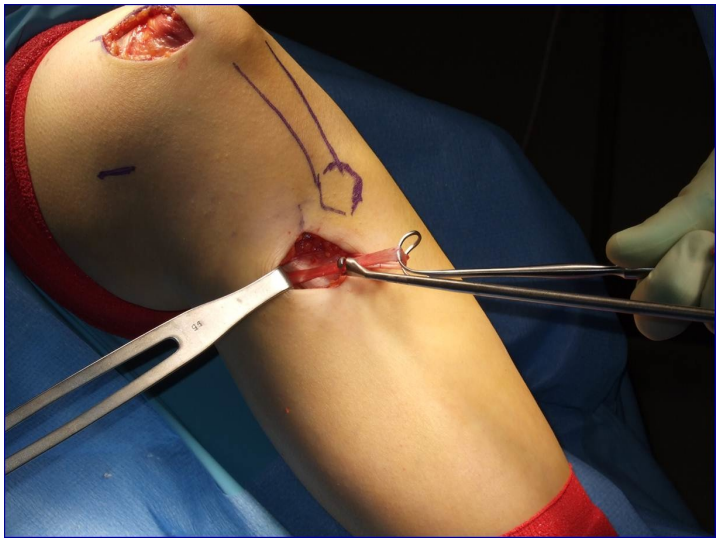

Figure 1. Hamstring Autograft Harvest Via an Anterior Approach. (Parikh, 2011)

Sakryd, & Noonan, 2010). Given the ever-increasing number of adolescents undergoing ACL reconstruction with a hamstring autograft, discerning best pain control practices following hamstring autograft harvest is a concern demanding more empirical attention.

Femoral peripheral nerve blockade (PNB) is the gold standard for providing analgesia following ACL reconstruction, however, femoral PNB alone does not provide adequate pain control following ACL reconstruction with a hamstring autograft (Williams, Kentor, Vogt, Williams, Chelly, Valalik, Harner, & Fu, 2003). Various modalities are available to provide analgesia at the hamstring donor site (Table 1), yet not all are available in the outpatient setting. Only intravenous opioids, local infiltration, intra-articular injection, or sciatic PNB are able to provide analgesia beyond discharge from the hospital. Of these modalities, most either inadequately control pain following ACL reconstruction with a hamstring autograft or are fraught with adverse side effects, such as nausea and vomiting, lethargy, hypopnea, constipation, and pruritus. Sciatic PNB,

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Table 1

Options for Blocking Pain at Hamstring Donor Site

Treatment Modality	Advantages	Disadvantages
Intravenous opioids	Gold standard in pain control, cost-effective	Undesirable side effects: N/V, pruritus, somnolence, urinary retention, hypoventilation
Epidural/spinal	Excellent postoperative pain control	Limited to in-hospital use
Local infiltration/intra-articular injection	Not technically challenging to perform, practical, cost-effective	Fails to consistently control donor site pain
Single-injection sciatic PNB	Minimizes opioid requirement, provides site-specific analgesia, improved early mobilization of major joints	Time consuming, limited duration of action
Continuous sciatic PNB	Minimizes opioid requirement, provides site-specific analgesia, improved early mobilization of major joints	Time consuming, costly, increased potential for toxicity and/or infection

however, provides adequate pain control while avoiding undesirable opioid-related side effects and has proven to abate hamstring donor site pain in a reliable fashion (Bushnell, Sakryd, & Noonan, 2010). The efficacy of sciatic PNB can be attributed to the origin of pain following hamstring autograft harvest, graft fixation, or both, which lies in the sciatic nerve distribution (Frost, Grossfeld, Kirkley, Litchfield, Fowler, & Amendola, 2000).

Controversy remains as to whether single-injection or continuous sciatic PNB is most appropriate following ACL reconstruction with a hamstring autograft. Single-injection sciatic PNB is a regional anesthetic technique employed to anesthetize the sciatic nerve with a single dose of local anesthetic. This technique offers pain control

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for a limited amount of time based on the volume and concentration of local anesthetic used. Continuous sciatic PNB entails placing a CPI catheter so that local anesthetic may be released slowly but continuously adjacent to the sciatic nerve (perineural) for several days postoperatively. While both techniques of sciatic PNB alleviate pain in the immediate postoperative period, only continuous PNB has the ability to reliably provide analgesia on subsequent postoperative days. No consensus exists regarding the duration of action necessary to adequately provide pain control following ACL reconstruction with a hamstring autograft. The disagreement among clinicians as to best practices of pain control following ACL reconstruction with a hamstring autograft is largely due to the lack of evidence comparing single-injection and continuous sciatic PNB following hamstring autograft harvest.

To date, there has only been one study reported in the literature comparing single-injection and continuous sciatic PNB. Continuous sciatic PNB was reported to offer significant advantages in pain control for adults only during the initial 24 hours following knee surgery (Wegener, van Ooij, van Dijk, Hollmann, Preckel, & Stevens, 2011). It should be noted, however, this study does not refer to ACL reconstruction, rather the study population is comprised of patients undergoing total knee replacement making it challenging to appropriately translate and apply the clinical knowledge gained from that study to other clinical scenarios.

Advantage/disadvantage of single-injection sciatic PNB. The two most significant advantages attributed to single-injection PNB techniques are ease and cost-effectiveness. Single-injection sciatic PNB requires little additional equipment or time to perform when compared to continuous sciatic PNB. This is a basic technique that

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requires no additional training beyond that received during anesthesia residency or nurse anesthetist training. In its simplest form, the only required equipment is antibacterial skin preparation, sterile gloves, a PNB injection needle, local anesthetic, and a nerve stimulator. In the hands of a skilled clinician, it takes no more than two minutes to perform a single-injection sciatic PNB. Depending on the volume and concentration of local anesthetic used, single-injection sciatic PNB has been reported to effectively provide analgesia up to 24 hours. There have been occasional reports of the duration of action lasting up to 36 hours when the maximum recommended dose of local anesthetic has been administered in adults, further bolstering the argument for the use of this technique. The main disadvantage of single-injection sciatic PNB is that it may fail to outlast the pain arising from the hamstring donor site (Ganesh & Cucchiaro, 2007). A duration of action greater than 24 hours in younger, smaller patients is challenging to achieve due to the weight-based dosing restrictions that limit the total dose that can safely be administered. The total dose of local anesthetic is the product of the volume and concentration of the local anesthetic. Furthermore, when multiple PNBs are administered concurrently, the total dose of local anesthetic must be divided between each PNB as to not exceed safe dosing recommendations. Therefore, while the initial costs attributed to a single-injection sciatic PNB are minimal, the use of this technique may lead to more costs, as increased dosing of pain medication is required to compensate for the limited duration of analgesia.

Advantage/disadvantage of continuous sciatic PNB. The primary advantage of continuous sciatic PNB when compared to single-injection PNB is the ability to extend the duration of analgesia postoperatively. Proponents of continuous PNB demonstrated

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that the extended duration of analgesia afforded by a CPI catheter following orthopedic-related surgeries improves overall pain control postoperatively and decreases the need for supplemental pain medications during the postoperative period (Ganesh & Cucchiaro, 2007). The additional costs attributed to continuous sciatic PNB may lead some clinicians to deem the modality prohibitive, as additional equipment is required, including catheters, needles, an infusion pump, dressing supplies and additional local anesthetic. It has been argued that the additional costs are justified, however, as the ability to provide extended analgesia postoperatively decreases the average length of hospitalization. Thus, improving postoperative pain control ultimately leads to efficient use of health resources and decreases overall costs for patients (Strassels, Chen, & Carr, 2002).

Several potential disadvantages exist related to the use of continuous sciatic PNB. Concerns of increased falls, decreased knee flexion, and masking of compartment syndrome following the placement of a sciatic CPI catheter as reasons to preclude their routine use following ACL reconstruction with a hamstring autograft (Liu & Wu, 2007). The sciatic nerve innervates the hamstrings, which are responsible for knee flexion (Distad & Weiss, 2013). The extended duration of anesthesia provided continuous sciatic PNB may prolong motor blockade, thereby limiting active knee flexion. Hindering active knee flexion postoperatively may impede rehabilitation. In addition, should a femoral PNB and sciatic PNB be administered on the same leg concurrently, the patient will lose sensation and motor function of the leg from the thigh to the toes. They will not have the strength to safely bear weight with the anesthetized extremity until the PNB has resolved.

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Although infrequently reported, a major risk factor of continuous PNB is CPI catheter infection (Lai, Jaeger, Jones, Kaderbek, & Malchow, 2011). While minimal, the rate of infection continues to rise as the duration the catheter is left in place increases. Local anesthetic toxicity is a potential hazard for both single-injection and continuous sciatic PNB. This concern is heightened for continuous sciatic PNB due to the continuous infusion of local anesthetic via the CPI catheter. To avoid reaching toxic level, the total dose of local anesthetic infused is based on patient weight.

Significance of the Problem

Currently the mean age of ACL reconstruction is 18 years, indicating half of the number of patients undergoing ACL reconstruction are adolescents (Silvers & Mandelbaum, 2007). Historically, adolescents with ACL injuries have been treated conservatively, with many orthopedic surgeons relying on non-surgical techniques, such as bracing and activity restrictions, for treatment. Due to the increased safety profile of ACL reconstruction in skeletally immature patients over time and the long-term detriment to the meniscus should ACL reconstruction be delayed, the incidence of ACL reconstruction in the adolescent population has increased by over 400 percent in the last decade. Despite this exponential growth, there is no professional standard of care addressing postoperative pain control for this patient population.

Mismanagement of pain can be detrimental, resulting in negative physiological, psychological, and economic consequences (Agin & Glass, 2005). Failure to address pain may lead to future impairment in functioning as well as heighten anxiety and fear, which in turn may further increase the perception of pain (Matthews, 2011). Continued mismanagement of pain results in increased suffering and misery that can ultimately

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impact one's lifestyle and personality (Beales, Holt, Keen & Mellor, 1983). In addition, unaddressed pain can cause great disruption to families caring for patients. From an economic perspective, the mismanagement of pain can lead to slower rates of recovery, resulting in increased healthcare-related costs and time away from school and work (Twycross, 2002).

Pain is an individual experience. While every patient has a different perception of pain, it is a reasonable expectation that evidence-based protocols exist to guide pain control following ACL reconstruction for the adolescent population given the frequency with which this surgery is performed. The goal of pain control is to decrease the intensity and duration of pain to the level that is tolerable for the patient without impeding recovery. Although acute pain is often managed successfully, further research is necessary to determine how to best provide pain control several days postoperatively following ACL reconstruction with a hamstring autograft such that negative physiological, psychological, and economic consequences are avoided.

Research Question

This study aims to answer the following research question: Does single-injection sciatic PNB or continuous sciatic PNB provide more effective postoperative pain control following ACL reconstruction with a hamstring autograft in the adolescent population?

Purpose of the Study

The purpose of this research is to compare the effect of single-injection sciatic PNB to continuous sciatic PNB on 1) postoperative pain control as measured by self-reported pain scores, pain medication use, and unplanned hospital admission due to poor pain control, 2) active knee flexion, and 3) patient satisfaction with pain control

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following ACL reconstruction with a hamstring autograft. The results of this research have the potential to positively impact pain control for the adolescent population undergoing this surgical procedure and foster responsible utilization of limited resources.

Chapter Summary

ACL reconstruction with a hamstring autograft is a surgical technique that has gained popularity among orthopedic surgeons caring for adolescent patients with ACL injuries due to the long-lasting nature of the graft. While the use of a hamstring autograft is a revered surgical technique, postoperative pain at the graft donor site can be significant. Sciatic PNB, in general, has proven to reliably provide analgesia at the hamstring donor site. Single-injection sciatic PNB is considered to be a basic and effective technique, making its use following ACL reconstruction routine practice in many institutions. The duration of action of a single-injection sciatic PNB, however, may fail to outlast the pain arising from the hamstring donor site, prompting some clinicians to employ a sciatic CPI catheter for continued infusion of local anesthetic medications. Use of a sciatic CPI catheter, however, adds additional cost, may lead to falls or hinder rehabilitation, increases the risk of local anesthetic toxicity, and is a potential vector for infection. No definitive evidence exists in the literature guiding practitioners in the decision to use either single-injection sciatic PNB or continuous sciatic PNB for pain control following ACL reconstruction with a hamstring autograft. This research has the potential to contribute to improving pain control strategies for adolescents undergoing ACL reconstruction with a hamstring autograft.

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Chapter Two: Literature Review

Chapter Introduction

Quite often, the choice of anesthesia and pain control is at the discretion of the anesthesia team and is based on the patient's medical history, presence of comorbid medical conditions, and surgical goals. In many instances, protocols are developed for frequently performed procedures and are refined over time to guide anesthetists toward delivering a safe and effective anesthetic. When caring for a patient undergoing an uncommon surgical procedure, however, anesthetists are charged with relying on their cadre of skills and experiences to quickly develop and implement an anesthetic plan to best serve the patient. Evidence uncovered in the current literature enables anesthetists to better understand aspects of care given an unfamiliar situation. While ACL reconstruction utilizing a hamstring autograft in adolescents is becoming more frequent, many anesthetists remain unfamiliar with caring for this patient population. In this chapter, the form and function of the ACL will be described, as well as the current surgical options for repairing an injured ACL. In addition, the definitions and components of pain will be summarized and the most current understanding of pain control for patients undergoing ACL reconstruction utilizing a hamstring autograft will be outlined.

The anterior cruciate ligament. The ACL is a band-like structure comprised of dense connective tissues that course from the femur to the tibia (Duthon, Barea,

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Abrassart, Fasel, Fritschy, & Menetrey, 2006). It is a key structure in the knee joint, as it functions as the primary restraint to anterior tibial translation. Without an intact ACL, anterior translocation of the tibia occurs during normal knee movement activity leading to pain and instability (Hudgens & Dahm, 2012).

It is widely accepted that the ACL, which lies intraarticular yet extrasynovial, is comprised of the anteromedial (AMB) and posterolateral bundles (PLB) (Bicer, Lustig, Servien, Selmi, & Neyret, 2010) (Figure 2). Debate exists, however, as to whether or not these bundles occur as separate, distinct bundles or as one unified bundle. The origin of each of these bundles is well documented (Bicer, Lustig, Servien, Selmi, & Neyret, 2010). Enveloped in synovium, the AMB originates at the most anterior and proximal aspects of the femoral insertion site with the PLB originating at the posterior and inferior aspect of the femoral attachment (Bicer, Lustig, Servien, Selmi, & Neyret, 2010). Distally, the ACL passes beneath the transverse meniscal ligament and inserts into the anterior intercondylar fossa, anterolateral to the medial tibial spine (Bicer, Lustig, Servien, Selmi, & Neyret, 2010). The AMB and PLB collectively function to maintain anterior and rotational stability utilizing varying tensioning patterns throughout the full range of motion of the knee (Bicer, Lustig, Servien, Selmi, & Neyret, 2010).

ACL durability: venerable or vulnerable? The knee is the most common site of injury requiring surgical repair (Kartus, Movin, & Karlsson, 2001). ACL injuries represent the largest single injury in orthopedic sports medicine and the incidence continues to increase, with approximately 250,000 ACL injuries occurring annually in the United States (Gagnier, Morgenstern, & Chess, 2012). Therefore, every year 1 out of every 3,000 Americans will sustain an ACL injury (Macaulay, Perfetti, & Levine, 2012).

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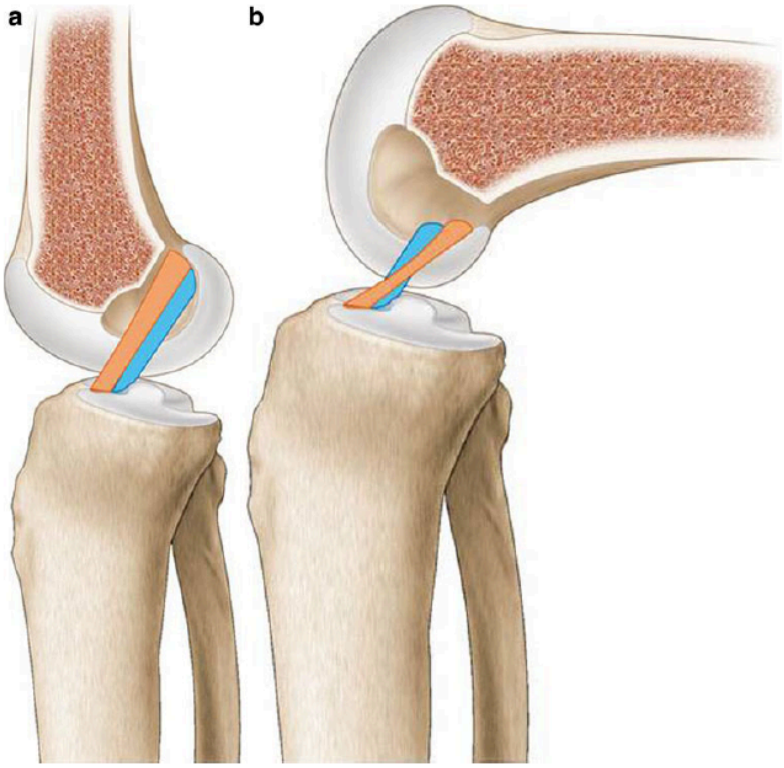

Figure 2. Schematic Drawings of the Sagittal View of the AMB (orange) and the PLB (blue) During Extension (a) and 90 Flexion (b) (Bicer, Lustig, Servien, Selmi, & Neyret, 2010).

A multitude of hormonal, anatomic, environmental, and neuromuscular factors can lead to ACL injury (Boden, Griffen, & Garrett, 2000). The degree to which specific etiologic factors contribute to ACL laxity, tensile failure, or increased flexibility, however, remains unknown (Boden, Griffen, & Garrett, 2000). Regardless of cause, the resultant ACL deficiency greatly increases the likelihood of ACL sprain or rupture, as the ACL is not able to function normally and properly restrict anterior neutral position shift. As a result, the anterior translation of the tibia relative to the femur is four times greater than that of normal knees in the presence of ACL deficiency (Beynnon, Flemming, Labovitch, & Parsons, 2002).

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ACL injury in adolescents. Among adolescent athletes, the knee is the most frequent site of muscloskeletal injury (Micheli & Foster, 1993). While ACL injury can be due to trauma or genetic defect, the most frequent cause of ACL injury in adolescents is participation in competitive sports (McConkey, Bonasia, & Amendola, 2011). The competitive nature of youth sports today is largely to blame for the increase in knee injuries among children and adolescents (Mohtadi &Grant, 2006). In adolescents, the mechanism of injury most often is a non-contact pivoting motion on a fixed foot, however, the ACL can also be injured secondary to hyperextension (Boden, Dean, Feagin, & Garret, 2000). Sports that force a pivoting motion are more likely to be associated with ACL injury, with the greatest incidence of ACL tears found among basketball and soccer players (Piasecki, Spindler, Warren, Andrish, & Parker, 2003). In fact, over a 5-year period Shea, Pfeiffer, Jo, Curtin, and Apel (2004) noted that in soccer players aged 5 to 18 years, knee injuries accounted for 22% of all injuries, with ACL injuries accounting for 31% of those claims.

During non-contact activity, ACL injury can occur in the adolescent population during deceleration or movement that involves a change of directional forces, such as when playing basketball, football or soccer (Adirim & Cheng, 2003). While injuries to the ACL are more frequent among certain cutting and pivoting sports, mechanisms of sustaining an ACL injury in various sports remains largely unknown (Granan, Inacio, Maletis, Funahashi, & Engebretsen, 2013). Non-contact, sudden deceleration, with the knee positioned near full extension, is considered the primary cause of the majority of ACL injuries, with valgus loading considered to be an important mechanism of injury

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(Podraza & White, 2010). ACL injuries may also be attributed to the inability to disperse energy by the ankle when impacting the ground (Podraza & White, 2010).

Historically, ACL tears were thought to only occur following the closure of the epiphyseal plate, which is a hyaline cartilage near the end of the long bones in children and adolescents (Rang, 1983). The incidence of skeletally immature patients requiring ACL reconstruction, however, continues to grow rapidly (Schachter & Rokito, 2007). Skeletal maturity refers to the acceleration in bone growth and subsequent obliteration of the cartilaginous zones, or growth plates, which occurs during puberty secondary to alterations in endogenous sex hormones (Wall, Meyer, & May, 2011). The risk for complete ACL tears continues to rise as children mature due to the increase in skeletal rigidity associated with maturation and closure of the cartilaginous growth plates in the knee (Prince, Laor, & Bean, 2005). ACL injuries typically occur in adolescents within 6-12 months of skeletal maturity (Woods & O'Connor, 2004). Multiple factors can be credited with the dramatic rise in ACL reconstruction in the adolescent population over the last decade, namely increased participation in sports at early ages, increased awareness of the potential for injury and improved diagnostic imaging techniques of such injuries (Hui & Chowdhary, 2011).

While Piasecki et al. (2003) found no significant differences relating to gender and mechanism of injury in adolescent ACL injuries, female athletes in general have an increased tendency towards knee injuries, being two to six times more likely to suffer an ACL tear. Likewise, year-round female soccer and basketball athletes have an ACL tear rate of approximately 5% per year, which is approximately three times that of their male counterparts (Prodromos, Han, Rogowski, Joyce, & Shi, 2007). Following

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skeletal maturation, females continue to have a higher risk of ACL rupture, with the incidence 2 to 8 times higher than that of males of equal age (Prince, Laor, & Bean, 2005). Prior to skeletal maturity, however, males have a higher incidence of ACL rupture (Hudgens & Dahm, 2012).

ACL reconstruction. ACL reconstruction is accomplished using a graft to replace the damaged ACL. Once it has been determined that ACL reconstruction is necessary, the surgeon is charged with deciding which graft type best suites the individual patient's needs. A graft is tissue from one's own body (autograft) , tissue from another person (allograft), or artificial tissue that is surgically implanted without a native blood supply (synthetic graft). Factors considered by the surgeon in making this determination are many, but often include donor site morbidity, graft failure rate, surgeon familiarity with the graft type, graft availability, surgical time, associated complications, ability to restore the patient's activity to pre-injury level and cost-effectiveness of the chosen technique (Dheerendra, Khan, Singhal, Shivarathre, Pydisetty, & Johnstone, 2012).

In the adult population, a variety of techniques have been successfully employed, namely the use of synthetic grafts, allografts, and autografts. The two most common autografts are the bone-patellar tendon-bone and hamstrings tendon grafts (Dheerendra et al., 2012). Multiple types of grafts have been employed to reconstruct the damaged ACL in adolescents, with the use of semitendinosus and gracilis tendon autografts being the preferred technique in this patient population. Once harvested, the semitendinosus and gracilis tendon are sutured together to form a single graft approximately the size of the native ACL or larger. Once sutured together, the graft is commonly referred to as a

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hamstring autograft. The use of a hamstring autograft is associated with decreased morbidity and proven long-term stability when compared to the other ACL replacement options, however, choosing to use a hamstring autograft leads to a second site of pain that must be accounted for in the postoperative period (Mehta, Mandala, Foster, & Petsche, 2010; Pallis, Svoboda, Cameron, & Owens, 2012).

Anesthetic challenges with ACL reconstruction. ACL reconstruction is recognized as a painful surgical procedure. Advances in surgical technique, the understanding of pain, and advances in pain management protocols, however, have improved clinicians' abilities to successfully manage the patient's pain on an outpatient basis in both the adult and adolescent population. Still, several challenges remain to providing adequate analgesia following ACL reconstruction with a hamstring autograft given there are two sources of tissue damage, the ACL and the hamstring donor site. Multiple prospective, randomized studies have examined how to best address pain at the reconstruction site following ACL repair in general. To date, however, little is known about the most effective techniques to abate donor site pain following hamstring autograft harvest.

The femoral nerve provides sensory and motor innervation to the anterior thigh, anterior knee, and the medial aspect of the leg below the knee (Mall & Wright, 2010). Femoral PNB involves injecting local anesthetic into the space surrounding the femoral nerve, thereby modulating sensory and motor signals traveling along the distribution of the femoral nerve. While femoral PNB is widely utilized for postoperative pain control following ACL reconstruction, this intervention fails to account for pain at the native

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donor site of the hamstring autograft (Kristensen, Pfeiffer-Jensen, Storm, & Thillemann, 2012).

Definitions of Pain

The International Association for the Study of Pain (IASP) describes pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage" (Mersky & Bogduk, 1994). A single definition of pain is challenging to capture, however, as there are many factors to consider and it is a subjective experience. In general, the definition of pain largely relates to a given circumstance. There is no objective measurement of pain (Farrar, Berlin, & Strom, 2003). Rather, the measurement thereof relies on report from the individual patient (Farrar, Portenoy, Berlin, Kinman, & Strom, 2000).

In 2008, the IASP greatly expanded the definition of pain, which reflects an improved understanding of the phenomenon of pain (Loeser & Treede, 2008). As the understanding of pain and pain pathways continues to expand, definitions of pain are likely to evolve accordingly. For the purpose of this study, acute postoperative pain will be the primary focus of interest, as this remains clinically challenging to manage in adolescents undergoing outpatient ACL reconstruction with a hamstring autograft (Brennan, 2011).

The Physiology of Pain

Pain has been described as the perception of an adverse stimulus (Almeida, Roizenblatt, & Tufik, 2004). This stimulus may be chemical, mechanical, or thermal in origin (Caterina & Julius, 2001). The phenomenon of pain occurs along a three-neuron pathway responsible for transmitting noxious stimuli from the periphery of the body to

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the cerebral cortex in the central nervous system, where the perception of pain or discomfort is realized (Morgan, Mikhail, & Murray, 2006).

Pain begins with the activation of nociceptors: sensory neurons that respond to potentially damaging stimuli by sending signals to the spinal cord and brain. Nociceptors are found widely in skin, mucosa, membranes, deep fascias, connective tissues of visceral organs, ligaments and articular capsules, periosteum, muscles, tendons, and arterial vessels (Almeida, Roizenblatt, & Tufik, 2004). Nociceptors represent the most distal aspect of first-order afferent neurons in the periphery and consist of A-delta, C, or A-beta fibers. First-order afferent neurons have a single bifurcating axon located in the dorsal root ganglia of the vertebral foramina, which sends one end to the peripheral tissue and the other to the dorsal horn of the spinal cord (Morgan, Mikhail, & Murray, 2006).

Nociception, the encoding and processing of harmful stimuli, is a peripheral phenomenon that ultimately concludes in the dorsal horn of the spinal cord (Loeser, 2000). Nociceptive input is conveyed from a peripheral end organ, such as the skin, to the central nervous system predominantly by two classes of first-order afferent fibers, A-delta fibers and C fibers (Katz & Rothenberg, 2005). A-delta fibers, which are myelinated, are classified into two groups, those with high-threshold mechanoreceptors that primarily respond to mechanical stimuli of high intensity, such as hitting one's finger with a hammer, and those with mechanoreceptors that respond to extremes of temperature such as in the case of burns (Almeida, Roizenblatt, & Tufik, 2004). Like A-delta fibers, C fibers are activated by a variety of high-intensity mechanical, chemical, and extreme hot and cold stimuli, however, these fibers are unmyelinated (Katz &

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Rothenberg, 2005). In contrast, A-beta fibers do not normally propagate noxious potentials. These fibers are key to pain circuitry as they participate in the mechanism of segmental suppression by causing presynaptic inhibition of pain signals (Katz & Rothenberg, 2005).

As first-order neurons enter the spinal cord from the peripheral tissues, they segregate according to size and travel the spinal cord to synapse with second-order neurons in the gray matter of the ipsilateral dorsal horn of the spinal cord (Morgan, Mikhail, & Murray, 2006) (Figure 3). Second-order neurons are one of two types, those that receive only noxious input or those that receive both noxious and non-noxious input. Second-order neurons cross to the contralateral aspect of the spinal cord and form the spinothalamic tract, which is classically considered the major pathway for the propagation of pain (Morgan, Mikhail, & Murray, 2006). The spinothalamic tract ultimately delivers signals to the primary sensory cortex of the brain via the thalamus, where the discriminative component associated with pain is ultimately perceived, and to the limbic cortical areas of the brain, where the affective aspects of the pain experience, such as depression, anger, anxiety, and despair, are perceived (Katz & Rothenberg, 2005).

Components of Pain

Pain is a complex, multifaceted phenomenon. It is not solely a sensory modality, rather it is an experience comprised of multiple components (Morgan, Mikhail, & Murray, 2006). There are four broad components of pain: nociception, perception of pain, suffering, and pain behaviors (Loeser & Melzack, 1999). Nociception is a physiologic

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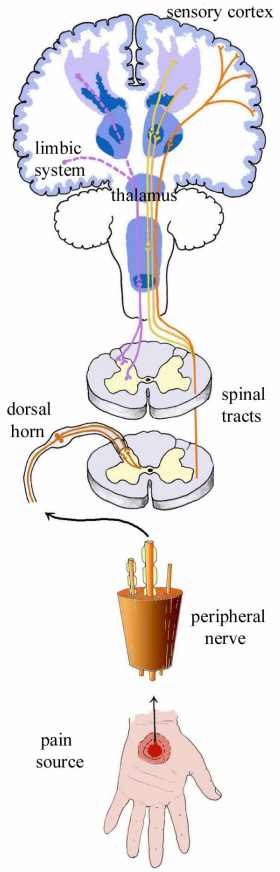

Figure 3. Depiction of the Pain Pathway (www.perioperativepain.com)

term describing the neural processes of encoding and processing noxious stimuli (Loeser & Treede, 2008). Once a harmful stimulus has been processed, the perception of pain leads to suffering and ultimately pain behaviors if the perception of pain continues.

These four main components of pain can be classified into one of two categories: those that can be quantified and those that cannot. Nociception, perception of pain, and suffering are internal events whose validity and intensity cannot be established by observation (Loeser, 2000). Pain behaviors, however, are based on actions rather than personal report and are observable, measurable, and objective (Loeser, 2000). When pain is experienced, patients exhibit a variety of behaviors that serve to communicate

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the presence and intensity of pain being experienced (Keefe & Wren, 2013). Pain behaviors, therefore, often guide pain control strategies as a reference point can be established to guide further intervention. Envisioning these four components as nested circles (Figure 4) aids in understanding the interplay between the aspects of pain that are readily quantified and those that are not.

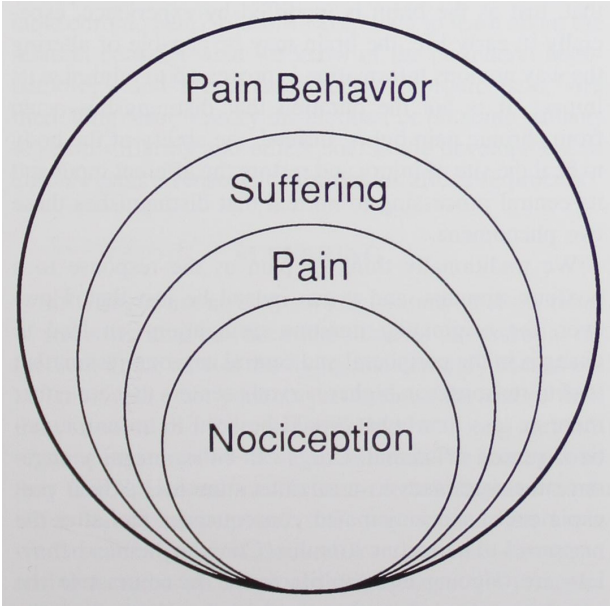

Figure 4. Depiction of the Universe of Pain (Loeser, 2000).

Nociception. Nociception accounts for the mechanisms by which noxious stimuli are detected by the peripheral nervous system, encoded, transferred, and unconsciously addressed by the nervous system within the human body (Barrot, 2012). More specifically, nociception is the detection of tissue damage by specialized transducers connected to A-delta and C fibers (Loeser, 2000). During surgery, for example, tissue damage caused by surgical incision or other surgical manipulation is detected primarily by A-delta and C fibers in the peripheral nervous system and subsequently transmitted to the central nervous system for interpretation.

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Perception of pain. The perception of pain refers to how one processes and reacts to physiological stimuli (Linton, 2005). This process begins in the dorsal horn of the spinal cord and involves the entire spinal cord and brain (Loeser, 2000). While frequently triggered by a noxious stimulus, pain can also be associated with potential, rather than actual, tissue damage (Loeser & Treede, 2008). Furthermore, noxious stimuli culminating in pain can be generated at any point in the pain pathway by either central or peripherally located lesions (Loeser & Melzack, 1999). Once perceived, pain triggers autonomic and somatic reflexes within the body to respond to the painful stimuli (Loeser & Melzack, 1999). When pain is perceived, the paraventricular nucleus of the hypothalamus is excited and short-term adaptive responses, known as the stress response, are initiated in the hypothalamo-pituitary-adrenocortical axis (Chapman & Gavrin, 1999). The stress response is an adaptive pattern of neural and endocrine activation and behavioral changes that occurs in the brain and is directed toward the restoration of homeostasis (Chapman & Gavrin, 1999).

The perception of pain, however, is more than simple nerve stimulation (Linton, 2005). Cognitive and emotional processing of pain occurs within the brain similar to the processing of input from noxious stimuli (Julius & Basbaum, 2001). Emotions have a powerful impact on pain perception, as pain and emotions are intimately related with robust reciprocal interaction (Roy, Piche, Chen, Peretz, & Rainville, 2009).

Suffering. In most instances, pain leads to suffering, which is a negative affective response generated in the brain (Loeser, 2000). Although commonly used interchangeably, the concepts of pain and suffering are distinctly different (Cassell, 1982). Pain is a perceived threat or damage to one's biological integrity and has

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sensory and emotional facets (Chapman & Gavrin, 1999). While pain can lead to suffering, not all pain causes suffering. Suffering is a broader concept than pain and can have many causes, one of which may be pain. Suffering connotes enduring an unpleasant and/or inconvenient experience (Chapman & Gavrin, 1999). It is an overwhelming state of severe distress that is both personal and subjective, and coincides with a range of intense emotions (Thompson & Chochinov, 2012).

The stress response initiated by the autonomic and somatic reflexes in response to the perception of pain are often short-term in nature. Should the perception of pain persist, however, dysregulation of the neural and endocrine pathways of the stress response can ensue, leading to alterations in signal pathways, abnormal neural firing patterns, and potentially lower firing thresholds. Ultimately, such alterations may debilitate one's sense of self, which is subjective sense of identity based on past experiences, resulting in suffering (Chapman & Gavrin, 1999). Suffering develops when discrepancies between expectation for one's self and reality arise (Chapman & Gavrin, 1999). Ultimately, suffering connotes enduring something unpleasant and inconvenient, sustaining loss or damage, or experiencing a disability (Chapman & Gavrin, 1999).

Pain behaviors. Pain behaviors are real and are influenced by previous experiences that have resulted in suffering (Loeser, 2000). As suffering progresses, human behaviors can develop such as saying "ouch", grimacing, or limping in response to pain. Such behaviors can be readily quantified when attempting to infer the degree of nociception, pain perception, and suffering (Loeser & Melzack, 1999). Failing to respond to painful stimuli typically associated with tissue damage as one would expect is another example of a pain behavior (Loeser, 2000).

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Theories of Pain

Several theories explaining the physiological basis of pain have been offered, yet to date no theory completely accounts for all aspects of pain perception (Moayedi & Davis, 2013). Whether a specific pathway mediates pain or a non-specific pathway in the nervous system meditates pain remains the primary dispute between competing pain theories (Chen, 2011). Of the theories pertaining to pain, four have proven to be the most influential regarding pain perception: intensity theory, specificity theory, pattern theory, and the gate control theory of pain (Moayedi & Davis, 2013). The intensity theory, specificity theory, and pattern theory all offer rationale for the peripheral identification of a painful stimulus. While each theory offers a unique explanation for the transmission of pain signals, it is possible that all three theories concurrently play a role in pain perception (Wildsmith & Armitage, 1987). The gate control theory was the first theory to explain the central modulation of pain impulses.

The intensity theory of pain. The intensity theory proposes that stimulation of any sensory receptor will cause pain if the stimulus is excessive or sufficiently intense (Wildsmith & Armitage, 1987). According to the intensity theory, peripheral afferent neurons are not differentiated into low-threshold and high-threshold neurons, therefore the intensity of the noxious stimulus alone dictates whether or not the stimulus is deemed innocuous or noxious (Chen, 2011). The intensity theory holds that strong activation of any non-specialized primary afferent neuron will elicit pain, as all the non-specialized primary afferent neurons ultimately converge onto central neurons (Prescott, Ma, & de Koninck, 2014). If the stimulus is weak, a non-painful sensation will be produced (Chen, 2011). Although the intensity theory was eventually rejected as

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evidence of primary afferent neuron specialization surfaced, it remains true that the intensity of a noxious stimulus is a factor in pain (Prescott, Ma, & de Koninck, 2014).

The specificity theory of pain. The specificity theory is one of the most influential theories of pain, as it suggested that a pathway specific to pain exists (Chen, 2011). The specificity theory of pain proposes that all sensations, including pain, are receptor-specific with associated sensory fibers that are sensitive only to one specific stimulus, thereby creating dedicated pathways for the transmission of specific signals (Moayedi & Davis, 2013). During its infancy, scientists supporting the specificity theory provided evidence linking specific sensory nerve endings in the skin to the sensation of pain, bolstering the concept of nociception (Perl, 2007). The concept of nociception was key to the specificity theory, which emphasized tissue injury as a common source of pain. Per the specificity theory, nociceptors in the skin remain at or near threshold and can only be stimulated by a unique, specific noxious stimulus (Chen, 2011). Once the nociceptors are stimulated, the transmission of specific pain signals ensues leading to the perception of pain. The intensity of the perception of pain depends upon which nociceptors were stimulated and how intense the stimulus was (Prescott, Ma, & De Koninck, 2014). Unfortunately, the specificity theory failed to account for neurons in the central nervous system that respond to both innocuous and noxious stimuli (Moayedi & Davis, 2012).

The pattern theory of pain. The pattern theory of pain proposed that there is no pathway specifically for the mediation of pain. Rather, the transmission of pain signals is achieved via receptors that are shared with other senses. The pattern theory of pain is a quantitative theory of pain. The spatial and temporal pattern of stimulation of the

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peripheral nerves determines the intensity of the stimulus and whether it is deemed innocuous or noxious (Moayedi & Davis, 2012). Therefore, the pattern theory proposes that sensory impulses are coded according to the number of receptors stimulated, as well as the rate of discharge (Melzack, 1993). The pattern of primary afferent neuron activation forms the basis of pain signals created by the stimuli (Prescott, Ma, & De Koninck, 2014). The pattern theory serves as the foundation for the gate control theory (Melzack, 1993).

The gate control theory of pain. During the mid-twentieth century, Melzack and Wall (1965) suggested the gate control theory of pain to explain the central modulation of pain impulses. The gate control theory provides a neural basis for the transmission of sensory information from the periphery to the brain, thereby helping to reconcile the apparent differences between the earlier pattern and specificity theories of pain (Moayedi & Davis, 2013). The gate control theory of pain has evolved over time, yet the original theory in its most simplistic form remains intact and is well embraced by the scientific anesthesia community as the most widely recognized theory of pain. The gate control theory of pain is a pattern-based theory that proposes that low-threshold and high-threshold primary afferent neurons both converge on non-specialized central neurons and if that if this convergent force is strong enough, pain will be signaled (Prescott, Ma, & De Koninck, 2014).

The gate control theory proposes that the substantia gelatinosa, which is located in the dorsal horn of the spinal cord, has the capacity to modulate the transmission of sensory information received from the periphery before it is transmitted via the spinal cord to the brain (Moayedi & Davis, 2013). Melzack and Wall asserted that the

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transmission of pain signals via first-order afferent fibers from the periphery initiate the stress response. Cells within the substantia gelatinosa, however, may function as a "gate" with the ability to modulate received signals prior to sending them onto the brain. Such modulation may ultimately limit the stress response secondary to the perception of pain (Roberge & McEwen, 1998).

The theory states also that the transmission of painful sensory information from peripheral nerve fibers via the spinal cord can be influenced by both intrinsic neurons and responses from the brain (Dickenson, 2002). One such example is an alteration in the release of enkelphalins, which can impact nociceptive signal transmission. Enkephalins are endogenous opioids that act as chemical neurotransmitters, inhibiting the release of Substance P in a manner similar to exogenous opioids. Substance P is the neurotransmitter responsible for transmitting the pain signal from first-order neurons to second-order neurons. An increase in enkephalin release, therefore, disrupts the perception of pain by inhibiting the transmission of pain signals from first-order to second-order neurons.

Per the gate control theory, pain can be modulated or "gated" at a number of points along the pain pathway, as opioid receptors are not isolated to the substantia gelatinosa. While opioid receptors are primarily located in the dorsal horn of the substantia gelatinosa, they can also be found throughout the spinal cord, the hypothalamus, the limbic system and in parts of the brain stem. Modulation of pain can occur at all of these sites due to the presence of opioid receptors at these locations (Wildsmith & Armitage, 1987). Inhibitory and excitatory pathways originating in the brainstem can modulate the transmission of pain signals in the spinal cord. These

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pathways function to either attenuate or augment pain signals in an effort to maintain homeostasis. The gate control theory offers a framework for clinicians to explore the transmission of pain signals from peripheral to central neurons when attempting to modulate, or exert a controlling force on, the experience of pain (Dickenson, 2002).

Classification of Pain

Understanding the various origins of pain aids in treatment planning. While the phenomenon of pain can be parceled into endless divisions, pain can generally be classified as one of three categories: the temporal element, mechanism of pain and the etiology of pain.

The temporal element of pain. Pain typically subsides when either the noxious stimulus is removed or enough time has elapsed to allow the body to heal. Accordingly, pain can be described as being transient, acute, or chronic. Classifying pain in terms of its temporal nature not only links the phenomenon to a given point in time relative to the causative factor, but it allows clinicians to better comprehend what mechanisms may be involved in producing the pain phenomenon.

Transient pain. Transient pain is pain that is associated with little to no tissue damage. While unpleasant, this type of pain is fleeting in nature and occurs when afferent pain fibers are activated by a brief, high intensity stimulus (Dray, 1995). Transient pain is not often viewed as a barrier to the recovery process following surgery. Rather, it is thought to have evolved as a protective mechanism, as a means of protection from physical damage by the environment or by over stress of the body tissues (Loeser & Melzack, 1999).

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Acute pain. Acute pain is more persistent than transient pain and is facilitated by the inflammation secondary to mild tissue damage, which makes the afferent pain fibers more susceptible to activation by lower intensity stimuli (Dray, 1995). Surgical pain begins with the incision and can continue to escalate throughout the procedure. Continued tissue injury beyond the initial insult initiates a cascade of inter-related physiological events to stave off infection, limit further damage, and initiate repair (Voscopoulos & Lema, 2010). When properly managed, acute pain does not overwhelm the body's reparative mechanisms and healing occurs without interruption.

Intraoperative acute pain. Intraoperative pain exceeds incisional pain. It is reported that intraoperative pain rapidly decreases and resolves within 30 minutes after incision (Brennan, 2011). Acute pain during the intraoperative period can be attributed to tissue dissection, positioning, the tourniquet, and visceral or somatic compression and/or stretching of bodily tissue secondary to the surgical technique.

Postoperative acute pain. Following surgery, pain may not be solely attributed to the surgical incision. Referred pain and variations in pain secondary to movement are key factors in acute postoperative pain. Referred pain is that which is felt in a different region away from the source of pain (Arendt-Nielson, Fernandez-de-las-Penas, & Graven-Nielsen, 2011). Unfortunately, pain at rest and evoked pain are likely transmitted by different afferent fibers and/or different receptors (Brennan, 2002). Currently, there remains no sound understanding of the algogenic, or pain producing, substances that are released to activate and sensitize the nociceptive nerve terminals in a surgical wound (Brennan, 2002).

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While much regarding acute postoperative pain remains uncertain, many contributing factors have been reported in the literature including; genetics, age, gender, preoperative anxiety, psychological distress, personality traits, presence of preoperative pain, and surgical factors such as type and duration of surgery (Ip, Abrishami, Peng, Wong, & Chung, 2009). In addition, multiple anesthesia-related factors play a large role in defining the extent of acute postoperative pain, such as the amount of opioid given, a patient's plasma opioid concentration, electroencephalogram factors, the use of adjuvant analgesia and whether or not local anesthetic was utilized (Law, Sleigh, Barnard, & MacColl, 2011).

Chronic pain. Chronic pain occurs when tissue injury exceeds the body's capability for healing (Loeser & Melzack, 1999). Peripheral and ultimately central nervous system sensitization leads to the transition from acute to chronic pain (Voscopoulos & Lema, 2010). Should pain persist beyond the anticipated healing period associated for a given injury or surgery (2 months or longer after most surgical procedures), a diagnosis of chronic or persistent postsurgical pain can be made once all other causes for the pain have been excluded (Wu & Raja, 2011).

Mechanism of pain. Pain serves as an early warning system, designed to signal the presence of potentially damaging or lethal stimuli in the environment (Katz & Rothenberg, 2005). Pain, however, can be nociceptive, inflammatory or neuropathic in nature, which refers to the mechanism by which the pain signals are transmitted. Regardless of mechanism, repeated pain signals have the capacity to initiate prolonged physiologic changes in both the peripheral and the central nervous systems, potentially

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culminating in sensitization or the amplification and prolongation of pain (Woolf & Chong, 1993).

Nociceptive pain. Nociceptive pain is activated only by noxious stimuli acting on a specialized high-threshold sensory pathway (Scholz & Woolf, 2002). When a harmful stimulus is applied to the body, primary sensory neurons sensitive to heat, mechanical stimuli, protons, and cold whose cell bodies lie in the dorsal root ganglia within the spinal cord are activated (Katz & Rothenberg, 2005). The signal is then transmitted via the spinal cord to the brain where the sensation of pain is experienced (Scholz & Woolf, 2002). Nociceptive pain serves a positive function, signaling the body to move away from danger. The threshold for eliciting nociceptive pain has to be high enough that it does not interfere with normal activity, however, the threshold should be low enough that the sensation of pain is evoked before tissue damage ensues (Scholz & Woolf, 2002). Pain associated with operative procedures is aching, sharp, or throbbing in nature, and may be either constant or intermittent.

Inflammatory pain. Inflammatory pain occurs secondary to the release of inflammatory mediators following damage to tissue. Inflammatory mediators function in one of two ways: they directly activate nociceptors thereby evoking pain, or they produce sensitization of the nervous system enabling easier activation of the pain pathway (Scholz & Woolf, 2002). The release of chemical mediators such as cytokines, growth factors, kinins, purines, amines, prostanoids and ions activates or modifies the stimulus response properties of the nociceptor afferent fibers, leading to changes in the responsiveness of neurons in the central nervous system (Scholz & Woolf, 2002). For example, a reduction in the threshold of nociceptor afferent peripheral terminals leads to

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peripheral sensitization, often secondary to the release of chemical inflammatory mediators inflammation from the site of surgical trauma (Raja, Meyer, & Campbell, 1988). Operative procedures produce a barrage of afferent pain signals and generate a secondary inflammatory response, both of which contribute substantially to postoperative pain (Reuben & Sklar, 2000).

Neuropathic pain. Neuropathic pain represents changes in the pain pathway that generate spontaneous and exaggerated pain with no discernable protective or reparative role (Scholz & Woolf, 2002). Unlike nociceptive pain, neuropathic pain serves no adaptive purpose (Katz & Rothenberg, 2005). It arises from damage to or dysfunction of either the peripheral or central nervous system secondary to injury, disease, or medical treatment, ultimately resulting in injury to nerves, the spinal cord, or the brain (Katz & Rothenberg, 2005). It is characterized by a combination of neurological deficits and pain, and ultimately becomes a pathological condition. Neuropathic pain is often perceived as a burning or tingling sensation. In contrast to nociceptive pain, which typically dissipates over time, neuropathic pain frequently continues to escalate and may become chronic.

Etiology of pain. Not all pain signals are transmitted via the same pathway and therefore cannot be treated with the same intervention. Failing to appreciate the extent of the anticipated postoperative pain following a given procedure often leads to inadequate pain control and poor patient experiences (Gerbershagen, Adukathil, van Wijck, Peelen, Kalkman, & Meissner, 2013). For example, all orthopedic surgeries are not equal with respect to the intensity and duration of the anticipated postoperative pain, as postoperative pain will vary according to the degree of bony versus soft tissue

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damage encountered during the surgical procedure (Chelly, Ben-David, Williams, & Kentor, 2003). Pain following orthopedic surgery, such as ACL reconstruction, is often categorized as severe (Stein, Srikumaran, Tan, Freehill, & Wilckens, 2012). When developing a strategy to address postoperative pain, it is imperative to consider the procedure the patient is undergoing, as not all procedures likely require equivalent analgesic regimens. Understanding how to optimize pain control following orthopedic procedures is of paramount importance to improving patient outcomes (Chelly, Ben-David, Williams, & Kentor, 2003).

While the benefits of optimal pain control are well recognized, refining postoperative pain control practices continues to prove challenging (Joshi & Kehlet, 2013). A key aspect to achieving optimal pain control is fully comprehending the degree of pain generated by various surgical procedures, particularly in relationship with the analgesic technique employed (Joshi & Kehlet, 2013). The web-based PROSPECT initiative (Procedure Specific Postoperative Pain Management) may represent the future of pain control, as Henrik Jehlet and his colleagues have addressed the issue of procedure-specific pain control (Pasero, 2007). Arming clinicians with evidence-based, procedure-specific pain control guidelines should allow for a balance between the invasiveness of the analgesic technique and the consequences of postoperative pain (Joshi & Kehlet, 2013). Such strategies should improve current practices that are often reliant upon less robust older studies and anecdotal evidence (Roberts, Brodribb, & Mitchell, 2012).

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ACL Reconstruction: Surgical Options

The primary goal of ACL reconstruction is to restore stability to the knee. Stability is impacted by multiple factors and largely dependent upon the patient's activity level, ultimately making it challenging to measure (Reinhardt, Hetsroni, & Marx, 2010). Nonetheless, measurement of stability during the postoperative period remains one of the key determinants of a successful ACL reconstruction (Macaulay, Perfetti, & Levine, 2012). Desired activity level, however, is not the sole metric considered when contemplating graft selection as patient age, history of patellar or hamstring problems, concerns regarding disease transmission, and the anticipation of postoperative pain all play equally important roles (Ryu & Provencher, 2011). In addition, cost effectiveness and associated morbidities, such as donor site pain, are key concerns.

Several options exist for replacement of the damaged ligament during ACL reconstruction in adolescents, namely the use of allograft tendon, the bone-patellar tendon-bone (BPTB) technique and the use of a hamstring tendon autograft. Reconstruction of damaged ligaments using any of these techniques for ligament reconstruction restores stability to the knee, allowing most patients to return to living an active lifestyle (Pallis, Svoboda, Cameron, & Owens, 2012).

Synthetic tendon. Several synthetic grafts have been utilized for ACL reconstruction, yet to date little success has been witnessed clinically. Graft failure rates, tunnel osteomyelitis and component deposits throughout the body has ultimately led to the discontinuation of most these products. While several promising new synthetic grafts have been introduced in the past few years, the associated complication

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profile historically has diminished the use of synthetic grafts for ACL reconstruction (Dheerendra et al, 2012).

Allograft tendon. The use of allograft not only has the potential to decrease postoperative pain by avoiding donor site morbidity, the operative time is likely shortened since graft harvesting is circumvented (Prodromos, Fu, Howell, Johnson, & Lawhorn, 2008). In addition to reducing postoperative pain, the use of allograft may lead to improved cosmesis (Carey, 2011). Furthermore, the potential for a quicker return to function during the immediate postoperative period exists, as the use of allograft is generally associated with less postoperative pain (Ryu & Provencher, 2011).

The use of allograft is not without potential disadvantage, however, as utilization of allograft can lead to an immunologic response from the host, thereby delaying graft incorporation. In addition, the use of allograft introduces the risk of disease transmission, as procurement and processing techniques vary largely (Carey, 2011). Sterilization methods common during the 1990s to ameliorate disease were known to affect the collagen structure of the graft as well as the mechanical properties. Allografts sterilized with osmotic treatment, oxidation, acetone solvent drying, and gamma irradiation all had a rupture rate of 45% at the 6-year postoperative interval (Macaulay, Perfetti, & Levine, 2012). The grafts that did not rupture were found to not have any statistically significant difference in knee stability (Carey, Dunn, Dahm, Zeger, & Spindler, 2009). Modern techniques, however, avert graft damage during sterilization. As a result, the demand for allograft has continued to rise over the last decade making allograft availability limited at times (Dheerendra et al., 2012).

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Autograft tendon. Commonly utilized autograft tissue for ACL reconstruction includes BPTB, hamstring tendons comprised of semitendinosus and gracilis tendons, quadriceps tendons and ilio-tibial band tendons. While all of these various autografts have been utilized successfully for ACL reconstruction, the two most commonly employed autografts continue to be the BPTB and the hamstring tendon (Dheerendra, Khan, Singhal, Shivarathre, Pydisetty, & Johnstone, 2012). The advantages of using autograft for ACL reconstruction include: the source and age of the graft is known, there is no risk of disease transmission, the graft is typically size-matched for the individual undergoing ACL reconstruction, and the possibility of hamstring regeneration exists following harvest (Carey, 2011). Disadvantages include: donor-site morbidity, long-term kneeling pain (depending on source of graft), risk of patellar fracture (depending on source of graft), long-term knee flexor strength deficit and risk of saphenous nerve trauma (Carey, 2011).

Bone-patellar tendon-bone autograft. The use of BPTB graft for ACL reconstruction was pioneered by Kurt Franke in the 1960's and has long stood as the gold standard to which all other graft choices are compared in regards to effectiveness (Dheerendra et al., 2012). This high regard can be attributed to the high strength and stiffness, consistency of the size of the graft, ease of harvesting, early graft incorporation and solid fixation when interference screws are utilized (Fineberg, Zarins, & Sherman, 2000). BPTB grafts heal quickly, as the end of the graft is bone, with bone-to-bone healing typically occurring in 6-8 weeks. No soft tissue repair is required with this approach. The BPTB autograft is also associated with less postoperative

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instrumented laxity and predictable function, yet graft biomechanics is thought to be inferior to that of the hamstring autograft (Reinhardt, Hetsroni, & Marx, 2010).

The morbidity attributed to the use of a BPTB graft, however, has led surgeons to explore alternative techniques. Donor site pain, anterior knee pain, pain when kneeling, patellar fracture, and numbness or quadriceps weakness secondary to injury to the infra-patellar branch of the saphenous nerve are among the primary commonly seen complications following the use of this technique (Busam, Provencher, & Bach, 2008).

Although the long-term sustainability of BPTB-supported repairs was similar to that of autograft repairs, one of the well-known drawbacks to BPTB repairs is chronic knee pain, making the use of hamstring autograft more desirable, as long-term pain at the donor site has not been a common issue associated with the use of hamstring autografts (Bushnell, Sakryd, & Noonan, 2010).

Hamstring autograft. In 1982, Lipscomb began employing the pes semitendinosus and gracilis tendons in an effort to avoid the donor site morbidity attributed to the BPTB technique (Lipscomb, Johnston, Synder, Warburton, & Gilbert, 1982). Following harvest, the tendons are typically looped over to create a quadruple strand structure, which is then sutured together to make a final graft with enough size and strength for successful ACL repair (Dheerendra et al., 2012). Fixation of the newly created graft is then achieved with either an interference screw or endo-button, giving way to a reconstructed ACL of equal strength as a BTPB graft, if not stronger (Hamner, Brown, Steiner, Hecker, & Hayes, 1999). Although the harvest of a hamstring autograft is typically less painful than that of a BPTB graft, healing occurs at a much slower rate,

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which may lead to premature ACL rupture should the patient attempt rehabilitation prior to healing of the bone tunnels.

Use of hamstring autograft has emerged as the technique of choice for ACL reconstruction in adolescents due to the overall decreased morbidity and proven long-term stability when compared to the other ligament replacement options (Mehta, Mandala, Foster, & Petsche, 2010; Pallis, Svoboda, Cameron, & Owens, 2012). This is a departure from the technique typically employed in the adult population, as use of allograft tendon has long been the predominant technique employed. The advantages of using an autograft are numerous and include the decreased incidence of graft failure, lower infection rate, decreased risk of disease transmission and a potential faster return to full activities (Ryu & Provencher, 2011).

BPTB vs. hamstring autograft. Hamstring autografts were initially thought to be inferior to the BPTB graft in regards to strength and stiffness. Much of this, however, was found to be due to the use of inappropriately sized grafts or inadequate fixation techniques (Dheerendra et al., 2012). The BPTB autograft has been shown to be approximately 175% as strong as a normal ACL, while a doubled hamstring autograft is typically 200% as strong as a normal ACL (Larson, 1996). Using a quadrupled hamstring autograft, Wilson, Zafuta, and Zobitz (1999) reported that no statistical significance existed in the stiffness of each graft and found the load failure of the hamstring autograft to be 2,422 Newtons compared to 1,784 Newtons of the BPTB graft.

It should be noted that there is a lack of consistency when comparing techniques in the literature, as fixation techniques, patient outcome measures and periods of follow-

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up vary greatly when reported making it challenging to discern the true superiority of a given technique. As such, the best evidence to date from methodologically sound meta-analysis suggests that hamstring autografts are superior in preventing anterior knee pain, with limited evidence that BPTB autografts provide more stability than hamstring autografts (Poolman, Farrokhyar, & Bhandari, 2007).

Autograft vs. allograft tendon. Criteria commonly used to vet graft superiority include rate of graft failure, knee range of motion, donor site morbidity, hamstring muscle strength, anterior knee laxity, return to pre-injury activity level, and standardized functional knee outcome scores (Reinhardt, Hetsroni, & Marx, 2010). One of the key determinants for surgeons in graft choice is the incidence of reconstructed ligament rupture. The incidence of ligament rupture following reconstruction is far different between adults and adolescent patients, as ligament rupture following reconstruction is only 3% in adult patients. Conversely, the rate of rupture following ACL reconstruction is considerably higher in active adolescents, with 10% of hamstring autografts and 20% of allografts rupturing following surgery. Pallis et al. (2012) found allograft rupture to be 7.7 times more likely to occur than BPTB repair, and 6.7 more likely to occur than autograft repairs. The incidence of ligament rupture following reconstruction is 3% in adult patients. Knowing that adolescents who sustained their injury secondary to sports are likely to return to sports following successful reconstruction, determining the method of ligament reconstruction that offers the best long-term survivability becomes a decision of utmost importance to the orthopedic surgeon when developing a reconstruction plan. Ultimately, superior long-term outcomes have lead to the increased utilization of a hamstring autograft during knee ligament reconstruction.

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Function level following ACL reconstruction remains a hotly debated topic. Many proponents of autograft use argue that its use leads to superior long-term outcomes. Carey et al. (2009), however, reported that allograft patients reported less pain at 1 and 6 weeks, better function at 1 week, 3 months, and 1 year and fewer activity limitations throughout the recovery period. Still, despite multiple similar reports, the autograft remains the workhorse among young patients with anticipated high physical demands following reconstruction (Ryu & Provencher, 2011).

Special considerations for the adolescent population. Historically, children and adolescents with ACL injuries have been treated conservatively, with many orthopedic surgeons relying on non-surgical techniques for treatment, such as bracing and activity restrictions. Surgical reconstruction of the ACL raises concern for damage to the physis, potentially resulting in limb length discrepancy and angular joint deformity (Hudgens & Dahm, 2012). Thus, determining how to best provide postoperative pain control in adolescents undergoing knee ligament reconstruction has traditionally not been a frequent concern for pediatric anesthetists.

Recent advances in epiphyseal-sparring surgical techniques have enabled orthopedic surgeons to safely and effectively repair ACL defects in adolescents that previously seemed irreparable. New techniques, such as those described by Brown and Ahmad (2008) have demonstrated that not only do these revolutionary surgical techniques successfully avoid the potential harms posed by traditional techniques, they result in a structurally sound repair based on 5 year follow up results. Subsequently, an expeditious rise in reconstructive knee surgeries has been witnessed in the adolescent population in response to the growing incidence of knee ligament injuries, leading to a

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400 percent increase in the number of adolescent ACL reconstructions performed over the last decade.

While surgical reconstruction caries the risk of growth plate disturbance, delaying operative repair until skeletal maturation increases the likelihood of subsequent instability episodes and intra-articular damage (McConkey, Bonasia, & Amendola, 2011). Furthermore, adolescents are known to be a poorly compliant group in regards to activity restrictions should attempts to delay surgery be made (Henry, Chotel, Chouteau, Fessy, Berard, & Moyen, 2009). Even postoperatively, adolescents continue to have difficulty modifying recreational activities sufficiently to avoid future instability episodes (McConkey, Bonasia, & Amendola, 2011). Therefore, whether or not they undergo surgical reconstruction, adolescents with ACL injury remain a vulnerable to continued ACL damage.

Delaying ACL reconstruction until skeletal maturity is an alternative, however, this route increases the risk of instability and intra-articular damage (McConkey, Bonasia, & Amendola, 2011). The main consideration when reconstructing an ACL in in the adolescent population is thought to be related to surgical approach rather than graft selection itself. In skeletally immature patients, caution must be taken not to impose upon or damage the physis in an effort to limit the potential of physeal injury. Accordingly, physeal sparing and partial transphyseal techniques are commonly employed when reconstructing the ACL in the adolescent population. Complications may occur regardless of the choice between BTPB or hamstring autograft and there remains no consensus as to the superior autograft choice. Despite the emphasis on

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surgical approach, allografts, synthetic grafts and ligament augmentation devices are not commonly used for the pediatric population (Hui & Chowdhary, 2011).

Recently, Beasley and Chudik (2003) reported that tunnels placed centrally and filled with soft tissue, such as a hamstring autograft, are less likely to cause growth disturbances unlike eccentrically placed tunnels or those filled with cancellous bone, as soft tissue across an open physis usually prevents premature closure. While the trend remains to use ephyseal-sparing techniques, this novel approach stays true to the current thinking that hamstring autograft is the superior graft choice among the skeletally immature population.

The impact of age on pain management. Type of surgery alone does not determine postoperative analgesia need, as age and psychological distress collectively predict postoperative analgesic consumption (Wu & Raja, 2011). Although no relationship exists between age and pain intensity following painful surgical procedures, distress in younger patients may be significantly greater (Stotts, Puntillo, Stanik-Hutt, Morris, Thompson, White, & Wild, 2007). While children suffer postoperative pain in the same fashion as adults, fear, anxiety, coping mechanisms, and social support play roles in shaping a pain control plan appropriate for the specific surgical procedure and the pain threshold of the patient (Verghese & Hannallah, 2010). An insensate extremity from regional anesthesia can potentially cause increased anxiety or distress postoperatively (Samol, Furstein, & Moore, 2012). Children over the age of 6 years, for example, may become distressed to the point of being inconsolable by the absence of sensation over large areas of their body (Wolf & Hughes, 1993). It is therefore

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imperative to consider psychological aspects and to thoroughly prepare patients in advance of any pain management intervention.

Technical challenges exist when considering pain management modalities in adolescents as well. Regional anesthesia in adolescents has proven to be safe, provided it is performed by an experienced clinician and attention to detail is taken (Bosenberg, 2012). Until recently, however, regional anesthesia was not used routinely in adolescents because of the need for general anesthesia to keep children from moving and cooperating with the clinician performing the neural blockade (Suresh, Birmingham, & Kozlowski, 2012). The use of nerve stimulators and ultrasound has contributed to the renewed interest in regional anesthesia among this patient population, as these tools have improved the success rate of nerve blocks in adolescents and theoretically make placement safer in the anesthetized patient (Kraemer & Rose, 2009).

Pain Management Following ACL Reconstruction

Description of pain specific to ACL reconstruction. ACL reconstruction is known to be associated with moderate to severe postoperative pain (Espelund, Fomsgaard, Haraszuk, Mathiesen, & Dahl, 2013). Most of the intra-articular structures of the knee have free nerve-endings that are capable of sensing painful stimuli and producing severe pain (Reuben & Sklar, 2000). When ACL reconstruction is performed as an arthroscopic procedure, there is a dramatic decrease in in tissue trauma and resultant pain (Brown, Curry, Ruterbories, Avery, & Anson, 1997). Although the surgical incisions are small when ACL reconstruction is performed arthroscopically, pain is not eliminated, as a variety of insults to native tissue still occur.

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In most instances, a diagnostic arthroscopy is done prior to ACL reconstruction to verify the diagnosis of ACL tear and to determine the presence of loose foreign bodies in the knee (Streich, Friedrich, Gotterbarm, & Schmitt, 2008). Any loose bodies or ACL remnant found during arthroscopy are removed prior to ACL reconstruction. In and of itself, this generally does not induce a great amount of pain, rather patients generally report that the knee is slightly sore should this procedure be performed without any additional surgical reconstruction or manipulation. Depending on the individualized plan for the patient, an autograft may be employed for ACL reconstruction. If an autograft is utilized, pain in the postoperative period can be elevated secondary to autograft harvest. As part of the reconstruction, tunnels are drilled through the femur and tibia to route and secure the replacement ACL (Streich, Friedrich, Gotterbarm, & Schmitt, 2008). Once the replacement ligament is in place, the new ligament is secured to bone with screws. The screws are metal, plastic, or a calcium-based product that turns to bone over time. Much of the postoperative pain following ACL reconstruction can be attributed to the drilling through bone necessary to complete this procedure.

Today, many medical centers are performing ACL reconstruction on an outpatient basis, making it imperative clinicians develop an appropriate postoperative pain control plan. With proper pain control, patients tolerate this surgical procedure on an outpatient basis well (Beck, Nho, Balin, Badrinath, Bush-Jospeh, Bach, & Hayden, 2004). Pain following ACL reconstruction has been reported to peak on the second postoperative day, with no significant diminution until the fourth days postoperatively (Brown, Curry, Ruterbories, Avery, & Anson, 1997). Femoral PNB is routinely employed to reduce pain, however, anesthetizing the femoral nerve fails to account for the

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posterior aspect of the knee capsule and autograft donor sites (Frost, Grossfeld, Kirkley, Litchfield, Fowler, & Amendola, 2000). As such, multimodal approaches typically include prescribing oral narcotics and nonsteroidal anti-inflammatory drugs (NSAIDs) for pain control after discharge. Acknowledging the presence and extent of autograft donor site pain is key in effectively controlling postoperative pain.

Considerations for inpatient vs. outpatient. As efforts continue to contain healthcare-related costs, an ever-increasing number of surgeries are being performed on an outpatient basis (Beck, Nho, Balin, Badrinath, Bush-Joseph, Bach, & Hayden, 2004). One of the many challenges associated with this initiative is effectively providing postoperative pain control away from the clinical arena. Providing adequate pain control on an outpatient basis can be difficult, as modalities for pain management are limited once the patient has been discharged from the hospital. While in the hospital, a wide array of pain control interventions is available to abate postoperative pain. Upon discharge, however, the list of available interventions becomes far more limited, as parenteral opioids and neuraxial anesthetics are no longer a viable option (Mall & Wright, 2009). The most common pain control protocols are comprised of oral narcotics with or without NSAIDs (Frost, Grossfeld, Kirkley, Litchfield, Fowler, & Amendola, 2000). The use of NSAIDs following ACL reconstruction with a hamstring autograft, however, remains controversial due to concerns of impaired bone and soft tissue healing (Chen & Dragoo, 2013). As such, clinicians have historically been forced to rely on oral, single-drug approaches for pain control following surgery, which may fail to provide adequate pain control.

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Oral, single-drug approaches have limited success, as parents often fail to provide their children with appropriate dosages of medication, resulting in suboptimal pain control (Gorodzinsky, Davies, & Drendel, 2013). Poor pain control following discharge can prove detrimental, as inadequate pain control may impede rehabilitation, delay recovery, lead to poor outcomes, increase the use of health care resources and decrease overall patient satisfaction (Reuben & Sklar, 2000). One of the keys to success with pain control following outpatient surgery is the administration of effective doses of analgesia. In an effort to avert the limitations associated with single-drug approaches to pain management, multimodal approaches are often utilized to extend pain control several days into the postoperative phase (Chandrakantan & Glass, 2011).

Intravenous opioids. To date opioids remain the cornerstone of systemic analgesia when treating moderate to severe acute pain (Macintyre, Scott, Schug, Visser, & Walker, 2010). Despite the fact that effective dosing of opioids is limited by deleterious side effects, the use of opioids for acute pain control remains based on guidelines from the early 1990s that reinforced the generous use of opioids for acute pain control (Gould, Crosby, Harmer, Lloyd, Lunn, Rees, Roberts, & Webster, 1992). Controversy exists regarding the role of inhibitory systems, however, implying that opioids may not be completely effective in treating neuropathic pain should it progress to that point (Dickenson, 2002). Furthermore, while long considered the gold standard in abating pain, opioids are not without negative consequence, as they elicit unwanted side effects such as nausea, vomiting, pruritus, somnolence, urinary retention and hypoventilation (Hanna, Murphy, Kumar, & Wu, 2009).

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Such side effects often prompt clinicians to seek out alternative treatment modalities to augment the analgesic plan. Non-opioid analgesics such as Acetaminophen, Ibuprofen, Naproxen, Diclofenac, and Ketorolac are commonly employed to treat mild pain and have proven to be effective adjuncts when used in combination with other agents to treat moderate to severe postoperative pain as well (Verghese & Hannallah, 2010). Both opioid and non-opioid analgesics can be administered via multiple routes, thereby affording clinicians the ability to tailor delivery to a specific patient or situation. The combination of non-opioid analgesics and low-dose narcotics may be administered in an effort to minimize unwanted side effects.

Local infiltration. Infiltration with local anesthetics is a technique that has long been employed by surgeons as a means of providing analgesia at the surgical site. The goal of injecting local anesthetics is to modulate the transmission of pain from the nerve fibers in the surgical field to the central nervous system, thereby decreasing the experience of pain. Local anesthetics prevent transmission of nerve impulses by inhibiting passage of sodium ions through ion-selective sodium channels in nerve membranes (Stoelting & Miller, 2006). Utilizing local anesthetics provides an extended period of pain relief following surgery, effectively reducing postoperative pain and overall narcotic requirements (Roberge & McEwen, 1998). Additionally, the local anesthetic lidocaine not only modulates pain transmission, it may have a transient anti-inflammatory effect in of itself, further decreasing pain (Lavelle, Lavelle, & Lavelle, 2007).

Intra-articular injection, which entails injection of medication directly into the joint to decrease postoperative pain, is far less technically challenging than PNB, which

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explains its frequent use historically (Lavelle, Lavelle, & Lavelle, 2007). Anatomic landmarks are utilized to guide where the anesthetic should ideally be deposited. Blind infiltration of this manner, however, fails to consistently control pain, as there is no guarantee that the anesthetic is deposited in the precise anatomic location necessary to achieve its intended goal.

Intra-articular injections have frequently been compared to femoral PNB, with no clear consensus being noted in the literature as to whether one technique is superior to the other. Anatomic studies, however, demonstrate that the posterior capsula of the knee and hamstrings are innervated by the sciatic nerve, thereby implying anesthetizing the sciatic nerve would improve analgesia (Nelissen & Hogendoorn, 2001). While effective, the efficacy of intra-articular injections is limited to the early postoperative period, thereby limiting their ability to manage pain several days postoperatively (Koh, Kang, Chang, Do, Cheol, & Kim, 2011). Furthermore, when compared to the combination of femoral and sciatic PNB, intra-articular injection failed to provide comparable analgesia (Tran et al., 2005).

Regional anesthesia. Many of the qualities inherent to PNB techniques make them the ideal, cost-effective outpatient analgesic intervention (Klein, Evans, Nielsen, Tucker, Warner, & Steele, 2005). The use of regional anesthesia affords clinicians the ability to reduce, if not eliminate, the incidence of opioid-induced negative sequelae that routinely delay discharge following ambulatory surgery (Hadzic, Williams, Karaca, Hobeika, Unis, Dermksian, Yufa, Thys, & Santos, 2005). The ability to provide site-specific analgesia coupled with the ability to reduce opioid requirements yields patients who are comfortable and symptom-free in the postoperative phase (Samol, Furstein, &

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Moore, 2012). As a result, the use of continuous PNB has greatly reduced the need for hospital admission following surgery, in addition to reducing the incidence of morbidity (Ganesh, Rose, Wells, Ganley, Gurnaney, Maxwell, DiMaggion, Milovcich, Scollon, Feldman, & Cucchiaro, 2007).

Over the last decade, PNB has gained increasing favor amongst clinicians caring for pediatric and adolescent patients as a technique for managing postoperative pain (Silvain, Camporesi, & Agostino, & Salvo, 2006). In the pediatric population, PNB is often achieved following the initiation of general anesthesia. Interventions may be useful not only in preventing or reducing pain, but may speed up the healing process as well (Loeser & Melzack, 1999). Compared with opioid analgesia, continuous PNB has proven to improve postoperative analgesia, reducing overall opioid requirements and the associated nausea, vomiting, pruritus and sedation (Richman, Liu, Courpas, Wong, Rowlingson, McGready, Cohen, & Wu, 2006). Most current outpatient pain control modalities have proven to be either ineffective or fraught with opioid-induced adverse effects. PNB, however, has proven to supply adequate pain control while effectively decreasing the frequency of undesired opioid-related side effects.

Neuraxial anesthesia. In many institutions, ACL reconstruction is routinely performed under epidural anesthesia (Mulroy, Larkin, Batra, Hodgson, & Owens, 2001). Benefits of neuraxial anesthesia include improved post operative pain control; decreased intraoperative anesthetic requirements; blunted adverse physiologic response to surgery; earlier ambulation; decreased opioid requirement and side effects; and decreased hypercoagulable events (Zwass, 2005). Neuraxial anesthesia is not without risk, however, as potential exists for neurologic injury from trauma, infection,

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ischemia, hypotension, seizures, and cardiac arrest (Gunter, 2002). While an epidural anesthetic is effective, its utility is limited in regards to outpatient surgery, as it must be discontinued prior to patient discharge, thereby limiting its ability to provide lasting analgesia in the postoperative period.

Peripheral nerve blockade. Compared to neuraxial analgesia, PNB is well suited for outpatient surgery. The use of PNB affords the anesthetist the ability to reduce, if not eliminate, the need for opioids. The reduction in opioid requirement associated with PNB decreases the incidence of opioid-induced nausea and vomiting, a common cause of discharge delay following ambulatory surgery (Hadzic et al., 2005). In addition, by diminishing the use of opioids patients are likely to be more alert during the recovery phase due to the lack of opioid-induced lethargy, leading to a decreased time required to meet discharge criteria. Therefore, the ability to provide site-specific analgesia coupled with the ability to reduce opioid requirements yields patients who are comfortable and symptom-free in the recovery room (Samol, Furstein & Moore, 2012).

In regards to ACL reconstruction, PNB has been found to be paramount in controlling pain following hamstring autograft. Pain at the donor site is most reliably relieved by sciatic PNB, due to the ability of sciatic PNB to reliably anesthetize the posterior thigh (Bushnell, Sakryd, & Noonan, 2011). Following ACL reconstruction, the addition of a sciatic PNB to femoral PNB significantly improves postoperative pain (Williams, Kentor, Vogt, Williams, Chelly, Valalik, Harner, & Fu, 2003). Dang, Guilley, Dernis, Langlois, Lambert, Nguyen and Pinaud (2006) demonstrated better pain relief at rest and decreased morphine consumption when combining continuous femoral and sciatic PNB. Unfortunately, in this study, data from patients with single-injection and

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continuous sciatic PNB were not analyzed separately. Nonetheless, PNB offers superior analgesia over opioid-based analgesia, with significant reductions in postoperative pain routinely attributed to the use of PNB (Kettner, Wilschke, & Marhofer, 2011).

Pain Management Following ACL Reconstruction with Hamstring Autograft in Adolescents

Historically, acute pediatric pain was poorly managed due to fear of severe adverse events such as central nervous system and respiratory depression (Kraemer & Rose, 2009). Today, it is recognized that untreated pain can be a significant cause of morbidity and even mortality after surgical trauma (Verghese & Hannallah, 2010). Subsequently, clinicians are now armed with a variety of modalities to abate postoperative pain. In addition to parental interventions, clinicians may employ local anesthetics and regional anesthesia, which prevent nociception from becoming pain (Loeser & Melzack, 1999). The ability of local anesthetics to prevent nociception from becoming pain is evidenced by the decrease in intraoperative need for systemic opioids when local anesthetics are utilized as part of a balanced anesthetic (Sumpelmann & Munte, 2003). Quite often, multimodal analgesia with NSAIDs acting on the periphery, PNB, and opiates acting centrally are utilized in combination to maximize acute pain control in adolescent patients (Kraemer & Rose, 2009). The use of multi-modal analgesia can readily be adapted for outpatient surgery, major surgery, the critically ill child, or the very young child (Lonnqvist & Morton, 2005).

Hamstring autograft donor site pain: factors to consider. Utilization of a hamstring autograft results in significant pain at the donor site that must be accounted

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for in the immediate postoperative period (Bushnell, Sakryd, & Noonan, 2010). Multiple variables likely impact the extent of autograft donor site pain. Two keys factors to consider when formulating a pain management plan, however, are the autograft technique utilized, being either BPTB or hamstring autograft, and the severity of pain associated with each of these two techniques. Remaining cognizant of these two factors affords the discerning clinician the ability to target pain sites specifically and to do so for an adequate duration such that rebound pain can be averted.

Technique-specific pain. When considering pain attributed to either the BPTB or hamstring autograft technique, much of the focus is on long-term pain, as anterior knee pain and pain when kneeling are well known issues following ACL reconstruction (Dheerendra, et al., 2012). As such, pain in the immediate postoperative period specific to donor site location or technique is rarely considered. Donor site pain following autograft harvest for ACL reconstruction is significantly more common should a BPTB graft, rather than a hamstring autograft, be employed (Macauley, Perfetti, & Levine, 2012). In fact, absolute pain scores in general have been reported as being higher when comparing BPTB to hamstring autograft techniques (Reinhardt, Hetsroni, & Marx, 2010). Likewise, Feller, Webster and Gavin (2001) reported a significant reduction in postoperative pain scores existed when a hamstring autograft was utilized compared BPTB autografts. The smaller incision and decrease in bone destruction involved with hamstring graft harvest may account for the fact that there typically is less postoperative pain when a hamstring tendon is used as opposed to other autograft techniques.

Characteristics of donor site pain. There remains no consensus as to the duration of donor site pain following hamstring autograft harvest (Tran, Ganley, Wells,

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Ganesh, Minger, & Cucchiaro, 2005; Bushnell, Sakryd, & Noonan, 2010). It has been reported that ACL reconstruction continues to be painful for the first 48 hours postoperatively, but definitive studies regarding pain duration are lacking (Frost, et al., 2000). While it is acknowledged that pain at the donor site can be significant, to date there has been little published regarding the impact sciatic PNB has on pain scores following hamstring autograft harvest (Williams, Bottegal, Kentor, Irrgang, & Williams, 2007). What is known, however, is that rebound pain scores following hamstring autograft harvest can be significant should the duration of analgesia be insufficient (Dauri, Fabbi, Mariani, Faria, Carpenedo, Sidiropoulou, Coniglione, Silvi, & Sabato, 2009). Such scenarios, however, can be successfully averted should analgesia be extended. Hoenecke, Pudilo, Moris, and Fronek (2002) have demonstrated success abating donor site pain following patellar tendon graft harvest utilizing a continuous bupivacaine infiltration at the donor site. Similarly, Wegener, van Ooij, van Dijk, Hollmann, Preckel, and Stevens (2011) reported that postoperative pain relief following total knee arthroplasty was much improved should sciatic PNB be employed, with those patients receiving continuous sciatic PNB reporting significantly less pain than those who did not.

Peripheral nerve blockade. A decade ago, adolescent patients undergoing orthopedic surgery were admitted to the hospital postoperatively to ensure adequate pain control. Quite often, these patients were given either an epidural or intravenous opioids to control postoperative pain. PNB has revolutionized the ability to provide site-specific pain control. Due to recent advances in ultrasound-guided techniques, the

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same cadre of peripheral nerve blocks used in adults can now be used safely and effectively in adolescent patients (Ivani & Mossetti, 2009).

At present, it is estimated that 50-60% of all operations are performed in the ambulatory setting (Khoury, Dagher, Ghanem, Naccache, Jawish, & Yazbeck, 2009). Adolescents are generally good candidates for outpatient surgery due to their inherent ability to recover rapidly from surgery. Pediatric orthopedic surgery, however, has historically rarely been done in the outpatient setting due to the inability to adequately control postoperative pain (Khoury et al., 2009). The utilization of PNB has proven beneficial in this setting, as it affords patients excellent pain control while decreasing the incidence of undesired opioid-related side effects. Not only does the use of PNB lead to a more desirable recovery for the patient, it decreases the time required to meet discharge criteria, thereby decreasing overall costs. PNB has also been found to improve the ability to perform orthopedic surgery on pediatric patients on an outpatient basis (Khoury et al., 2009). With the advent of improved technology and anesthetics that possess better safety profiles, PNB now plays a key role in pain control for adolescent patients undergoing orthopedic surgery on an outpatient basis (Ivani & Mossetti, 2009).

Nerve block distribution. While femoral PNB has proven to be an effective means of decreasing pain following ACL reconstruction, it fails to abate pain arising at the harvest site should a hamstring autograft be utilized (Frost, Grossfeld, Kirkley, Litchfield, Fowler, & Amendola, 2000). Graft harvest and graft fixation both contribute to significant postoperative pain in the sciatic nerve distribution (Williams et al., 2003). Therefore, clinicians should consider additional modalities to ensure adequate pain

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control in the postoperative period. Various approaches to managing pain at the donor harvest site exist, yet only sciatic nerve block reliably covers the posterior thigh and subsequently the hamstring donor site (De Tran, Clemente, & Finlayson, 2007).

Duration of PNB. Several clinical trials suggest the addition of sciatic PNB following total knee arthroplasty (TKA) improves postoperative analgesia, however, the extent of the role sciatic PNB plays in pain control remains undetermined (Ben-David, Schmalenberger, & Chelly, 2004). While a different surgical procedure, much of the pain experienced by patients during the postoperative period is similar that of patients undergoing knee ligament reconstruction due to the anatomical areas disrupted during surgery. Ben-David et al. (2004) reported that following TKA, pain scores were greatly reduced in patients receiving a sciatic CPI when compared to those who received only a single-injection sciatic nerve block. Wegener et al. (2011) investigated whether the addition of sciatic PNB to continuous femoral PNB would shorten the time-to-discharge readiness following TKA. Although no impact on time-to-discharge readiness was appreciated, a distinction in postoperative pain control was noted, as a single-injection sciatic PNB reduced severe pain on the day of the surgery, whereas continuous sciatic PNB reduced moderate pain during mobilization on the initial two postoperative days.

To date, sciatic PNB has been reported to most reliably decrease hamstring donor site pain, however, there remains no consensus as to the duration of action required to effectively control donor site pain throughout the postoperative period (Tran, Ganley, Wells, Ganesh, Minger, & Cucchiaro, 2005; Bushnell, Sakryd, & Noonan, 2010). While both single-injection sciatic PNB and continuous sciatic PNB alleviate pain the day of surgery, only continuous sciatic PNB has the ability to reduce pain on

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subsequent postoperative days. Proponents of continuous sciatic PNB assert that the extended duration of analgesia afforded by the use of a sciatic CPI catheter improves overall pain control postoperatively and decreases the need for supplemental pain medications (Ganesh & Cucchiaro, 2007). Ganesh and Cucchiaro's (2007) contention that the duration of action of single-injection sciatic PNB may fail to outlast the pain arising from the hamstring donor site has prompted some clinicians to employ continuous sciatic PNB.

The use of continuous sciatic PNB is not without its detractors, however. Advocates of single-injection sciatic PNB, which can last up to 24 hours or longer, note that in adult studies sciatic PNB offered significant advantages in pain control only during the initial 24 hours following knee surgery (Wegener et al., 2011). Furthermore, concerns regarding increased risk of falls, decreased active knee movement and the masking of compartment syndrome precludes routine use of continuous sciatic PNB by many clinicians (Liu & Wu, 2007). Not only are these potential risks undesirable, they can be costly should they occur and may require further medical or surgical intervention to correct.

PNB under general anesthesia. While improvements in pain control have given rise to improved patient outcomes postoperatively, many questions remain as to appropriate resource management and utilization. The ability to hastily resolve these issues is further hampered by the prolific rate at which advances in surgical approaches occur, such as epiphyseal sparring approaches to ligament reconstruction that allow patients to undergo repair at much earlier age than previously possible. The gap in knowledge created by such rapid advancements is demonstrated by the lack of

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literature defining best practice for providing donor site pain control when hamstring autografts are harvested in the adolescent population.

Traditionally, regional anesthesia has been performed in awake or sedated patients, as it was thought that this was safest for patients, as they would be able to serve as a monitor of untoward events. Recently, this line of reasoning has been challenged, with opponents asserting that this premise is based on antiquated knowledge and the utilization of venerable paresthesia techniques. Due to the variance witnessed in practice, the American Society of Regional Anesthesia (ASRA) developed a practice advisory based on existing scientific literature, pathophysiological principles, and expert opinion (Bernards, Hadzic, Suresh, & Neal, 2008). The advisory panel examined the ability of anesthetized and heavily sedated patients to indicate the presence of the signs and symptoms of impending neurologic injury or intravascular injection of local anesthetic. Subsequently the advisory panel offered revised practice guidelines to promote best practice amongst clinicians.

Bernards, Hadzic, Suresh, and Neal (2008) found that the potential ability of general anesthesia or heavy sedation to obscure early signs of systemic local anesthetic toxicity is not a valid reason to forgo performing peripheral or neuraxial nerve blockade in anesthetized or heavily sedated patients. However, because general anesthesia or heavy sedation removes all opportunity for adults to communicate symptoms of potential nerve injury, Bernards et al. (2008) offered that PNB should not be routinely performed in adults under general anesthesia or heavy sedation, but that the risk-to-benefit ratio of performing PNB under these conditions may improve in select patient populations, such as pediatric patients. Based largely on these

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recommendations, PNB is routinely performed under general anesthesia at Cincinnati Children's Hospital Medical Center.

Stimulation-based PNB. Prior to the introduction of ultrasound in anesthesia practice, the most reliable technique available to identify peripheral nerves was nerve stimulation (Gurnaney, Ganesh, & Cucchiaro, 2007). A portable transistorized nerve stimulator with variable current would allow clinicians to assess the proximity of the tip of a block needle to the nerve. By connecting the cathode to the stimulating electrode, a circuit can be created once the anode is connected to the patient's skin. Depolarizing the nerve membrane results in contraction of the effector muscles (motor fibers) or in paresthesia (sensory fibers). It was believed that these responses could be used to confirm the proximity of a needle or catheter to the nerve. However, limitations exist with peripheral nerve stimulation techniques. Utilizing nerve stimulation for guidance when performing PNB is useful only when a motor response is elicited, therefore should muscle relaxants be utilized, the utility of nerve stimulation is negated.

Historically, once a motor response achieved at or less than 0.5 mA, it was thought that the tip of the needle was in sufficient proximity of the nerve to achieve successful blockade with the injection of the local anesthetic. Clinical data suggest that reliance on a nerve stimulator for performance of peripheral nerve blockade does not eliminate the potential for nerve injury (Urmey, 2000). The relationship between the lowest current amperage used to obtain a motor response, the success rate and the incidence of neurological complications with PNB has also been challenged. In fact, it has been argued that it may not be necessary to perform needle manipulations to

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achieve a low stimulation threshold (0.5 mA), as this may increase the risk of intraneural injection (Gurnaney, Ganesh, & Cucchiaro, 2007). The advent of ultrasound-guidance has greatly improved clinicians' ability to safely and effectively perform PNB, as nerve stimulation-based techniques do not prevent intravascular, intraneural or pleural puncture.

Ultrasound-guided PNB. The failure rate for nerve stimulation-based techniques ranges from 4-23% depending on the study and their definition of success. This high margin for failure led clinicians to seek out improved techniques and approaches to peripheral nerve blockade. The advent of ultrasound-guided PNB techniques marked the dawn of a new era of pain control modalities. The utilization of ultrasound guidance affords the practitioner the ability to visualize target nerves and visualize real-time perineural spread of local anesthetic. Because of this, ultrasound has the ability to improve upon the false negative rate due to real-time visualization during needle insertion and injection of the local anesthetic. The ability to visualize structures not only improves the block success rate, quality and onset time. It also allows this to occur with a reduced number of needle insertions being necessary. Ultrasound is not without its limitations. Performing ultrasound-guided PNB requires mastery of additional knowledge and sound hand-eye coordination. Ultrasound-guided PNB also requires a sound understanding of "sonoanatomy" prior to utilizing these techniques in the clinical arena (Ivani & Ferrante, 2009).

The recent advances in technology and knowledge in ultrasound-guided PNB have further sparked a renewed enthusiasm and interest in regional anesthesia, as evidenced by the plethora of scholarly articles, and the abundance of studies and

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publications devoted to continuing medical educating and developing superior regional anesthetic techniques. One such area of focus is the utilization of PNB for adolescent patients. The use of ultrasound guidance now affords clinicians the opportunity to perform many peripheral nerve blocks that would have been difficult to perform in adolescents based on pure landmark techniques due to the potential for injection into contiguous sensitive vascular areas (Tsui & Suresh, 2010). This has greatly impacted anesthetic practices, as adolescent patients who receive PNB have shown earlier functional recovery following surgery (Ganesh & Gurnaney, 2009).

Like any other acquired technical skill, ultrasound-guided PNB is a modality that must be utilized often to remain proficient with this clinical skillset. While it is imperative the practitioner remains cognizant of potential adverse outcomes associated with regional blockade, the ability to visualize the anatomy allows the practitioner to go forward with a newfound confidence and sense of safety when performing regional blockade.

Continuous perineural infusion (CPI) catheters. While effective at abating pain, single-injection PNB is not without its confines. As highlighted by Richman et al. (2006), single-injection PNB is limited by the duration of action of the local anesthetic utilized. This limitation has, at times, led to the underuse of PNB for post-operative pain control.

A number of studies have demonstrated that resting and break-through pain scores are lower with continuous PNB versus conventional techniques (Swenson, Bay, Loose, Bankhead, Davis, Beals, Bryan, Burks, & Greis, 2006). The success of continuous PNB using CPI catheters and elastomeric pumps in adult outpatient

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orthopedics has been replicated in the adolescent population (Dadure, Pirat, Raux, Troncin, Rochete, Ricard, & Capdevila, 2003). Ludot, Berger, Pichenot, Belouadah, Madi, and Malinovsky (2008) were able to show that analgesia achieved via a disposable pump connected to a CPI catheter effectively controlled pain and enabled adolescents to undergo surgery on an ambulatory basis (Ludot et al., 2008). Ganesh and Cucchiaro (2007) demonstrated that the use of CPI catheters facilitates early discharge from the hospital and decreases overall opioid requirement throughout recovery.

Multiple catheters. Ganesh and Cucchiaro (2007) reported the feasibility of optimizing postoperative pain control in adolescents via multiple continuous PNBs. Multiple, simultaneous CPI catheters have been used safely and effectively in adolescents (van Geffen, Scheuer, Muller, Garderniers, & Gielen, 2006). The safety and efficacy of continuous PNB with a CPI infusion catheter and elastomeric infusion pump allows for broad application in ambulatory and adolescent patients (Swenson, 2010). Careful selection of local anesthetic concentration when utilizing multiple CPI catheters not only improves the ability to extend postoperative analgesia, but also averts undesired motor blockade (McLeod, Dale, Robinson, Checketts, Columb, Luck, Wigderowitz, Rowley, 2009). The primary concern when utilizing multiple CPI catheters is local anesthetic toxicity. Keeping plasma concentrations of local anesthetic within safe ranges and providing adequate pain relief are not concepts at odds when utilizing multiple CPI catheters simultaneously (Ganesh & Cucchiaro, 2007). In fact, the effective dose of local anesthetic when employing simultaneous femoral and sciatic PNB is substantially lower than commonly employed concentrations in the clinical arena

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(McLeod et al., 2009). Therefore, proper knowledge of dosing guidelines can improve patient safety and prevent undesired local anesthetic side effects (Ganesh & Cucchiaro, 2007).

Discharging to home with indwelling CPI catheters. Dadure, Bringuier, Raux, Rochette, Troncin, Canaud, Lubrano-Lavadera, and Capdevila (2009) reported that children have been discharged home with indwelling CPI catheters without significant complication. Although discharging patients with an insensate extremity remains controversial and puts greater emphasis on patient/guardian selection, the data suggest that the risk of injury to these patients is relatively minimal (Ludot et al., 2008; Klein et al., 2005). Furthermore, patients with continuous PNB do not fall more frequently than either patients without PNB or other surgical patients (Chelly, Miller, Conroy, Hudson, & Williams, 2008). Appropriate patient selection and thorough patient education prior to discharge have also been the keys to success (Verghese & Hannallah, 2010). Although the potential for complication exists with any procedure, studies in large cohorts of pediatric patients discharged with indwelling CPI catheters have failed to highlight the severe complications reported in adult studies, as only minor side effects have been commonly noted in the pediatric population (Dadure & Capdevila, 2012).

The Risks and Benefits of PNB

Risks. Although there is a paucity of reported complications following lower extremity PNB, these interventions are not without risk (Enneking, Chan, Greger, Hadzic, Lang, & Horlocker, 2005). As with any medical procedure, the benefits of PNB must be weighed against the potential risks.

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Injury. The widespread use of single-injection and continuous PNB is associated with few complications, yet neurological deficits, CPI catheter-related issues, and local anesthetic toxicity still occur (Jeng, Torrillo, & Rosenblatt, 2010). Injury and complication following PNB, however, is not common. Auroy, Narchi, Messiah, Litt, Rouvier, and Samii (1997) estimated that the potential for serious complication per 10,000 peripheral nerve blocks performed to be 0 to 2.6 deaths, 0.3 to 4.1 cardiac arrests, 0.5 to 4.8 neurologic injuries, and 3.9 to 11.2 seizures. While neurologic injury is often one of the most feared complications following PNB, it should be noted that it is often difficult to determine how much of a neurologic deficit, if any, is attributable to the use of a CPI catheter, as all surgical procedures are associated with a variable incidence of nerve injury regardless of the use of continuous PNB (Ilfeld, 2011). Potential complications include local anesthetic toxicity, hemorrhagic complications, neurologic complications, and infectious complications (Enneking, Chan, Greger, Hadzic, Lang, & Horlocker, 2005). In addition, further potential complications include infusion pump malfunction, skin irritation or allergic reaction secondary to dressing material, unintentional catheter dislodgement, or fluid leakage at the insertion site of a CPI catheter (Ilfeld, 2011).

Infection. Infectious complications secondary to PNB are exceedingly rare (Hebl & Niesen, 2011). To date, there have been no reports in the literature of infection following single-injection PNB (Enneking, Chan, Greger, Hadzic, Lang, & Horlocker, 2005). Though rare, transient symptoms of bacteremia have been reported in the literature following the use of CPI catheters (Enneking, Chan, Greger, Hadzic, Lang, & Horlocker, 2005). In the literature, there is consensus that a major risk factor to CPI

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catheter infection is duration of catheter use (Lai, Jaeger, Jones, Kaderbek, & Malchow, 2011). In most cases of reported bacteremia symptoms resolve upon removal of the catheter and no long-term sequelae were reported. Psoas abscess requiring drainage and antibiotic therapy has rarely been reported in the literature following the use of CPI catheters for continuous femoral PNB (Adam, Jaziri, & Chauvin, 2003).

Benefits. Value is a matter of perspective. Significant pain following ACL reconstruction can be detrimental to the patient's postoperative course and lead to much patient dissatisfaction (Koh, Chang, Seo, Kim, Seong, & Kim, 2012). From a surgeon's standpoint, longevity and durability of a surgical reconstruction are key considerations when comparing available options. From the anesthetist's perspective, costs of time and materials alone must not be considered, as efficacy of a chosen modality can lead to future cost savings and increased patient satisfaction.

Costs. Costs secondary to PNB are often attributed to the billable time to perform PNB, in addition to all the necessary equipment (Mariano, 2008). One great advantage of PNB, however, is the ability to discharge the patient postoperatively, which decreases cost to both the patient and the hospital. Continuous PNB offers the ability to prolong the analgesic effect of a single-injection PNB and may be the ideal choice for analgesia following outpatient orthopedic procedures.

Use of a sciatic CPI is more costly than single-injection sciatic PNB, as additional equipment is required, including catheters, needles, an infusion pump, dressing supplies and additional local anesthetic. When considering costs secondary to continuous PNB, the measurable differences between various pumps and local anesthetics should be considered carefully, as fixed rate elastomeric pumps are an

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attractive option with respect to cost and ease of use for patients (Swenson, 2010). Improving postoperative pain control, however, is thought to result in more efficient use of health resources and to decrease overall costs (Strassels, Chen, & Carr, 2002). Utilization of a single-injection sciatic PNB, while requiring less equipment, may also lead to more costs as increased pain medications may be required to compensate for the limited duration of analgesia offered. Ultimately, when trying to minimize actual costs attributed to a given procedure, strategies should focus on variable costs, such as pain management, as most overhead is considered to be a fixed cost (Macario, Vitez, Dunn, & McDonald, 1995). Given the precarious economic landscape of healthcare, it is imperative clinicians remain cognizant of the financial implications tied to all clinical decisions. This has never been more true for anesthetists, as changes in Medicare will soon tie a percentage of reimbursement to patients' perceptions of quality of care, based on post-discharge surveys with an emphasis on pain management (Geiger, 2012).

Value of PNB to patients and family. The patient should always be an active participant in all decision-making processes related to their care. The patient's perceived quality of care is influenced by a host of factors, ultimately combining to determine their overall satisfaction following ACL reconstruction (Farber, 2010). Knee pain during the immediate postoperative phase can result in significantly decreased patient satisfaction scores (Kocer, Steadman, Briggs, Zurakowski, Sterett, & Hawkins, 2002). Therefore, from the patient's perspective, PNB may be perceived as highly valuable due to the ability to prevent pain while reducing the risk of nausea and vomiting after surgery (Mariano, 2008).

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Porter (2010) contends that value should always be defined around the customer, and depends on results, not inputs. Utilizing PNB to facilitate same-day discharge following ACL reconstruction is well aligned with this shifting paradigm, as ACL reconstructions performed as an outpatient procedure is well tolerated by patients. In addition, performing ACL reconstructions as an outpatient provides a cost-efficient alternative to performing this surgery as inpatient (Nakamura, Conte-Hernandez, & Galloway, 1997). Furthermore, since value is defined as outcomes relative to costs, it encompasses efficiency, thereby making the utilization of PNB a valuable endeavor (Porter, 2010).

Parents whose children are undergoing surgery report greater satisfaction when the procedure is performed on an outpatient basis (Khoury, Dagher, Ghanem, Naccache, Jawish, & Yazbeck, 2009). PNB offers clinicians the ability to discharge patients home following painful surgical procedures with an effective pain control plan. PNB reduces postoperative pain, particularly during movement of the operative extremity (Macfarlane, Prasad, Chan, & Brull, 2009). Furthermore, optimal pain control has been reported to be key in accelerating rehabilitation following knee reconstruction (Wegener et al., 2011).

One of the major factors influencing parental satisfaction is parental preparation and involvement in postoperative pain control (Khoury et al., 2009). Patient and parental preferences are often more important than small differences in outcomes when determining the optimal individualized plan for a patient (Rice, Waterman, & Lubowitz, 2012). Even in the absence of significant differences in pain scores, when comparing postoperative pain modalities, patients and their parents report higher satisfaction

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scores when continuous PNB is utilized to abate orthopedic surgical pain (Seet, Leong, Yeo, & Fook-Chong, 2006).

Value of PNB to surgeons. Anesthesia is a service that benefits patients and surgeons alike. Without some form of anesthesia most surgery cannot occur. Therefore, orthopedic surgeons are both consumers and providers of healthcare services. It is the charge of anesthesia providers to provide a safe, effective anesthetic that does not hinder the patient's intraoperative and postoperative course. Early rehabilitation is reliant upon regaining motion, as immediate weight bearing is commonly allowed in the postoperative period as tolerated by the patient (Mehta, Mandala, Foster, & Petsche, 2010). PNB has been reported to hasten postoperative rehabilitation, making is a valuable resource to surgeons (Macfarlane, Prasad, Chan, & Brull, 2009). Both immediate and long-term postoperative knee movement is reported to significantly improve when comparing PNB with systemic modalities for pain management (Kettner, Wilschke, & Marhofer, 2011). Another point to consider is that stress may be pathological and contribute to postoperative morbidity and mortality. When determining postoperative care, it should be noted that PNB has the ability to obtund the neuroendocrine stress response (Bosenberg, 2011). These are all aspects impacting care that should be discussed with surgeons when considering utilizing various modalities to manage postoperative pain.

Surgery itself is costly, however, in the United States surgical treatment of ACL rupture is more cost-effective than conservation treatment (Farshad, Gerber, Meyer, Schwab, Blank, & Szucs, 2011). ACL reconstruction is often performed on an outpatient basis as a means of containing cost. A significantly lower incidence of

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hospital admission following ACL reconstruction in the adolescent population has been reported when PNB is utilized (Schloss, Bhalla, Klingele, Phillips, Prestwich, & Tobias, 2013). Furthermore, in an ambulatory setting, the use of allograft is far most costly for the consumer than the use of autograft despite the decrease in overall operative room time, as the time necessary for harvest was not needed (Macaulay, Perfetti, & Levine, 2012). This is one of many reasons leading to the predominance of autograft use for ACL reconstruction in adolescents. Should increased pain secondary to autograft harvest result in hospital admission, ACL reconstruction with a hamstring autograft becomes more costly than ACL reconstruction with allograft (Cole, Ginn, Chen, Smith, Curl, Martin, & Poehling, 2005).

Value of PNB to anesthetists. PNB affords clinicians the ability to provide targeted analgesia, thereby providing optimal pain control while avoiding undesired sequelae associated with alternative pain modalities (Macfarlane, Prasad, Chan, & Brull, 2009). Regardless of the skill level of the clinician, PNB requires additional time (Ilfeld & Madison, 2011). Nonetheless, ultrasound-guided PNB has been reported to be highly cost-effective (Ehlers, Jenson, & Bendtsen, 2012). Furthermore, decreasing nursing time, or time spent in the PACU due to poor pain control, leads to decreased overall costs, in addition to minimizing postoperative admission rates (Mariano, 2008).

The time spent in PACU is often quantified as the time until discharge criteria is met, which indicates the length of time elapsed from the end of surgery until a patient is deemed ready for discharge home following surgery. The length of this time period varies among patients and involved anesthetic technique. Not only do these times drive costs, they are often used as a measure of efficacy when comparing anesthetic

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techniques (Pavlin, Rapp, Polissar, Malmgren, Koerschgen, & Keyes 1998). Therefore, should PNB decrease overall time required to meet discharge criteria, its use could prove highly valuable to patients and hospitals alike.

Chapter Summary

ACL reconstruction due to injury in the adolescent population continues to rise at an exponential rate. While the increase in knee injuries among adolescents can largely be attributed to the competitive nature of sports today, the actual mechanism of injury remains variable. Regardless of the cause of injury, ACL reconstruction is often the treatment of choice for adolescents. The primary goal following surgery is the restoration of stability to the knee at a pre-injury level or better. Knee stability and returning to a desired activity level, however, are not the sole considerations when a surgeon contemplates graft selection for ACL reconstruction. Patient age, history of patellar or hamstring problems, concerns regarding disease transmission, cost effectiveness, and postoperative pain are all equally important considerations in this decision.

Amongst the many options available for reconstructing an injured ACL, the use of a hamstring autograft has surfaced as the favored technique for the adolescent population. Hamstring autografts are associated with decreased morbidity and proven long-term stability when compared to the other ACL replacement options. Unfortunately, pain at the hamstring donor site can be significant during the postoperative period and providing analgesia for two separate sources of pain can prove challenging.

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Employing the tenets of the gate control theory, acute postoperative pain can be managed via a variety of interventions (Kim, Jeong, Jung, & Kim, 2011). To date a multitude of pain control strategies have been employed to abate pain at the hamstring donor site, including systemic opioid and non-narcotic adjuvants, superficial wound infiltration with local anesthetic intra-articular injection, neuraxial anesthesia, and PNB. Only sciatic PNB, however, has proven to routinely and reliable abate pain at the hamstring donor site (Bushnell, Sakryd, & Noonan, 2010). Despite the recognized superiority of sciatic PNB, the technique employed remains inconsistent amongst clinicians, as questions remain regarding the severity and duration of pain at the donor site. Subsequently, failure to incorporate the existing knowledge regarding sciatic PNB into clinical practice has led to substantial numbers of patients suffering unnecessarily (Pizzo & Clark, 2012).

Determining the duration of sciatic PNB required to effectively control pain following ACL reconstruction with a hamstring autograft, without impeding active knee movement, will help define best practice going forward. The purpose of this research is to compare the effect of single-injection sciatic PNB to continuous sciatic PNB on 1) postoperative pain control as measured by self-reported pain scores, pain medication use, and unplanned hospital admission due to poor pain control, 2) active knee flexion, and 3) patient satisfaction with pain control following ACL reconstruction with a hamstring autograft. The results of this research have the potential to positively impact pain control for the adolescent population undergoing this surgical procedure and foster responsible utilization of limited resources.

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Chapter Three: Methodology

Chapter Introduction

A lack of comparative effectiveness studies exists in the literature regarding the ideal duration of sciatic PNB following hamstring autograft harvest resulting in disagreement among clinicians as to best practice. Considered an otherwise basic and effective technique, single-injection sciatic PNB, when used for ACL reconstruction, may fail to outlast the pain arising from the hamstring donor site leading clinicians to employ continuous sciatic PNB with a CPI catheter to extend postoperative analgesia. The costs related to continuous sciatic PNB, however, can lead to significant increases in the patient's overall healthcare-related expenses (Hudson, Chelly, & Williams, 2011). Additionally, advocates of the single-injection sciatic PNB cite concerns associated with sciatic CPI catheters known to be detrimental to rehabilitation such as decreased active knee movement and increased risk of falls thereby precluding its routine use. Determining the duration of sciatic PNB required to effectively control pain following ACL reconstruction with a hamstring autograft, without impeding active knee movement, will help define best practice going forward. This chapter describes the theoretical basis, research methods, and statistical analyses that will be employed to compare the effect of single-injection sciatic PNB to continuous sciatic PNB on postoperative pain control, active knee movement, and patient satisfaction following hamstring autograft harvest for ACL reconstruction in the adolescent population.

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Theoretical Framework

The ability to inhibit excitatory influences and enhance inhibitory influences within the pain pathway provides the theoretical foundation for alleviating pain via peripheral nerve blockade. The gate control theory of pain proposes that small neuronal C fibers activate excitatory systems that subsequently excite output cells which enhances pain. Conversely, large neuronal A fibers mediate inhibitory processes and descending control systems from the central nervous system, thereby mitigating further enhancement of pain by excited output cells (Dickenson, 2002). More specifically, the cells of the substantia gelatinosa in the dorsal horn of the spinal column are believed to function as the gate control mechanism with the capacity to modulate pain signals before they are sent to the central nervous system (Roberge & McEwen, 1998). Melzack and Wall (1965) asserted that pain could be modulated or "gated" not only in the dorsal horn, but also at a number of points in the pain pathway. Hence, the gate control theory of pain suggests that certain interventions, including regional anesthesia, have the ability to "close the gate" by modulating the pain pathway, ultimately altering the perception of pain.

Melzack and Wall (1965) acknowledged that medications impacting either excitation or inhibition of substantia gelatinosa activity may be of particular importance in attempts to control pain. PNB does not directly affect activity in the substantia gelatinosa, however, the reception of pain signals in the central nervous system is altered by this procedure thereby interfering with signal transmission from the peripheral nervous system (Schechter, Berde & Yaster, 2003). Pain impulses generated by tissue damage, such as that caused by surgery, travel from the site of insult, to the spinal cord,

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and finally to the brain, ultimately producing a pain response in the body. Theoretically, regional anesthesia can delay and/or minimize the transmission of a pain signal for hours after the initial trauma. Through the administration of local anesthetic medications, regional anesthesia serves to greatly reduce the actual impulse transmitted to the spinal cord, thus keeping the "gate" mostly closed (Roberge & McEwen, 1998).

Application of Theory to Anesthesia Practice

Since the time the gate control theory of pain was first introduced, regional anesthesia has witnessed tremendous growth and has become an integral component of anesthesia practice. Over the last two decades, regional anesthesia in the pediatric population has evolved from a specialty performed infrequently to a practice performed routinely in many pediatric institutions worldwide (Samol, Furstein, & Moore, 2012). This evolution is largely in part to the advent of ultrasound-guidance in regional anesthesia practice, which has fostered the development of new and improved techniques, such as continuous PNB with CPI catheters. Recently, several pediatric institutions have found success in discharging patients home with local anesthetic infusing via indwelling CPI catheters (Samol, Furstein, & Moore, 2012).

Advances in regional anesthesia mirror the progression in surgical techniques. While ACL reconstruction has been a surgical mainstay in the adult population, it has only recently been performed with any regularity in the adolescent population. Many anesthesia providers caring for adolescents undergoing ACL reconstruction aptly employ pain control techniques known to successfully control pain in adults undergoing ACL reconstruction. The adult population, however, typically receives an allograft rather

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than an autograft for ACL reconstruction. Therefore, while the pain control techniques routinely employed in the adult population provide adequate pain control for allograft reconstructions, hamstring autograft donor site pain has not been a primary concern in the adult population.

The gap in knowledge regarding management of hamstring autograft donor site pain in adolescents is demonstrated by a lack of literature of the same. While improvements in pain control for adolescents have given rise to better patient outcomes postoperatively, many questions remain as to appropriate resource management and utilization, as both the cost and duration of action vary greatly between various PNB techniques. To date, no comparison of single-injection sciatic PNB versus continuous sciatic PNB use for abating hamstring autograft harvest pain has been performed in a randomized, prospective manner. This study has the potential to help define best practices surrounding the use of a sciatic PNB to address postoperative pain following hamstring autograft harvest in adolescents for ACL reconstruction.

Research Hypotheses

The purpose of this research is to compare the effect of single-injection sciatic PNB to continuous sciatic PNB on 1) postoperative pain control as measured by self-reported pain scores, pain medication use, and unplanned hospital admission due to poor pain control, 2) active knee flexion, and 3) patient satisfaction with pain control following ACL reconstruction with a hamstring autograft. The following aims will be undertaken:

Specific Aim 1. The first aim of the study is to explore the impact of sciatic PNB technique on hamstring donor site pain control postoperatively. There is evidence that

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sciatic PNB, regardless of technique, significantly reduces pain when compared to intravenous opioids during the initial 24-hour postoperative period following knee surgery (Wegener et al., 2011). As such, single-injection sciatic PNB, which can last up to 24 hours, should provide adequate analgesia precluding the need for oral narcotic or nonsteroidal anti-inflammatory medications following ACL reconstruction with a hamstring autograft during the immediate postoperative phase. It remains unknown, however, if any benefit is gained during the initial 72 hour postoperative period from extending analgesia for the hamstring donor site via continuous sciatic PNB.

$H_{1.1}$. Pain scores during the initial 72 hours following hamstring autograft harvest will be lower in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.

$H_{1.2}$. The use of oral pain medication during the initial 72 hours following hamstring autograft harvest will be lower in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.

$H_{1.3}$. The incidence of unplanned admission to the hospital due to poor pain control during the initial 72 hours following hamstring autograft harvest will be lower in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.

Specific Aim 2. The second aim of the study is to explore the impact of sciatic PNB duration on active knee flexion postoperatively. While continuous sciatic PNB with a CPI catheter extends the duration of analgesia, it also extends the duration of anesthesia leading to a decrease in motor function and subsequently active knee flexion. The sciatic nerve innervates the hamstrings, which are responsible for knee

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flexion (Distad & Weiss, 2013). The decrease in active knee flexion may impede the ability of the patient to begin rehabilitation on the first postoperative day. This is an important consideration because early rehabilitation, which includes contraction of the quadriceps and hamstring muscles as well as weight bearing exercises with the aid of crutches, leads to faster recovery of long-term range of motion and a lower incidence of knee laxity following ACL reconstruction when compared to delayed rehabilitation (Shaw, Williams, & Chipchase, 2005; Pinczewski et al., 2007).

$H_{2.1}$. Active knee flexion during the initial 72 hours following hamstring autograft harvest will not be delayed in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.

Specific Aim 3. The third aim of the study is to explore the impact of sciatic PNB duration on patient satisfaction with postoperative pain control.

$H_{3.1}$. Patient satisfaction with pain control during the initial 72 hours following hamstring autograft harvest will be improved in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.

Research Design

This study employs an experimental posttest-only design with repeated follow-up, with the gate control theory of pain serving as the theoretical foundation (Figure 5). An experimental posttest-only design with repeated follow-up is appropriate for this study, as the outcome is not relevant until after the intervention is complete. This study seeks to examine the impact of two different techniques of sciatic PNB during the postoperative period on pain control, active knee flexion, and patient satisfaction.

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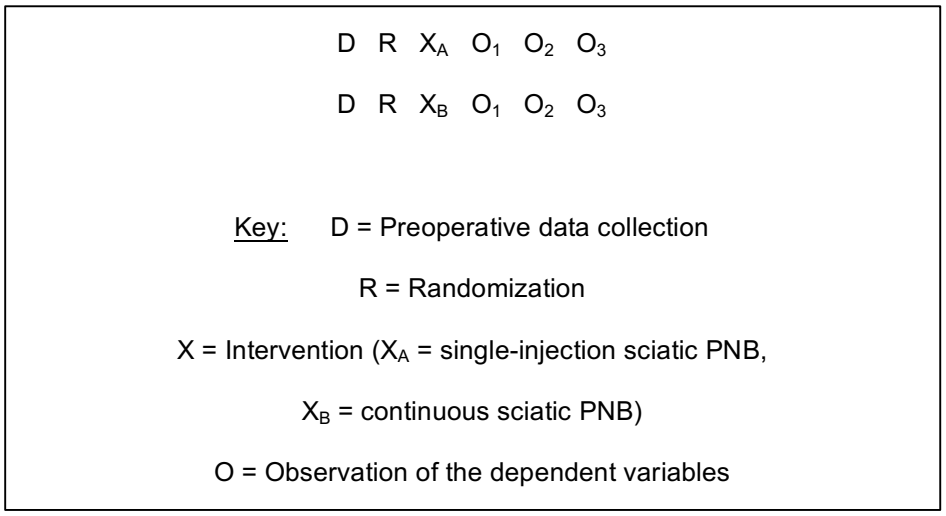

Figure 5. Schematic Diagram of Study Design.

Setting. Following Institutional Review Board approval from both Cincinnati Children's Hospital Medical Center in Cincinnati, Ohio and Virginia Commonwealth University in Richmond, Virginia this study will take place at the Liberty Campus of Cincinnati Children's Hospital Medical Center (CCHMC) in Cincinnati, Ohio. The Liberty Campus of CCHMC is a pediatric ambulatory surgical center where ACL reconstruction is routinely performed on an outpatient basis. With approximately 250 ACL reconstructions with a hamstring autograft performed there over the last two years, the composition of adolescent patients undergoing ACL reconstructive surgery at the Liberty Campus of CCHMC parallels that of the population at large.

The patient population undergoing ACL reconstruction at the Liberty Campus of CCHMC is comprised of both healthy, active adolescents as well as those with a host of congenital deficiencies requiring surgical intervention. Both genders and a variety of age ranges routinely present for ACL reconstruction with hamstring autograft at the Liberty Campus of CCHMC. In addition, a variety of ethnic backgrounds and levels of

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preoperative physical activity are represented by the population routinely undergoing ACL reconstruction at this facility. Therefore, use of a convenience sample from the Liberty Campus of CCHMC is appropriate for this study. Polit and Beck (2012) note a convenience sample may not produce a sample typical of the population with regard to critical variables, however, it is anticipated the sample in this study will be diverse and will be representative of patients who comprise the target population given the study-defined inclusion and exclusion criteria.

Two pediatric orthopedic surgeons perform all ACL reconstruction and hamstring autograft procedures using identical procedures. Any anesthesia team member from the Department of Anesthesia at CCHMC determined to be proficient in ultrasound-guided PNB, defined as having previously performed a minimum of ten successful femoral and ten successful sciatic nerve blocks, will be performing all PNB defined in the study protocol.

Target population. The target population for this study is adolescents undergoing ACL reconstruction utilizing a hamstring autograft for ACL reconstruction on an outpatient basis.

Selection criteria. Inclusion criteria includes patients of both genders of any ethnic group between the ages of 10 years and 18 years scheduled to undergo unilateral ACL reconstruction with hamstring autograft. Patients must have an American Society of Anesthesiologists (ASA) physical classification of I or II. The ASA physical classification system is a means of assessing patient fitness prior to surgery with classifications ranging from I to V, and has been recommended as a reliable measure of comorbidity (Rius et al., 2004). Patients who previously underwent ACL

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reconstruction either with or without a hamstring autograft on the contralateral leg will be included in the study.

Exclusion criteria include any preexisting allergy to local anesthetic, the administration of oral sedation preoperatively, admission to the hospital either before or after surgery, the existence of an imminent life threatening condition that impacts the ability to obtain informed consent, unsuccessful single-injection PNB or placement of CPI catheter, or patient refusal. Additionally, the presence of any other condition which in the opinion of the primary investigator (PI) would not be suitable for participation in the study, including but not limited to coagulopathy, preexisting central or peripheral nervous systems disorders, and local infection or sores at the anticipated site of needle insertion, would lead to exclusion. Patients returning for revision of a previous ACL reconstruction will be excluded, as use of a hamstring autograft from the contralateral leg is often employed during ACL revision. If any additional surgical procedures are being performed concurrently and are not typically part of ACL reconstruction, the subject will be excluded from the study.

Acceptable surgical procedures that may accompany ACL reconstruction include arthroscopy, arthrotomy, partial and/or full meniscal repair, partial and/or full meniscectomy, removal of loose body, and open reduction and internal fixation. These procedures will be allowed, as they are often necessary steps in proper ACL reconstruction. Arthroscopy allows the surgeon to examine the interior of the joint via very small incisions. An arthrotomy is when the surgeon cuts into the joint to gain further access for exploration or more extensive repairs. ACL injury has long been associated with the occurrence of degenerative arthritis that may benefit form

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intervention during arthroscopy (Johnson, Urban, Caborn, Vanarthos, & Carlson, 1998). The medial meniscus is the secondary restraint to anterior tibial translation and meniscal tears are the most common injury associated with an ACL injury (Millett, Willis, & Warren, 2002). Approximately 60 percent of ACL injuries occur in combination with damage to the meniscus, and up to 46 percent have damage to the collateral ligaments (Spindler & Wright, 2008). Therefore, partial and/or full meniscal repair, partial and/or full meniscectomy, and removal of loose bodies are commonly required during ACL reconstruction to provide optimal outcomes.

Recruitment. The PI will work closely with the research coordinator and the three co-investigators (Appendix A) to screen and identify appropriate subjects listed on the daily operating room schedule at the Liberty Campus of CCHMC according to the inclusion and exclusion criteria defined in the study protocol (Table 2). Once a potential subject is identified, either the PI or the research coordinator will discuss the purpose and procedures of the study with the patient and his or her guardian(s). Hospital-approved interpreters will be utilized for non-English speaking patients and/or guardian(s). Participants and their guardians will be informed of the voluntary nature of participation and the ability to drop out of the study at any time without negative consequences. If the guardian(s) express interest in participating in the study, they will be asked to read the written informed consent. When appropriate, assent or consent to participate will be obtained from the patient. Written assent will be obtained from the patient if the patient is ≥ 7 years of age and is able to provide written assent, which represents standard policy with regards to age of assent at CCHMC.

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Table 2

Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Either male or female	Additional surgical procedures are being performed concurrently not related to ACL reconstruction
Any racial or ethic group	Preexisting allergy to local anesthetic
Age 10 to 18 years (inclusive) on the day of recruitment	Sedation administered preoperatively
Scheduled to undergo unilateral ACL reconstruction with hamstring autograft	The subject is scheduled for overnight hospital admission
ASA I-II	An imminent life threatening condition exists that impacts the ability to obtain informed consent
Written informed consent to participate in the study obtained from the subject's legally authorized representative and when appropriate, the subject has given assent or consent to participate	Any other condition exists, which in the opinion of the PI, would not be suitable for participation in the study, including but not limited to coagulopathy, preexisting central or peripheral nervous systems disorders, and local infection or sores at the anticipated site of needle insertion
	Unsuccessful PNB or CPI catheter placement
	Patient refusal

A $20.00 gift card will be distributed as incentive to all participants who enroll in this study. The recruitment period for the study has been set for 18 months based on

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the number of cases done in one year, and assuming a seventy-five percent patient enrollment rate. Similar on-going studies at the Liberty Campus of CCHMC, the site for this proposed study, are experiencing a recruitment success rate of approximately 80% without the aid of participant incentives.

Study protocols. The intervention in this study will be one of two techniques for sciatic PNB: single-injection PNB or continuous sciatic PNB with a CPI catheter (Figure 6). All study participants will receive standard care, including standard anesthetic care as recommended by the ASA and the AANA, and the surgical procedures will be in accordance with those set forth by the American College of Surgeons. No sedative medication will be given to patients preoperatively per standard practice. Patients receiving midazolam, an anxiolytic, or any sedative preoperatively will be excluded from the study as this may affect scores obtained in the initial postoperative period. Following the induction of general anesthesia, the patient's airway will be secured. The amount of inhalation anesthetic and intravenous opioids each patient receives throughout the intraoperative portion of the study will be at the discretion of the clinical team providing anesthetic care.

All sciatic PNB will be performed following the induction of general anesthesia, but prior to the start of surgery. For patients randomized to the single-injection sciatic PNB group, ultrasound will be utilized to identify the sciatic nerve in the sub-gluteal region. Once the sciatic nerve is identified, 1 mL/kg (to a maximum volume of 20 mLs) of 0.2% ropivacaine without epinephrine will be injected into the perineural space surrounding the sciatic nerve.

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Single-injection sciatic PNB: Single-injection sciatic PNB will be performed by the anesthesia team under ultrasound-guidance utilizing 1 mL/kg (to a maximum volume of 20 mLs) of 0.2% ropivacaine without epinephrine. PNB will be performed following the induction of general anesthesia, but prior to the start of surgery.

Continuous sciatic PNB: The anesthesia team will place sciatic CPI catheters under ultrasound-guidance such that the catheter tip is adjacent to the sciatic nerve for continuous infusion postoperatively. PNB will be performed following the induction of general anesthesia, but prior to the start of surgery. Sciatic CPI catheters will be injected with 1 mL/kg (to a maximum volume of 20 mLs) of 0.2% ropivacaine without epinephrine with catheter placement. An infusion of 0.125% ropivacaine will begin to infuse at the end of surgery at a rate of 6-8 mL/hr (based on patient weight) for 48 hours postoperatively.

Figure 6. Study Group Protocols.

For patients randomized to the continuous sciatic PNB group, ultrasound will be utilized to assist the anesthesia team with placing the catheter tip adjacent to the sciatic nerve in the sub-gluteal region in preparation for continuous infusion of local anesthetic postoperatively. Once proper placement of the sciatic CPI catheter is verified, 1 mL/kg (to a maximum volume of 20 mLs) of 0.2% ropivacaine without epinephrine will be administered incrementally over two minutes. An infusion of 0.125% ropivacaine will be

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started at the end of surgery at a rate of 6-8 mL/hr (based on patient weight) for 48 hours postoperatively. While assessments will be made through 72 hours postoperatively, CPI catheters will only remain in-situ for 48 hours, as the incidence of infection increases should an indwelling CPI catheter remain greater than 48 hours (Jeng, Torrillo, & Rosenblatt, 2010).

Following sciatic PNB, continuous femoral PNB will be performed. Patients in both study groups will receive continuous femoral PNB with a CPI catheter to provide analgesia to the anterior aspect of the knee, as this is an accepted standard of practice following ACL reconstruction. Ultrasound will be utilized to assist the anesthesia team with placing the catheter tip adjacent to the femoral nerve in the inguinal region in preparation for continuous infusion of local anesthetic postoperatively. Once proper placement of the femoral CPI catheter is verified, 1 mL/kg (to a maximum volume of 20 mLs) of 0.2% ropivacaine without epinephrine will be administered incrementally over two minutes. An infusion of 0.125% ropivacaine will be started at the end of surgery at a rate of 6-8 mL/hr (based on patient weight) for 48 hours postoperatively.

The recommended dosing range of ropivacaine is 0.2-0.4 mg/kg/hr (Chelly, 2009). Therefore, patients weighing 60 kg or more will receive infusions of 0.125% ropivacaine at a rate of 8 mL/hr via both femoral and sciatic CPI catheters (as applicable). Patients weighing less than 60 kg will receive infusions of 0.125% ropivacaine at 6 mL/hr. These parameters ensure that the total local anesthetic dose remains within the recommended dosing guidelines should a patient be randomized to receive both continuous femoral PNB and continuous sciatic PNB. In addition, establishing weight based infusion rates allows for the study group receiving one CPI

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catheter and the group receiving two CPI catheters to be as similar as possible thereby improving the ability to compare the outcomes of each study group.

Patients will not be blinded as to what study group they have been randomized to participate in. Blinding of subjects can be beneficial in studies because it minimizes the introduction of biases stemming from awareness. Blinding is not always possible, however. For example, in this study it would be challenging to blind subjects to the sciatic nerve block treatment group, as one group will have an indwelling sciatic CPI catheter and the other will not. One means of blinding study participants would be to insert sciatic CPI catheters in all patients and infuse local anesthetic in one group and a placebo in the other group, however, the costs and potential risks, such as opportunity for infection, potential tissue damage and potential for abscess formation secondary to infusion of a placebo, makes blinding of study participants prohibitive.

Variables. The independent variable (IV) in this study is sciatic PNB technique, either single-injection sciatic PNB or continuous sciatic PNB. The dependent variables (DVs) in this study are pain control, active knee flexion, and patient satisfaction during the 72 hours following hamstring autograft harvest. The control variable (CV) will be continuous femoral PNB (Table 3).

A confounding variable is a variable that is extraneous to the research question, yet confuses the relationship between independent and dependent variables (Polit & Beck, 2012). Confounding variables in this study include, but may not be limited to: patient age, patient gender, body mass index (BMI) score, ASA status, prior surgical history, individual patient tolerance of pain, level of activity preoperatively, orthopedic surgeon, intraoperative analgesic requirement, the total time required for surgery (as an

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Table 3

Study-Related Variables

Variable	Type	Measure(s)	Type of Data
Sciatic PNB technique	Independent variable	1 = Single-injection sciatic PNB 2 = Continuous sciatic PNB	Categorical
Pain control	Dependent variable	Self-reported pain scores Self-reported oral pain medication use Unplanned admission due to poor pain control	Ordinal Continuous Dichotomous
Active knee flexion	Dependent variable	1 = Able to bend with no pain 2 = Able to bend, but with pain 3 = Too much pain to bend	Ordinal
Patient satisfaction	Dependent variable	1 = Not at all satisfied 2 = Not satisfied 3 = Partially satisfied 4 = Satisfied 5 = Highly satisfied	Ordinal
Continuous femoral PNB	Control variable	1 = Continuous femoral PNB 0 = Failed continuous femoral PNB	Dichotomous
Age	Confounding variable	Age in years	Continuous
Gender	Confounding variable	1 = Male 2 = Female	Dichotomous
BMI	Confounding variable	$\frac{\text{Weight (kg)}}{\text{Height2 (m}^2\text{)}}$	Ratio
ASA status	Confounding variable	1 = ASA I 2 = ASA II	Ordinal

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Table 3 continued

Previous surgery of any type	Confounding variable	0 = No 1 = Yes	Dichotomous
Tolerance of pain	Confounding variable	1 = Low pain tolerance 2 = Moderate pain tolerance 3 = High pain tolerance	Ordinal
Level of physical activity preoperatively	Confounding variable	1 = Not active at all 2 = Not active 3 = Partially active 4 = Active 5 = Highly active	Ordinal
Orthopedic surgeon	Confounding variable	1 = Wall 2 = Parikh	Dichotomous
Intraoperative analgesic requirement	Confounding variable	Total of intravenous opioids administered during the intraoperative period (converted to mg of morphine equivalent)	Continuous
Length of surgery	Confounding variable	Length of surgery in minutes	Continuous
Tourniquet inflation time	Confounding variable	Total inflation time in minutes	Continuous
Tourniquet pressure	Confounding variable	Tourniquet set pressure (mmHG)	Continuous
Tourniquet pressure:SBP	Confounding variable	Tourniquet pressure (mmHg) minus SBP at time of inflation	Ratio
Prior ACL with hamstring autograft on contralateral leg	Moderator variable	0 = No 1 = Yes	Dichotomous
Prior ACL without hamstring autograft on contralateral leg	Moderator variable	0 = No 1 = Yes	Dichotomous

indicator of the complexity of the surgical repair), the total time of tourniquet inflation, the pressure setting of the tourniquet, and the difference between tourniquet pressure

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and systolic blood pressure at the time of tourniquet inflation. All of these confounding variables have the potential to impact the patient outcomes being measured in this study. ASA classification system has been demonstrated to be a reliable predictor of postoperative functional status and morbidity following surgery on the lower extremity, such as ACL reconstruction (Hooper, Rothwell, Hooper, & Frampton, 2012). Therefore, for the purposes of this study only patients classified as ASA I-II will be deemed eligible, thereby limiting any negative influences on pain and knee movement secondary to variation in physical characteristics and health. Activity level prior to surgery, yet after the injury, may serve as an indicator of the severity of the ACL injury. A decreased activity level after ACL injury, but before surgery, could indicate unwillingness to ambulate in the presence of pain, despite the functional capacity to do so. Either of these explanations for alterations in activity level may impact a patient's active knee flexion following ACL reconstruction with hamstring autograft. Therefore, activity level prior to surgery will be assessed during the pre-anesthetic evaluation.

As this is a sizable list of confounding variables, these variables will be categorized into two groups to ease future analyses (Table 4). Additionally, clustering the confounding variables into two distinct categories may aid in discerning which group of variables most impacts the outcome variables. Categorizing the confounding variables will also allow the entire dataset to be presented in a less cumbersome manner when discussing the results of the study.

A moderating variable affects the strength or direction of a relationship between the independent and dependent variables (Polit & Beck, 2012). The list of moderator variables that may influence the relationship between the independent and dependent

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Table 4

Categories of Confounding Variables

Patient Characteristics	Surgery-Related Characteristics
Age	Orthopedic surgeon
Gender	Length of surgery
BMI	Tourniquet inflation time
ASA status	Tourniquet pressure
Previous surgery of any type	Pressure of tourniquet compared to systolic blood pressure at time of tourniquet inflation
Tolerance of pain	
Level of physical activity preoperatively	
Intraoperative analgesic requirement	

variables in this particular study includes prior ACL repair, either with or without the utilization of a hamstring autograft. Patients who previously underwent ACL reconstruction either with or without a hamstring autograft on the contralateral leg will not be automatically excluded, however, such prior surgical experience will be noted as a moderator variable, as the prior experience may potentially influence the relationship between technique for sciatic PNB and the patient's postoperative pain scores, medication use, active knee movement, and satisfaction with pain control.

Measures. The data for the IV is categorical and will be noted to be either single-injection or continuous sciatic PNB. The CV, continuous femoral PNB, will be dichotomous, with 1 = indicating successful placement of the femoral CPI catheter and 0 = failed femoral PNB.

The primary DV, pain control, will be measured via three separate assessments: self-reported pain scores, frequency of oral pain medication use, and the incidence of unplanned hospital admission due to poor pain control. Data for self-reported pain

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scores will be ordinal in nature, using the 0 (no pain) to 10 (worst pain) verbal Numerical Rating Scale (NRS). The patient or their guardian will record these scores on the supplied data collection tool once every 6 hours for 72 hours postoperatively. Likewise, patients or their guardian will record this continuous data (time and dose of each oral pain medication taken) on the supplied data collection tool. Unplanned admission due to poor pain control will also be used to measure pain control. This measure provides an objective measure of pain control, whereas the other two measures are subjective in nature. The data for this measure is dichotomous and will be noted by the research coordinator during the 72-hour postoperative period.

Ordinal data will be collected via self-report in regards to active knee flexion. Once every 12 hours, the patient will record the ability to actively bend the knee (active flexion) using the following three measure: 0 = able to bend the knee without feeling pain, 1 = able to bend the knee, but feel pain doing so, 2 = too much pain to try to bend the knee. Patient satisfaction with pain control will be recorded on the data collection tool once every 12 hours for 72 hours postoperatively. Data for satisfaction scores will ordinal, as the patients will use a 5-point Likert scale ranging from 0 (not at all satisfied) to 4 (highly satisfied) to scale responses.

Data for the confounding and moderating variables will be collected as well. Data regarding patient age will be continuous and measured in years. Dichotomous data for gender will be noted, with 1 = male and 2 = female. BMI scores will be calculated by dividing the weight in kilograms by the height in meters squared. ASA physical status data will be ordinal in nature, with 1 = ASA I and 2 = ASA II. Dichotomous data indicating whether the patient has had any previous surgery of any

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type will be collected, with 0 = no and 1 = yes. Data pertaining to self-reported tolerance of pain will be ordinal in nature, with 1 = low tolerance of pain, 2 = moderate tolerance of pain, and 3 = high tolerance of pain. Data regarding preoperative level of physical activity will be self-reported and gathered preoperatively. This data will be ordinal with 1 = not active at all, 2 = not active, 3 = partially active, 4 = active, 5 = highly active when compared to pre-injury activity levels. The orthopedic surgeon performing surgery will be noted, being either Dr. Wall or Dr. Parikh. The total intraoperative analgesia requirement/administration will be noted. All doses of opioids, either while in the hospital or following discharge, will be converted to morphine equivalents to facilitate analysis. The length of surgery will be noted in minutes as well as the total pneumatic tourniquet inflation time will be noted in minutes. Both the length of surgery and the length of tourniquet inflation have been associated with postoperative pain, with pain increasing as surgery length or tourniquet inflation time increases. Tourniquet inflation times less than 120 minutes are recommended to prevent ischemic nerve injury (Horlocker, Hebl, Gail, Jankowski, Burkle, Berry, Zepeda, Stevens, & Schroeder, 2006). The tourniquet inflation pressure will be noted in mmHg. Data regards the difference between the tourniquet inflation pressure and the systolic blood pressure at the time of inflation will be recorded. Inflating the tourniquet greater than 100 mmHg above the systolic blood pressure has been associated with postoperative pain and nerve injury (Chidambaran, Rosing, Soler, & Sadhasivam, 2012). Dichotomous data regarding patient history of prior ACL reconstruction with or without a hamstring autograft on the contralateral leg will be collected.

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Sample size. Power analysis was performed to estimate an adequate sample size to support statistical conclusion validity and so that correct inferences can be made about the relationships between study variables. The standardized effect size was calculated to equal 0.5 (Figure 7). Assuming an alpha of 0.05, power of 0.80 and a standardized effect size of 0.5, 64 patients will be required for each treatment group. Projected sample sizes were increased approximately ten percent from 64 per group to total of 70 subjects per group in an effort to account for patient attrition and lost data, therefore, a total of 140 patients will be enrolled in the study.

Two-tailed: alpha = 0.05

Power = 0.80

Effect size: estimated as 50% difference being clinically relevant, 50% change in average pain score (0.5)

Standard deviation = 1 (change in score of 1 out of 5)

Standardized effect size = 0.5/1 = 0.5

Figure 7. Power Analysis Calculations.

Despite the presence of multiple cofounding variables, the calculated sample size is sufficient to determine if a significant difference in outcomes measures exists secondary to sciatic PNB technique. Additionally, the sample size does not need to be altered based on the equation: $N > 50 + 8k$, where N is the number of cases and k is the number of predictors (Warner, 2013). In this study there is only one predictor, sciatic PNB technique, which is anticipated to impact outcomes following ACL reconstruction.

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Following the enrollment of the initial 30 subjects (with 15 in each study group), an interim analysis utilizing the statistical tests later described will be performed to determine if statistically significant differences exist between the outcome measures of each sciatic PNB technique. Performing an interim analysis limits the number of patients exposed to study procedures. If statistically significant differences exist such that one of the two sciatic PNB techniques clearly produces superior patient outcomes, the study will be stopped. However, should the outcomes measures of each sciatic PNB technique be found to be equivalent and without statistically significant differences enrollment will continue.

Randomization. It is acknowledged that great variation in demographic composition exists from patient to patient, hence attempts will be made to match the study groups to each other in regards to the previously listed confounding variables in an effort to eliminate factors that might obscure the relationships between the independent and dependent variables (Polit & Beck, 2012). Enrolled subjects will vary in their physical characteristics to the greatest extent possible given the inclusion and exclusion criteria and the composition of the available convenience sample, thereby allowing for broad application of knowledge gained from this study in the clinical arena.

One hundred and forty adolescents undergoing ACL reconstruction with a hamstring autograft on an outpatient basis at the Liberty Campus of CCHMC will be randomized to one of two study groups: patients receiving single-injection sciatic PNB and patients receiving continuous sciatic PNB. Group assignments will be computer generated and will take into consideration key demographic elements, such as age,

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gender, BMI, and ASA status, to ensure equally matched groups. Patients will be assigned to the study groups in a 1:1 allocation ratio.

Data Collection

Once enrolled in the study, a unique study identification number will be assigned to each study participant. Assigning a unique patient identifier to each study participant allows any data gathered pertaining to them to be attached to this number rather than any patient identifiers, further ensuring that a breach in confidentiality does not occur (Polit & Beck, 2012). After obtaining written consent from the guardian(s), the medical record of the patient will be reviewed for further inclusion and exclusion criteria.

All data gathered will be used specifically for research purposes (Table 5). Data collected preoperatively will include age, gender, BMI, ASA physical status, previous surgical history, self-reported tolerance of pain, self-reported level of activity since time of ACL injury, and the name of the orthopedic surgeon scheduled to perform ACL reconstruction. This data will be collected from the patent's medical record during the preoperative phase and directly from the patient and/or guardian(s) when appropriate. Data on study group assignment, analgesic requirement, the length of surgery, length of pneumatic tourniquet inflation time, pneumatic tourniquet inflation pressure, and systolic blood pressure at time of pneumatic tourniquet inflation will be gathered during the intraoperative phase.

In an effort to discern the impact of sciatic PNB technique on the outcome measures, data on self-reported pain scores, doses of oral pain medications, unplanned admission to the hospital due to poor pain control, and patient satisfaction will be gathered while the patient remains in the post anesthesia care unit (PACU). Data

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Table 5

Data Collected and Associated Phase of Care

Preoperative Phase	Intraoperative Phase	Immediate Postoperative Phase	72-hour Postoperative Phase
Age	Sciatic PNB technique	Pain score	Pain score
Gender	Analgesic requirement	Use of oral pain medications	Use of oral pain medications
BMI	Length of surgery	Unplanned admission due to poor pain control	Unplanned admission due to poor pain control
ASA status	Tourniquet time	Patient satisfaction	Active knee flexion
Previous surgery of any type	Tourniquet pressure		Patient satisfaction
Tolerance of pain	Pressure of tourniquet compared to systolic blood pressure at time of tourniquet inflation		
Level of physical activity preoperatively			
Orthopedic surgeon			

collection will continue for 72 hours postoperatively. In addition to the previously listed measures, data regarding active knee flexion will be collected. Patients will document data measures on supplied data collection instruments. All data collected following discharge will be collected via telephone interview by the research coordinator. Data

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will be collected using the same data collection tool given to the study participants to avoid instrumentation and maintain interrater reliability. This information will be collected from the patient or guardian once every 24 hours by the research coordinator during the 72-hour postoperative period that data is scheduled to be collected; this period begins at the time of discharge from the PACU.

Only one research coordinator, who has prior experience and understanding of the postoperative assessments involved, will be utilized to gather and enter data, eliminating need to assess for interrater reliability. Limiting the number of clinicians gathering data involved should result in minimal variability and inconsistency in results and assessments. The blinded research coordinator will gather patient reported outcomes data once every 24 hours for 72 hours postoperatively. Assessments will start in the recovery room and continuing via telephone following discharge once every 24 hours for three consecutive days. In addition to pain scores, pain medication use, and hospital readmission, data regarding active knee flexion and patient satisfaction will be collected. Every effort will be made to keep the research coordinator gathering postoperative outcome data blinded to the treatment group, however, it is acknowledged that unblinding may inadvertently occur during telephone follow-up with the patient and/or guardian.

Instruments. The goal of the data collection tool is to promote accurate data recording, limit the likelihood of missing information, and to promote efficient and accurate data entry into REDCap™ (Park City, Utah). Prior to the start of study enrollment, the data collection tool will be piloted in an effort to reduce error in the measurement process. Five volunteers undergoing ACL reconstruction with a

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hamstring autograft at the Liberty Campus of CCHMC will be sought out to trial the data collection tool. Refinement of the data collection tool will center on reliability and validity of the tool. Focusing on stability, internal consistency, and interrater reliability during the pilot of the tool will allow for estimates of the tool's reliability. Stability, or test-retest reliability, is determined by administering the tool two different times to the same individuals and determining the correlation between the two sets of scores (Kimberlin & Winterstein, 2008). Cronbach's alpha, which is a function of the average intercorrelations of items and the number of items in the scale, is the most widely used method for estimating internal consistency (Kimberlin & Winterstein, 2008). Interrater reliability requires completely independent ratings of the same event by more than one individual (Kimberlin & Winterstein, 2008). Tests of the tool's validity will focus on construct validity, content validity, and criterion-related validity. Evaluation of construct validity requires an examination of the relationship between the outcome measures being evaluated and variables related to the construct being measured by the instrument (Kimberlin & Winterstein, 2008). As there is no statistical test to determine whether a measure adequately represents a construct, content validity typically relies upon the judgment of experts in the field (Kimberlin & Winterstein, 2008). Assessment of criterion-related validity will focus on the tool's ability to accurately predict how well the scores of a given measure correlate with the scores of the other measures of the same construct. Revisions will be made to the data collection tool as necessary prior to the start of the study.

Patients and their guardian will be given data collection instruments to complete postoperatively at the time of enrollment to facilitate recall when conveying information

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to the study staff during telephone conversations. The patient and their guardian(s) will receive training regarding the data collection tool both during the time of enrollment and again prior to discharge from the hospital. At the time of enrollment, essential phone numbers, including home phone and cell phone numbers, will be collected. Should the patient and/or guardian lose the data collection sheet, additional copies can be emailed to them upon request. Hospital-approved interpreters will be utilized for non-English speaking patients and/or guardian(s).

Data management. All data is collected from the study participant will be entered into REDCap™ by the research coordinator. REDCap™ is a secure web application for building and managing databases securely that was specifically designed to support clinical and translational research (Harris, Taylor, Thielke, Payne, Gonzalez, & Conde, 2009). Confidentiality of the data will be maintained through the use of a password-protected computer and any hard copies of subject information stored in a locked office accessible only to members of the Department of Anesthesia.

The study records will be made available for review only to the Institutional Review Board and the Food and Drug Administration (FDA) per CCHMC policy. The FDA is a branch of the federal government that establishes regulations and guidelines for clinical research to protect participants from unreasonable risks. Furthermore, the FDA ensures consumers have reliable information and that medical treatments are not only safe, but effective as well. The subjects' names or any other identifiers will not be used in published information relating to this study and will be treated as confidential per the Health Insurance Portability and Accountability ACT (HIPAA) of 1996. Per the HIPAA Privacy Rule, prior to dissemination of results, all health information will be

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deemed individually unidentifiable by employing the approved Safe Harbor method of de-identification that entails the removal of 18 types of identifiers.

Protection of Human Subjects

Risks to the subjects. The risks related to this study are no more than the risks related to regional anesthesia in general. Furthermore, unless otherwise contraindicated or refused by the patient, regional anesthesia of some nature is administered to most patients regardless of their enrollment in this study. While the general risks for PNB apply to both the single-injection and continuous sciatic PNB techniques, sciatic PNB is considered relatively low risk and both techniques of sciatic PNB have well-established safety records and are currently routinely utilized in clinical practice.

Risks related to the drug utilized in the current study (ropivacaine) are characteristic of those associated with other amide-type local anesthetics, which include: uticaria, pruritus, erythema, angioneurotic edema, tachycardia, sneezing, nausea, vomiting, elevated temperature, and possibly anaphylactoid symptomology. The risks related to the use of ropivacaine in this study are no different than would be expected with any administration of this drug. As with the administration of any local anesthetic, high doses or unintentional intravascular injection may lead to high plasma levels and related myocardial depression, decreased cardiac output, heart block, hypotension, bradycardia, ventricular arrhythmias, including ventricular tachycardia and ventricular fibrillation, and possibly cardiac arrest.

Addition risks include a low risk of mild discomfort at the PNB needle insertion site or inconvenience to the subject secondary to sensory and/or motor blockade.

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Temporary soreness at the site of injection and/or CPI catheter placement is not uncommon, as PNB needles must pass through various layers of tissue and muscle to reach the targeted nerve. This soreness typically requires no intervention and quickly resolves. Additionally, unforeseen risks may include, but are not limited to: needle trauma, intraneural injection, intravascular injection, local anesthetic toxicity, hematoma, infection, and poor/failed block. All complications or untoward events that occur during the course of this study will be reported.

Protection against risk. As a safety check, only experienced, qualified clinicians will be performing all PNB associated with this study. Furthermore, all PNB will be performed under ultrasound guidance to ensure real-time advancement of the nerve block needle and visualization of injected local anesthetic.

Vulnerable populations. Patients from 10 years of age to 18 years of age (inclusive) will be recruited for this study. The only way study participants will be identified is by their unique study identification number. All information collected will be treated as confidential, as provided by law.

Exploratory and Confirmatory Analytical Strategies

The hypothesis that scores during the initial 72 hours following hamstring autograft harvest will be different in patients receiving single-injection sciatic PNB than those receiving continuous sciatic PNB will be tested with two separate tests. Both Pearson's correlation and the Wilcoxon-Mann-Whitney test will be utilized to test his hypothesis, as controversy surrounds the analysis of Likert scale data. It has been argued that only nonparametric statistics should be used on Likert scale data, as the intervals between the scale values may not be equal (Jamison, 2004). Taking this into

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consideration, the pain scores recorded for each patient will be totaled and an average pain score will be calculated for each study participant. This will allow the data to be measured on a continuous scale, thereby meeting the criteria of Pearson's correlation. Pearson's correlation is a parametric test that measures the degree and direction of linear relationship between two variables (Gravetter & Wallnau, 2000). The Wilcoxon-Mann-Whitney test will also be used to analyze pain scores recorded at each 12-hour interval to determine if there is a difference in outcomes related to the duration of analgesia provided by sciatic PNB technique. This test is appropriate when there is one IV with two independent groups and the DV is ordinal in nature. The Wilcoxon-Mann-Whitney test is a nonparametric test of the null hypothesis that two populations are the same against an alternative hypothesis. This test uses the relative position of the data in a rank ordering, rather than the actual values. Using both parametric and nonparametric tests will increase confidence when drawing conclusions should both tests lead to the same results.

The hypothesis that the dose of oral pain medication during the initial 72 hours following hamstring autograft harvest will be different in patients receiving single-injection sciatic PNB than those receiving continuous sciatic PNB will be tested with the independent samples *t*-test. The independent samples *t*-test is appropriate when there is on IV with two independent groups and the DV is continuous in nature (Field, 2009). The independent samples *t*-test is used to compare differences between separate groups when there are two experimental groups (single-injection sciatic PNB and continuous sciatic PNB) and different study participants have been used in each group (Field, 2009).

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The hypothesis that unplanned hospital admissions due to poor pain control during the initial 72 hours following hamstring autograft harvest will be different in patients receiving single-injection sciatic PNB than those receiving continuous sciatic PNB will be tested with the chi-square test. The chi-square test is used to determine if there is a relationship between two categorical variables (Field, 2009). As the data for this DV are categorical, the focus during analysis is placed on frequencies rather than means. The chi-square test can be used to determine if there is a significant difference between the expected frequencies and observed frequencies in one or more categories (Field, 2009).

The hypothesis that active knee flexion during the initial 72 hours following hamstring autograft harvest will be different in patients receiving single-injection sciatic PNB than those receiving continuous sciatic PNB will be tested using the chi-square test. The hypothesis that patient satisfaction with pain control during the initial 72 hours following hamstring autograft harvest will be different in patients receiving single-injection sciatic PNB than those receiving continuous sciatic PNB will also be tested using the Wilcoxon-Mann-Whitney test. The Wilcoxon-Mann-Whitney test is appropriate to test both these hypotheses, as this test is designed to evaluate the difference between two treatments (single-injection sciatic PNB and continuous sciatic PNB) using data from an independent measures study (Gravetter & Wallnau, 2000). During analyses, testing may be altered based on the recommendations of the statistician to better analyze the collected data. Intention-to-treat analysis will not be employed, as this may skew results and it is often difficult to obtain outcome data for study participants who have dropped out of the study (Polit & Beck, 2012).

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Resolution of Challenges

As with any study, multiple challenges can be expected. Enrolling adolescents into clinical studies can be challenging. Parents are often reluctant to provide written consent for their child to participate in a clinical trial, as they prefer the care provided to their child adhere to the current accepted gold standards of care. Explaining that the two techniques of sciatic PNB being compared in this study are not experimental, rather they are well-established techniques that offer reliable pain control may alleviate concerns related to enrollment in this study. While adolescents may be reluctant to undergo regional anesthesia, this reluctance may be overcome once the patient learns he or she will be under general anesthesia when PNB is done. In addition, all participants who enroll in the study will receive a $20.00 gift card. Incentives have been found to have a substantial effect on study participation (Polit & Beck, 2012). While previously found as a form of undue influence or coercion, the use of incentives is innocuous when the risk of participation is relatively low, the research is not degrading, and the incentive is relatively small (Grant & Sugarman, 2004).

Attrition of study participants is also a concern, however, several tactics can be employed to minimize the attrition rate. Multiple points of contact for the patient and their guardian(s) will be collected at the time of study enrollment to provide the research coordinator multiple avenues for contacting the study participant for data collection. Requiring the study participant and his or her guardian to sign an agreement at the time of enrollment that sates contact with the research coordinator will be maintained during the 72 hour postoperative period may dissuade attrition. An alternative approach would be to withhold dispensing the $20 incentive until the data collection period is complete

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and all data has been gathered. Utilizing home health nurses to maintain study participant contact is yet another approach to decreasing attrition. Currently, the practice at the Liberty Campus of CCHMC is to train patient's guardians how to safely remove CPI catheters at home. Should attrition become rampant home health nurses could be utilized for CPI catheter removal, thereby serving as a point of contact with study participants. The costs associated with this tactic, however, would likely prove to be prohibitive.

Potential threats. Several threats to internal validity have been considered. To ensure internal validity, prior to commencement of the study all levels of measurement will be reassessed to confirm that the tool aligns with the constructs within the design of the study. During the study design, methodology was compared with similar previously performed studies to assess for potential pitfalls and bolster this study's level of robustness. Outcome measure data will be reviewed during the interim analysis to discern whether or not the research study has been developed in a manner that adequately addresses the specific aims of the study. Study participants will be randomized to avoid threats to internal validity, thereby enabling the ability to draw valid inferences about differences in outcomes. Randomization is the most effective method of controlling individual characteristics and removes selection bias, in addition to decreasing the chance for homogeneity (Polit & Beck, 2012). Although convenience sampling may lead to the use of subjects who are atypical of the target population, utilizing a prospective randomization plan increases the generalizability of the results, thereby ensuring external validity. During analyses, patient demographics can be

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compared to that of the target population to ascertain whether or not the study is indeed generalizable.

The threat of history is likely to equally affect both groups in the study and have minimal to no effect on outcome measures. Attrition during the postoperative phase is likely, however, the anticipated attrition rate is low. Although participant attrition remains a concern, maturation is minimized by the relatively short data collection period. Data collection continues only 72 hours postoperatively, attenuating the impact of the passage of time during the study.

To negate potential threats to construct validity via researcher expectancies, only the research coordinator will have contact with the patient and their guardian during the postoperative data collection phase. The research coordinator will remain blinded to the study group the patient was randomized to throughout the course of the study. Novelty and compensatory effects should be diminished due to adequate sample sizes and the fact that all patients receive at least one CPI catheter (femoral nerve). Criterion-related validity is supported, as the utilization of sciatic PNB for pain control following hamstring autograft is grounded in the literature. The study is designed to offer predictive validity, as it differentiates between the efficacy of single-injection sciatic blockade and continuous sciatic blockade following hamstring autograft.

Finally, adherence to study protocols is essential to safeguarding fidelity, or the extent to which the intervention has been implemented as intended. Should study protocols be violated, variability due to PNB technique can be suppressed and variability due to other factors can be inflated, possibly leading to erroneous conclusions (Polit & Beck, 2012). Prior to the start of the study, a presentation will be made to the

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anesthesia department reviewing the study, as well all study-related protocols. Time will be allotted for a question and answer period to ensure no questions or concerns go unanswered. After the enrollment of each patient, the PI will be in contact with all clinical team members providing anesthesia care for each study patient to further ensure study protocols are adhered to and that there are no unintentional deviations.

Chapter Summary

This chapter discussed the methods by which an experimental, posttest-only with repeated follow-up design will be employed to compare the effect of single-injection sciatic PNB to continuous sciatic PNB on 1) postoperative pain control as measured by self-reported pain scores, pain medication use, and unplanned hospital admission due to poor pain control, 2) active knee flexion following ACL reconstruction with a hamstring autograft, and 3) patient satisfaction with pain control following ACL reconstruction with a hamstring autograft in the adolescent population. Details of the methods by which it would be determined whether the duration of sciatic PNB impacts hamstring donor site pain control, postoperative active knee flexion, and patient satisfaction were discussed. All study-related variables and the associated measures thereof were described. Rationale for the target population, selection criteria and recruitment was provided. Study protocols, data collection methods, and planned statistical analysis were offered. In addition, anticipated efforts to protect human subjects were reviewed. Chapter Four will discuss in detail data preparation and the statistical analysis of the collected data.

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Chapter Four: Results

Chapter Introduction

Sciatic PNB has proven to be the most reliable means of abating the significant pain attributed to hamstring autograft harvest (Bushnell, Sakryd, & Noonan, 2010). To date, the ideal duration of sciatic PNB following hamstring autograft harvest remains undetermined leading to disagreement among clinicians as to best practice. The purpose of this research was to compare the effect of single-injection sciatic PNB to continuous sciatic PNB on 1) postoperative pain control as measured by self-reported pain scores, pain medication use, and unplanned hospital admission due to poor pain control, 2) active knee flexion, and 3) patient satisfaction with pain control following ACL reconstruction with a hamstring autograft.

This study employed an experimental posttest-only design with repeated follow-up, with subjects enrolled in this study receiving one of two techniques for sciatic PNB: single-injection PNB or continuous sciatic PNB with a CPI catheter. Data was gathered preoperatively, during the intraoperative phase, and postoperatively for 72 hours.

This chapter describes the data preparation and statistical analyses that were employed to compare the effect of single-injection sciatic PNB to continuous sciatic PNB on the stated outcomes of interest at a predetermined interim analysis point which consisted of 30 patients total. The chapter begins with a brief review of the data collection procedures, followed by a description of the data cleaning process. In

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addition, the results of the data analyses as they relate to the specific aims and research hypotheses are summarized.

Data

Review of data collection. Following Institutional Review Board approval from both CCHMC in Cincinnati, Ohio and VCU in Richmond, Virginia, data was collected from a convenience sample of adolescents scheduled to undergo unilateral ACL reconstruction utilizing a hamstring autograft on an outpatient basis at the Liberty Campus of CCHMC. Prior to the start of enrollment, a novel data collection tool was developed and piloted in an effort to reduce error during the measurement process. Five volunteers undergoing ACL reconstruction with a hamstring autograft at the Liberty Campus of CCHMC were sought out to trial the data collection tool, with the ensuing refinement of the data collection tool focused on reliability and validity.

Once initiated, the data collection phase lasted approximately nine months. A total of 50 subjects were screened for recruitment. Inability to recruit all potential study patients was attributed to failure to meet inclusion criteria (n = 4), the use of a patellar graft rather than a hamstring autograft (n = 3), subject refusal (n = 3), and lack of clinical staff to support study enrollment (n = 3). Subsequent to enrollment, data was gathered preoperatively, during the intraoperative phase, and postoperatively. Data was gathered 72 hours postoperatively via the data collection tool and entered into REDCap™ by the research coordinator.

Following enrollment, five subjects were excluded from the study due to the inability to contact the family postoperatively (n = 4) and the occurrence of transient global amnesia postoperatively in an adolescent with a recent history of concussion (n =

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1). While unrelated to the study, it was thought the patient's transient inability to recall or create new memories deemed them an unreliable data source. Exclusion following enrollment lead to the utilization of a sample size slightly larger than projected to ensure equal groups were available for analysis. Ultimately, data from 32 subjects was available for analyses (Figure 8). Data collected on all measures were manually entered into REDCap™ by the research coordinator. Data was then exported directly to SAS™ (Cary, NC) v9.3 for analysis.

Data preparation and cleaning. All data were inspected for accuracy and variable names and labels were amended as needed. Table 6 defines the relevant variable abbreviations used throughout the analyses.

Age in years on the day of surgery was entered for the AGE variable. Value labels were assigned to GENDER (1 = male, 2 = female) and ASA physical status (1 = ASA I, 2 = ASA II). Calculated BMI, based on the patient's height and weight the day of surgery, was entered was entered for the BMI variable. It was noted whether or not the patient had a history of previous surgery of any type (0 = no, 1 = yes). Self-reported tolerance of pain scores were entered for the PAIN_TOLERANCE variable (1 = low tolerance of pain, 2 = moderate tolerance of pain, 3 = high tolerance of pain). Self-reported level of activity since the time of ACL injury was entered for the ACTIVITY_SINCE_ACL_IJNURY variable (1 = not active at all, 2 = not active, 3 = partially active, 4 = active, 5 = highly active).

Data regarding which of the two orthopedic surgeons performed the ACL reconstruction with the ORTHOPEDIC_SURGEON variable (1 = Wall, 2 = Parikh). All intravenous opioids administered during the intraoperative phase were converted to

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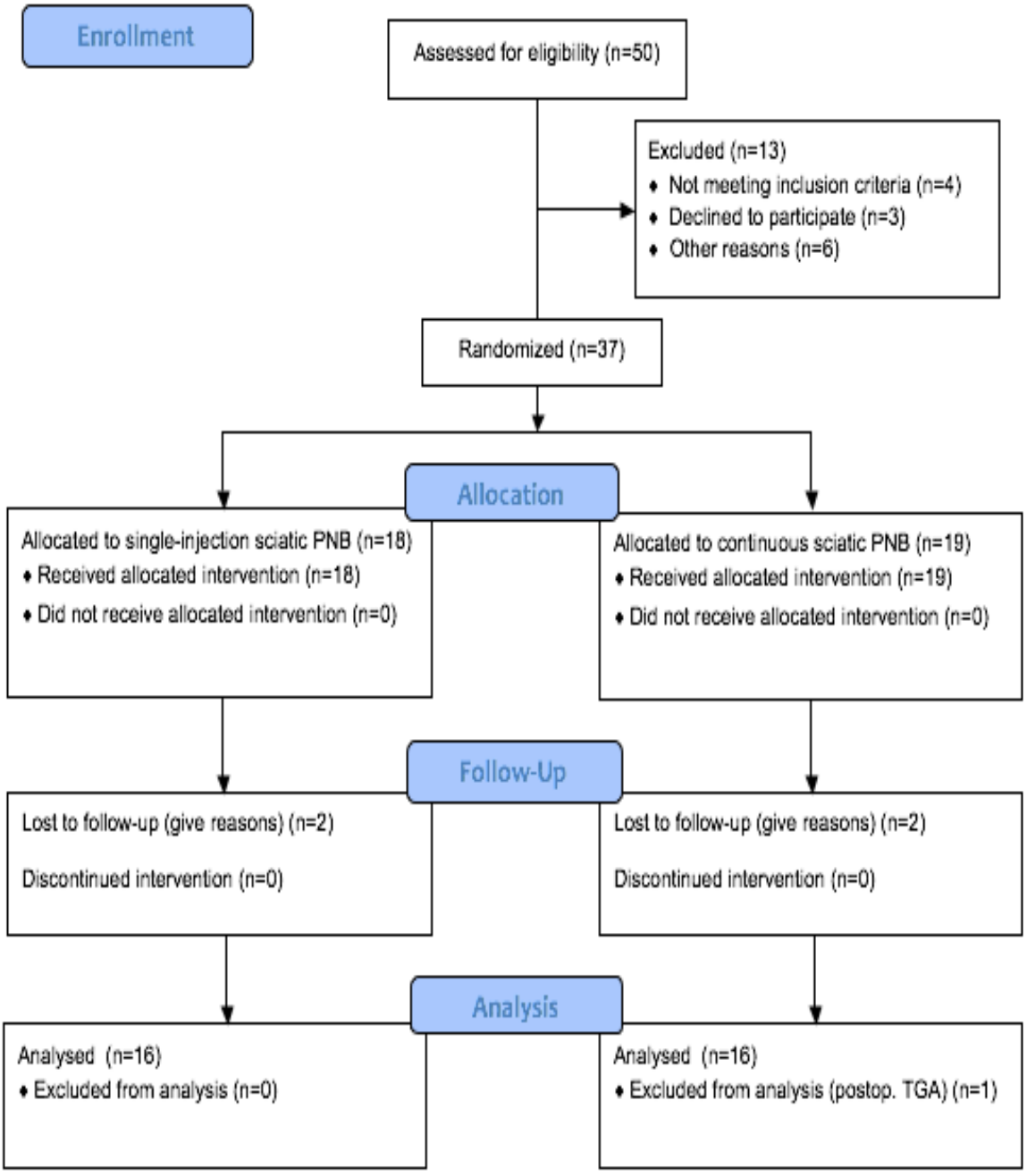

Figure 8. CONSORT Flow Diagram Displaying Progress of All Participants Through the Study.

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Table 6

Relevant Variables Abbreviations in Analyses

AGE	Age in years on day of surgery
GENDER	Gender (1=Male, 2=Female)
ASA	ASA physical status (1=ASA I, 2=ASA II)
BMI	Calculated BMI based on height and weight day of surgery
PREVIOUS_SURGERY	History of previous surgery (0=No, 1=Yes)
PAIN_TOLERANCE	Reported tolerance of pain (1=low, 2=moderate, 3=high)
ACTIVITY_SINCE_ACL_INJURY	Reported level of activity since the time of ACL injury (1=not active at all, 2=not active, 3=partially active, 4=active, 5=highly active)
ORTHOPEDIC_SURGEON	Surgeon performing procedure (1=Wall, 2=Parikh)
INTRAOP_MSO4	Total intraoperative morphine equivalents in mg administered
SURG_LENGTH	Surgery length in minutes
TOUR_INFLA_TIME	Tourniquet inflation time in minutes
TOUR_GREATER_120	Tourniquet inflation time greater than 120 minutes (1=Yes, 2=No)
RANDOMIZATION_GROUP	Study group randomized to (1=Single-injection sciatic PNB, 2=Continuous sciatic PNB)
PV	Morphine equivalents administered postoperatively
KNEE_MOVEMENT	Reported ability to bend leg at the knee (1=Able to bend with no pain, 2=Able to bend but with pain, 3=Too much pain to bend)
FRONT	Reported pain score: Anterior aspect of knee (0= No pain, 10=Worst pain)
BACK	Reported pain score: Posterior aspect of knee (0= No pain, 10=Worst pain)
SATISFACTION	Reported satisfaction with pain management (1=Not satisfied at all, 2=Not satisfied, 3=Partially satisfied, 4=Satisfied, 5=Highly Satisfied)

morphine equivalents in milligrams (mg). Following conversion to morphine equivalents, weight-based dosing was calculated using milligrams per kilograms (kg). The weight-based dose administered was then entered for the INTRAOP_MSO4

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variable. Surgery length in minutes was entered for the SURG_LENGTH variable. Tourniquet inflation time in minutes was entered for the TOUR_INFLA_TIME variable.

The RANDOMIZATION_GROUP variable denotes which study group the patient was randomized to for the study (1 = single-injection sciatic PNB, 2 = continuous sciatic PNB). The reported ability to flex the operative leg at the knee following surgery was entered for the KNEE_MOVEMENT variable (1 = able to bend with no pain, 2 = able to bend but with pain, 3 = too much pain to bend). Data for the KNEE_MOVEMENT variable was captured once every twelve hours through the 72 hour postoperative period. Pain scores were collected postoperatively for 72 hours. Scores were collected for the anterior aspect of the knee, as well as the posterior aspect of the knee, to better discern if the reported pain score correlated with sciatic nerve distribution. Reported pain scores for the anterior aspect of the knee were entered for the FRONT variable (0 = no pain, 10 = worst pain) and reported pain scores for the posterior aspect of the knee were entered for the BACK variable (0 = no pain, 10 = worst pain). Data regarding FRONT and BACK scores were captured once every six hours through the 72 hour postoperative period. In addition, reported scores for pain in both the anterior and posterior aspect of the knee were averaged per each of the three 24 hour time periods throughout the 72 hour data collection period and entered under the appropriate supplemental variable. It was thought that the ability to compare pain in 24 hour intervals may provide a broader perspective of the impact of each sciatic PNB technique. Scores regarding satisfaction with overall pain management were collected postoperatively for 72 hours and entered for the SATISFACTION variable (1 = not satisfied at all, 2 = not satisfied, 3 = partially satisfied, 4 = satisfied, 5 = highly satisfied).

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Data for the SATISFACTION variable were captured once every twelve hours through the 72 hour postoperative period.

Following inspection of the data set several data points and variables were addressed prior to analysis. It was discovered that several of the time points pertaining to the timing of medication administration postoperatively were entered incorrectly. Subsequently, eight data points were corrected to military time to reflect proper timing of occurrence. On the data collection tool, data was gathered pertaining to the "date and time the leg was no longer numb behind the knee", which was intended to refer to the time the posterior aspect of the leg was no longer numb. It was thought that this metric would provide insight as to the occurrence of rebound pain once the posterior aspect of the leg was no longer insensate. Upon initial inspection of the data set, it was found that despite the training given to the patients and their parents prior to surgery, this data point on the data collection tool was either omitted (n = 7) or recorded incorrectly (n = 9). With over half of the data for this variable unavailable, this variable was excluded from analyses.

BMI calculations were converted to *z*-scores and added to the data set under the supplemental variable BMIZ. BMIZ reflects the measures of weight-for-height adjusted for patient age and sex relative to a national standard. This conversion was done via a program in SAS ™ that can be used to calculate *z*-scores and percentiles for patients up to 20 years of age based on Center for Disease Control and Prevention (CDC) growth charts. The conversion was not exact, however, as the CDC charts are based on age in months rather than age in years. In adults BMI cut points exist that define obesity and overweight that are not linked to age and do not differ based on gender (Must &

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Anderson, 2006). In growing children, BMI varies with age and gender. Therefore, for BMI calculations to be meaningful it must be compared to a reference standard that accounts for both age and gender (Must & Anderson, 2006).

To simplify analysis, data gathered for "number of pills" administered postoperatively were converted to morphine equivalents to align with intraoperative opioid measurement. A conversion factor of 5 mg of oral Percocet® (Endo Pharmaceuticals, Malvern, PA) being equivalent to 2.5 mg of intravenous morphine and 5 mg of oral Vicodin® (Mallinckrodt, St. Louis, MO) being equivalent to 2.0 mg of intravenous morphine was employed. Following conversion to morphine equivalents, the data was entered under the supplemental label "PV", which captured the morphine equivalents of all opioids administered during the 72 hour postoperative period.

As one of the primary focuses of the study was to examine the impact duration of sciatic PNB had on postoperative opioid consumption, data collected regarding the use of Tylenol® (Johnson & Johnson, New Brunswick, NJ) postoperatively was not included in the analyses as oral Tylenol® offers 10% or less opioid sparing effects for immediate postoperative pain. Likewise, data collected regarding the use of Valium® (Genentech, San Francisco, CA) or Robaxin® (Endo Pharmaceuticals, Malvern, PA) was omitted from analyses as PNB does not impede the occurrence of postoperative muscle spasm for which the medications were prescribed.

Two additional variables regarding tourniquet-related data were added to simplify analyses. Tourniquet times were change to a dichotomous measure, >120 minutes and < 120 minutes, and entered under the newly created variable TOUR_GREATER_120. Tourniquet times greater than 120 minutes have been reported as being associated with

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an increased risk of clinically significant compression resulting in nerve palsy (Horlocker et al., 2006). Tourniquet pressure was also transformed into a supplemental dichotomous variable, TOUR_INFL_GREATER_THAN_100, with data indicating if the tourniquet pressure was greater than 100 mmHg when compared to SBP at time of inflation (1 = yes, 2 = no). Tourniquet inflation pressures greater than 100 mmHg higher than systolic blood pressure have been associated with an increased risk of clinically significant compression resulting in nerve palsy (Horlocker et al., 2006).

Following initial inspection of the data set, multiple supplemental variables were created to allow further analysis of the outcomes of interest. More specifically, variables were established to explore the outcomes of interest in 24 hour intervals and over the entire 72 hour postoperative period. The list of created variables includes: the total number of opioids required per 24 hour interval, the average morphine equivalents per 24 hour interval postoperatively, the average morphine equivalents during the 72 hour postoperative period, the average pain score at the front of the knee per 24 hour interval, the average pain score at the front of the knee during the 72 hour postoperative period, the average pain score at the back of the knee per 24 hour interval, the average pain score at the back of the knee during the 72 hour postoperative period, the average satisfaction score per 24 hour interval, and the average satisfaction score during the 72 hour postoperative period.

Data Analysis

Descriptive statistics. The distribution of the demographic variables was assessed via descriptive statistics, with histograms used to depict continuous distributions and bar charts used to compare statistical summaries of the distributions of

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the same continuous variable across the categories of categorical variables (Gray & Kinnear, 2012). Normality of variables was assessed by either statistical or graphical methods. Tests of normality employed empirical distribution function (EDF) statistics to assess for goodness of fit. EDF statistics are based on a comparison of the hypothesized distribution function $F(x)$ with the empirical distribution function $F_n(x)$ (Davis & Stephens, 1989). When $F(x)$ is continuous and completely satisfied, EDF statistics give a more powerful tests of H_0 than the classical chi-square test (Davis & Stephens, 1989). Findings pertinent to outcomes of interest in this study are discussed in this section.

Descriptive statistics for the four demographic variables were generated in SAS™ and are summarized in Table 7. AGE represents the continuous variable age in years. Once enrolled, patients were categorized into one of two age groups, 10 to 14 years of age inclusive and 15 to 18 years of age inclusive, in an attempt to negate the impact of age on outcomes with age being used as a surrogate for maturity. Patients enrolled in this study age 10 to 14 years accounted for 37.5% (n = 12) of the study sample, with patients age 15 to 18 years accounting for 62.5% (n = 20) of the study sample (Figure 9). Overall, the mean age of patients enrolled in the study was 14.63 years with a standard deviation of 1.84. Using the NPAR1WAY Procedure in SAS™ to perform a Wilcoxon-Mann-Whitney test revealed that the age of patients who received single-injection sciatic PNB (*Mdn* = 15) did not significantly differ from those who received continuous sciatic PNB (*Mdn* = 15), $W_s = 257.0000$, $z = -0.2501$, $p = 0.8025$.

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Table 7

Observed Frequencies and Percentages of Demographic Variables

Variable	Number missing	Category	Frequency	Percent
AGE	0	10 years	1	3.13
		11 years	1	3.13
		12 years	3	9.38
		13 years	3	9.38
		14 years	4	12.50
		15 years	8	25.00
		16 years	9	28.13
		17 years	2	6.25
		18 years	1	3.13
GENDER	0	Male	14	43.75
		Female	18	56.25
ASA	0	ASA I	21	65.63
		ASA II	11	34.38
BMI	0	BMI > 30	3	9.68
		BMI < 30	28	90.32

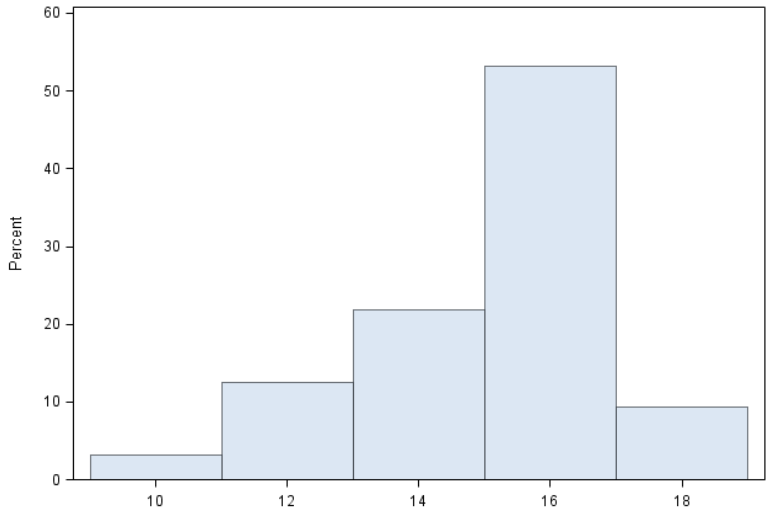

Figure 9. Age in Years of Patients in the Study.

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The percentages of males and females enrolled in the study were similar, with males comprising 43.75% of the study population and females comprising 56.25% of the study population (Figure 10).

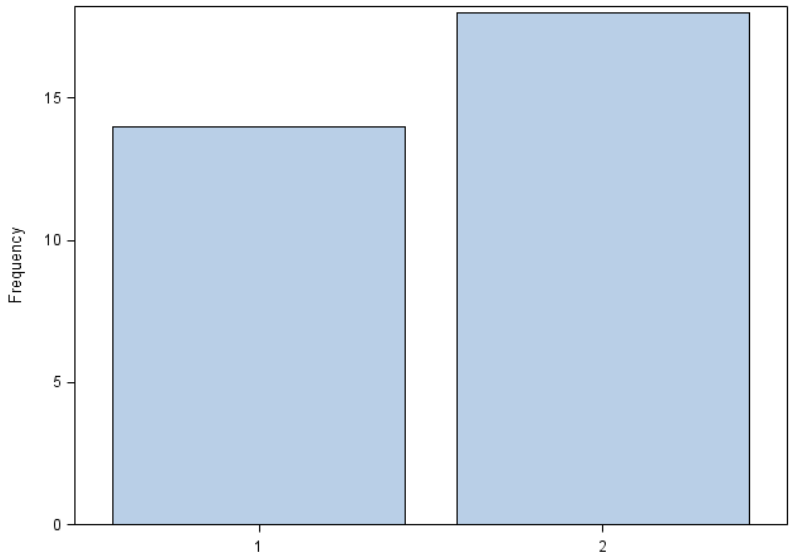

Figure 10. Gender of Patients in the Study (1 = male, 2 = female).

Not surprisingly, the frequency distribution for ASA physical status demonstrated that more patients classified as ASA physical class I (n = 21) underwent ACL reconstruction than those classified as ASA physical class II (n = 11) (Figure 11). Given that the population of adolescents undergoing ACL are largely athletes who sustained their injury while playing sports, it is of no surprise that the vast majority of patients enrolled in the study are healthy patients without preexisting comorbidities. As anticipated, the use of a computer generated randomized scheme yielded study groups that did not significantly differ in regard to ASA physical classification ($x^2 = 0.1385$, df = 1, p = 0.7097).

Few patients enrolled in this study had a BMI greater than 30 (n = 3) (Figure 12). BMI *z*-scores were calculated based on CDC growth charts. In children and

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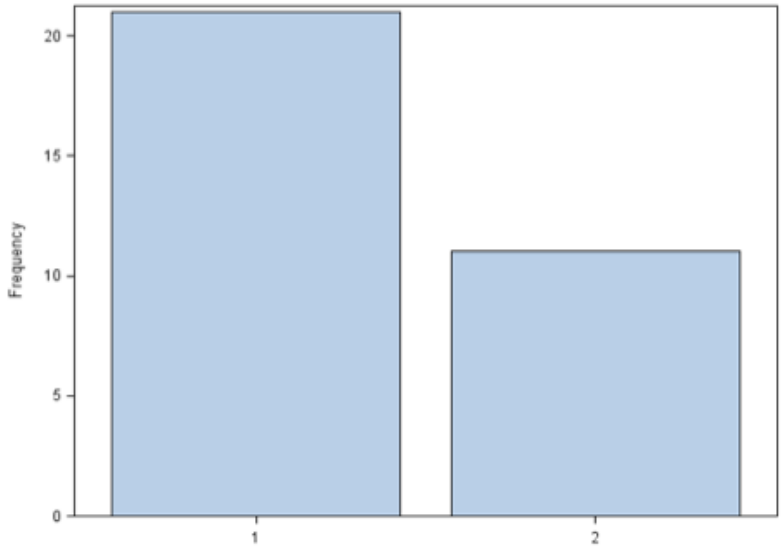

Figure 11. ASA Physical Class of Patients in the Study (1 = ASA I, 2 = ASA II).

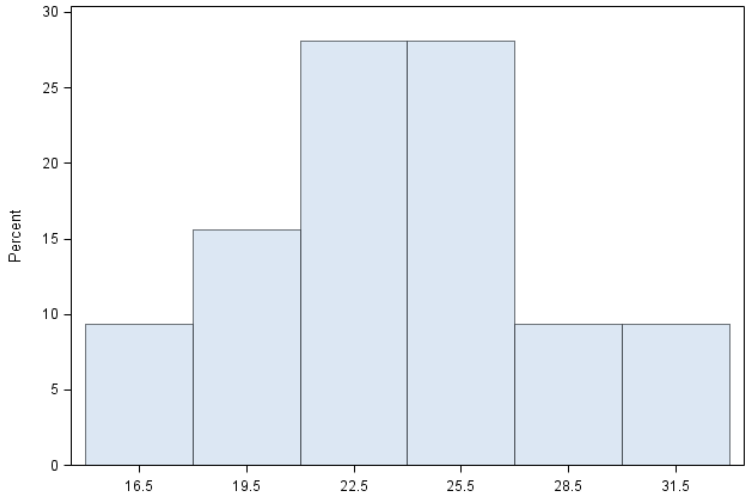

Figure 12. Calculated BMI of Patients in the Study.

adolescents, BMI *z*-scores are typically used in research rather than actual BMI as they are particularly useful to monitor changes in patients with a BMI above the 99th percentile or below the 1st percentile. Tests of normality indicated a normal distribution of BMI *z*-scores between groups existed with no significant differences noted (W = 0.9532, p = 0.1785), allowing for parametric testing. No significant difference was found in BMI *z*-scores between study groups, with patients randomized to the single-injection

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sciatic PNB group (M = 0.8856, SE = 0.2286) having similar BMI z-scores to those randomized to the continuous sciatic PNB group (M = 0.9253, SE = 0.2286), $t(30)$ = -0.12, p = 0.9030.

A Spearman's rank-order correlation was run that determined there was a relationship between BMI z-scores and reported pain at the posterior aspect of the knee 42, 48, and 54 hours postoperatively. In addition, there was a relationship between BMI z-scores and satisfaction scores for the final 12 hour interval of the 72 postoperative phase. BMI z-score was significantly related to posterior knee pain reported 42 hours postoperatively, r_s = 0.4480, p = 0.0101. Likewise, BMI z-score was significantly related to posterior knee pain reported 48 hours postoperatively, r_s = 0.4764, p = 0.0058. BMI z-score was also significantly related to posterior knee pain reported 54 hours postoperatively, r_s = 0.3986, p = 0.0238. BMI z-score was significantly related to satisfaction scores for the final 12 hour interval of the 72 postoperative phase, r_s = -0.4083, p = 0.0203.

Prior to initiation of this study, several confounding variables were identified. Data was collected regarding these variables and analyzed to assess their potential impact on the outcomes of interest. Data regarding history of previous surgery of any type was captured during the preoperative phase. Eighteen (56.25%) of the thirty-two patients enrolled in this study had previously undergone surgery, which was distributed equally among study group with nine patients in each group having undergone surgery previously. In three of the eighteen cases, it was noted that the patient previously underwent ACL reconstruction. History of previous surgery proved significant at several points during analyses (Table 8). More specifically, at several data collection time

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Table 8

Results of Wilcoxon-Mann-Whitney Analysis Based on History of Previous Surgery

Variable	Description	Previous Surgery	N	Mean Score	Statistic	Z	*p*
BACK_12	Pain at back of knee 12 hours postop.	1	18	19.6111	175	-2.1717	0.0299
		0	14	12.5			
BACK_18	Pain at back of knee 18 hours postop.	1	18	19.75	172.5	-2.2407	0.025
		0	14	12.3214			
BACK_30	Pain at back of knee 30 hours postop.	1	18	19.6388	174.5	-2.1508	0.0315
		0	14	12.4643			
BACK_36	Pain at back of knee 36 hours postop.	1	18	19.6667	174	-2.1636	0.0305
		0	14	12.4286			
BACK_024	Average pain score at back of knee first 24 hour interval postop.	1	18	19.6111	175	-2.1164	0.0343
		0	14	12.5			
BACK_2448	Average pain score at back of knee second 24 hour interval postop.	1	18	19.4167	178.5	-1.9789	0.0478
		0	14	12.75			
BACK	Average pain score at back of knee over 72 hours postop.	1	18	19.5278	176.5	-2.0515	0.402
		0	14	12.6071			
SATIS_2448	Average satisfaction score second 24 hour interval postop.	1	18	13.2222	290	2.2949	0.0217
		0	14	20.7143			
SATIS_4872	Average satisfaction score third 24 hour interval postop.	1	18	11.9722	312.5	3.1637	0.0016
		0	14	22.3214			
SATISFACTION	Average satisfaction score over 72 hours postop.	1	18	13.3056	288.5	2.199	0.0279
		0	14	20.6071			

intervals patients who previously underwent surgery reported significantly higher pain scores at the posterior aspect of their knee. Patients who previously underwent surgery also reported significantly lower satisfaction scores at several data collection intervals.

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Data regarding self-reported pain tolerance was gathered in the preoperative phase, with patients rating their pain tolerance as low (1), moderate (2), or high (3). Most patients reported having a moderate (n = 15) or high (n = 13) pain tolerance (Table 9). Composition of study groups (Table 10) was not significantly different in regards to representation of self-reported pain tolerance ($x^2 = 0.4451$, df = 2, $p = 0.8005$).

Table 9

Frequencies of Self-Reported Pain Tolerance

pain_tolerance	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	3	9.68	3	9.68
2	15	48.39	18	58.06
3	13	41.94	31	100.00

Table 10

Distribution of Self-Reported Pain Tolerance Among Study Groups

Table of randomization_group by pain_tolerance				
randomization_group	pain_tolerance			
Frequency Percent Row Pct Col Pct	1	2	3	Total
1	2 6.45 13.33 66.67	7 22.58 46.67 46.67	6 19.35 40.00 46.15	15 48.39
2	1 3.23 6.25 33.33	8 25.81 50.00 53.33	7 22.58 43.75 53.85	16 51.61
Total	3 9.68	15 48.39	13 41.94	31 100.00
Frequency Missing = 1				

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Activity since ACL injury was gathered as potential indicator of severity of ACL injury and possible presence of collateral damage and inclination for active knee flexion in the face of pain. Patients ranked their activity level as 1 = not active at all, 2 = not active, 3 = partially active, 4 = active, 5 = highly active. Most patients (54.84%) reported that at the time of surgery they remained partially active (Table 11). Composition of study groups (Table 12) was not significantly different in regards to representation of self-reported level of activity since injury ($x^2 = 3.5008$, df = 4, $p = 0.4778$).

Table 11

Frequencies of Self-Reported Activity Level Among Study Groups

activity_since_acl_injury	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	2	6.45	2	6.45
2	2	6.45	4	12.90
3	17	54.84	21	67.74
4	6	19.35	27	87.10
5	4	12.90	31	100.00

Two orthopedic surgeons performed all of the ACL reconstructions in this study. Although Orthopedic Surgeon 1 performed the majority (87.10%) of the surgeries, composition of study groups in regard to surgeon was not significantly different ($x^2 = 0.0048$, df = 1, $p = 0.9449$). When compared between study groups, average postoperative morphine equivalent administration over the 72 hour postoperative phase did not significantly differ for patients who received single-injection sciatic PNB (*Mdn* =

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Table 12

Distribution of Self-Reported Activity Level Among Study Groups

Table of randomization_group by activity_since_acl_injury						
randomization_group	activity_since_acl_injury					
Frequency Percent Row Pct Col Pct	1	2	3	4	5	Total
1	0 0.00 0.00 0.00	1 3.23 6.67 50.00	10 32.26 66.67 58.82	3 9.68 20.00 50.00	1 3.23 6.67 25.00	15 48.39
2	2 6.45 12.50 100.00	1 3.23 6.25 50.00	7 22.58 43.75 41.18	3 9.68 18.75 50.00	3 9.68 18.75 75.00	16 51.61
Total	2 6.45	2 6.45	17 54.84	6 19.35	4 12.90	31 100.00
Frequency Missing = 1						

30.00) when compared to those who received continuous sciatic PNB (*Mdn* = 45.00), W_s = 91.5000, z = 1.5944, p = 0.1109

The anesthetic delivered during the intraoperative phase, including intravenous opioid administration, was left to the discretion of the team providing direct care. Suggested dosing guidelines, however, were made available to each team in an effort to minimize variability in opioid dosing. Despite the available dosing guidelines, there was a wide variety of opioid dosing ranging from 0.03 mg/kg of morphine equivalents to 0.19 mg/kg of morphine equivalents. The variation in opioid dosing resulted in a non-normal distribution among the study population (W = 0.7783, p < 0.0001). When

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compared between study groups, however, intraoperative morphine equivalents administered those randomized to receive single-injection sciatic PNB (*Mdn* = 0.07mg/kg) did not significantly differ from those who received continuous sciatic PNB (*Mdn* = 0.07mg/kg), W_s = 233.0000, z = -1.1913, p = 0.2335.

Surgery length in this study ranged from 75 minutes to 240 minutes and was found not to have a normal distribution among the study population (W = 0.8455, p = 0.003). Surgery length for patients randomized to the single-injection sciatic PNB group (*Mdn* = 97.00) did not significantly differ from those who received continuous sciatic PNB (*Mdn* = 121.50), W_s = 297.5000, z = 1.2445, p = 0.2133. A Spearman's rank-order correlation was run that determined there was a relationship between surgery length and reported pain at the anterior aspect of the knee 60 hours postoperatively and 72 hours postoperatively. Surgery length was significantly related to anterior knee pain reported 60 hours postoperatively, r_s = -0.4184, p = 0.0192. Likewise, surgery length was significantly related to anterior knee pain reported 72 hours postoperatively, r_s = -0.4571, p = 0.0097.

Tourniquet inflation time ranged from 72 minutes to 173 minutes, with tourniquet inflation greater than 120 minutes occurring in 34.48% of the cases (n = 11). Tourniquet times were change to a dichotomous measure, with data indicating whether the tourniquet inflation time was > 120 minutes or < 120 minutes. Date regarding distribution of tourniquet inflation times in relation to the 120 minute benchmark came from a normally distributed population (W = 0.9401, p = 0.0752). On average, study participants randomized to the single-injection sciatic PNB group experienced similar tourniquet times (M = 104.6, SE = 6.4478) to those randomized to the continuous sciatic

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PNB group (M = 112.2, SE = 5.4515), $t(30) = -0.90$, $p = 0.3737$. Tourniquet inflation times for patients having surgery with Orthopedic Surgeon 1 (M = 109.7, SE = 4.6002) were not significantly different than those having surgery with Orthopedic Surgeon 2 (M = 107.3, SE = 11.8418), $t(29) = 0.19$, $p = 0.8493$.

A Spearman's rank-order correlation was run that determined there was a relationship between tourniquet inflation time and reported pain at the anterior aspect of the knee 60 hours postoperatively and 72 hours postoperatively. Tourniquet inflation time was significantly related to anterior knee pain reported 60 hours postoperatively, $r_s = -0.4736$, $p = 0.0071$. Likewise, tourniquet inflation time was significantly related to anterior knee pain reported 72 hours postoperatively, $r_s = -0.5010$, $p = 0.0041$. Accordingly, tourniquet inflation time was significantly related to the average anterior knee pain reported during the final 24 hours of the 72 hours postoperative period, $r_s = -0.3937$, $p = 0.0258$. This mirrors of the correlation found between surgery length and reported anterior knee pain 60 and 72 hours postoperatively.

Tourniquet inflation pressure was transformed into a dichotomous variable with data indicating if the tourniquet pressure was greater than 100 mmHg when compared to SBP at time of inflation. Tourniquet inflation ranged between 200 mmHg and 250 mmHg, with the predominate setting being 225 mmHg (Table 13). All but one of the patients enrolled in this study experienced tourniquet inflation pressures greater than 100 mmHg higher than their systolic blood pressure at the time of inflation. Composition of study groups in regard to tourniquet inflation pressure was not significantly different ($x^2 = 2.0400$, df = 3, $p = 0.5641$) (Table 14).

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Table 13

Frequencies of Tourniquet Inflation Pressures (in mmHg)

tour_set_press	Frequency	Percent	Cumulative Frequency	Cumulative Percent
200	4	12.50	4	12.50
210	1	3.13	5	15.63
225	25	78.13	30	93.75
250	2	6.25	32	100.00

Table 14

Distribution of Tourniquet Inflation Pressures (in mmHg) Among Groups

Table of randomization_group by tour_set_press					
randomization_group	tour_set_press				
Frequency Percent Row Pct Col Pct	200	210	225	250	Total
1	1 3.13 6.25 25.00	1 3.13 6.25 100.00	13 40.63 81.25 52.00	1 3.13 6.25 50.00	16 50.00
2	3 9.38 18.75 75.00	0 0.00 0.00 0.00	12 37.50 75.00 48.00	1 3.13 6.25 50.00	16 50.00
Total	4 12.50	1 3.13	25 78.13	2 6.25	32 100.00

Table 15 provides a summary of key variables in the analyses per each treatment group in the study.

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Table 15

Summary of Variables by Study Group

Randomization Group	Variable	N	# Missing	Mean	Std Dev
	AGE	16	0	14.81	1.38
	BMI	16	0	23.77	3.58
	PREOPERATIVE_PAIN_SCORE	15	1	0.53	1.46
	INTRAOP_MSO4	16	0	0.09	0.03
	SURG_LENGTH	16	0	109.63	40.45
	TOUR_INFLA_TIME	16	0	104.56	25.79
	PV_POD1	16	0	12.05	5.22
	PV_POD2	16	0	14.83	8.09
	PV_POD3	16	0	9.63	5.59
	PV	16	0	36.5	16.74
1	FRONT_024	16	0	3.45	3.43
	FRONT_2448	16	0	3.48	2.91
	FRONT_4872	16	0	4.38	2.52
	FRONT	16	0	3.77	2.74
	BACK_024	16	0	4.43	2.72
	BACK_2448	16	0	4.24	2.63
	BACK_4872	16	0	3.69	2.67
	BACK	16	0	4.12	2.49
	SATISFACTION_024	16	0	3.84	1.01
	SATISFACTION_2448	16	0	3.81	0.83
	SATISFACTION_4872	16	0	3.94	0.83
	SATISFACTION	16	0	3.86	0.77
	AGE	16	0	14.44	2.25
	BMI	16	0	23.63	4.29
	PREOPERATIVE_PAIN_SCORE	16	0	1.25	1.81
	INTRAOP_MSO4	16	0	0.07	0.02
	SURG_LENGTH	16	0	115.75	25.93
	TOUR_INFLA_TIME	16	0	112.19	21.81
2	PV_POD1	16	0	10.61	5.22
	PV_POD2	16	0	14.02	6.38
	PV_POD3	16	0	8.77	5.83
	PV	16	0	33.39	13.76
	FRONT_024	16	0	2.81	2.55
	FRONT_2448	16	0	3.38	2.41

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Table 15 continued

Randomization Group	Variable	N	# Missing	Mean	Std Dev
2	FRONT_4872	16	0	2.71	1.97
	FRONT	16	0	2.81	1.79
	BACK_024	16	0	2.48	2.73
	BACK_2448	16	0	2.38	1.77
	BACK_4872	16	0	1.65	1.51
	BACK	16	0	2.17	1.51
	SATISFACTION_024	16	0	3.88	1.06
	SATISFACTION_2448	16	0	4.16	0.91
	SATISFACTION_4872	16	0	4.41	0.58
	SATISFACTION	16	0	4.15	0.76

Hypothesis Testing

Prior to hypothesis testing, all variables included in the analyses were examined through various SAS ™ programs for accuracy of data entry, missing values, and fit between their distributions and the assumptions of multivariate analysis. The variables were examined separately for each of the treatment groups, single-injection sciatic PNB and continuous sciatic PNB, and then compared between groups.

Assignment into one of two treatment groups was determined via a computer generated randomization model, based on age, gender, and ASA physical status. Two groups for age were established: 10 to 14 years of age (inclusive) and 15 to 18 years of age (inclusive). To satisfy inclusion criteria, only patients classified as ASA physical status I or II were enrolled. While considered a confounding variable, BMI was not considered in the randomization scheme as most adolescents undergoing ACL

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reconstruction with the available sample population were not obese. As planned, the demographic data of each study group was reasonably balanced.

Once the descriptive data analyses were reviewed and it was confirmed that confounding variables did not significantly impact the outcomes of interest, the Specific Aims and associated research hypotheses were then tested.

Specific Aim 1. Sciatic PNB significantly reduces pain following hamstring autograft harvest when compared to intravenous opioids. It remains unknown, however, if any benefit is gained during the initial 72 hour postoperative period from extending analgesia for the hamstring donor site via continuous sciatic PNB. Specific Aim One posited that the extended duration of analgesia offered by continuous sciatic PNB improves pain control during the 72 hour postoperative period following hamstring autograft harvest when compared to single-injection sciatic PNB. Pain control is a multifaceted phenomenon, therefore, three hypotheses were developed to more completely explore the question: Does continuous sciatic PNB improve pain control following hamstring autograft harvest when compared to single-injection sciatic PNB?

$H_{1.1}$. Pain scores during the initial 72 hours following hamstring autograft harvest will be lower in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.

$H_{1.2}$. The use of oral pain medication during the initial 72 hours following hamstring autograft harvest will be lower in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.

$H_{1.3}$. The incidence of unplanned admission to the hospital due to poor pain control during the initial 72 hours following hamstring autograft harvest will be lower in

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patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.

Hypothesis $H_{1.1}$ focused on reported pain scores as a metric for determining pain control. Hypothesis $H_{1.1}$ was tested via non-parametric statistical testing as the distribution across the study population was not normal. Pain scores were collected from each patient enrolled in the study once every six hours for 72 hours following the completion of surgery. Scores for both the anterior and posterior portion of the knee were collected in an effort to better discern if the reported pain was attributable to the sciatic nerve distribution, which is the particular area of interest in this study. After initial analysis, scores correlating to the anterior and posterior aspects of the knee were averaged per each of the three 24 hour intervals observed during the postoperative phase. In addition, scores for anterior and posterior knee pain over the entire 72 hour postoperative phase were average for each patient.

Several time points during the 72 hour postoperative phase were found to have significantly different posterior knee pain scores between each of the treatment groups. Using the NPAR1WAY Procedure in SAS™ to perform a Wilcoxon-Mann-Whitney test revealed that the posterior knee pain scores reported 24 hours postoperatively by patients who received single-injection sciatic PNB (Mdn = 3.75) significantly differed from those who received continuous sciatic PNB (Mdn = 0.00), W_s = 213.5000, z = -1.9719, p = 0.0486. Posterior knee pain scores reported 48 hours postoperatively by patients who received single-injection sciatic PNB (Mdn = 4.50) also significantly differed from those who received continuous sciatic PNB (Mdn = 1.50), W_s = 212.0000, z = -1.9740, p = 0.0484. In addition, posterior knee pain scores reported 54 hours

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postoperatively by patients who received single-injection sciatic PNB (*Mdn* = 5.00) significantly differed from those who received continuous sciatic PNB (*Mdn* = 1.00), W_s = 208.5000, z = -2.1058, p = 0.0352.

In addition to the individual time points, averages of posterior knee pain scores over each 24 hour interval, as well as the entire 72 hour postoperative phase, significantly differed. During the initial 24 hour interval of the postoperative phase, the average posterior knee pain score reported by patients who received single-injection sciatic PNB (*Mdn* = 4.13) significantly differed from those who received continuous sciatic PNB (*Mdn* = 1.75), W_s = 210.0000, z = -2.0242, p = 0.0430. During the second 24 hour interval of the postoperative phase, the average posterior knee pain score reported by patients who received single-injection sciatic PNB (*Mdn* = 4.63) significantly differed from those who received continuous sciatic PNB (*Mdn* = 2.00), W_s = 205.0000, z = -2.2089, p = 0.0272. During the final 24 hour interval of postoperative phase, the average posterior knee pain score reported by patients who received single-injection sciatic PNB (*Mdn* = 2.68) significantly differed from those who received continuous sciatic PNB (*Mdn* = 1.25), W_s = 202.5000, z = -2.3049, p = 0.0212. The average posterior knee pain score over the 72 hour postoperative phase significantly differed as well, with patients who received single-injection sciatic PNB (*Mdn* = 3.46) reporting higher pain scores than those who received continuous sciatic PNB (*Mdn* = 1.93), W_s = 203.0000, z = -2.2804, p = 0.0226.

Hypothesis $H_{1.2}$ focused on oral pain medication use as a metric for determining pain control. Hypothesis $H_{1.2}$ was tested via non-parametric statistical testing as the distribution across the study population was not normal. Pain medication use was

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recorded at the time of administration rather than at set intervals as with pain scores. To better discern the amount of pain medication administered, morphine equivalents administered for each patient were averaged per each of the three 24 hour intervals observed during the postoperative phase. In addition, the total morphine equivalents administered over the entire 72 hour postoperative phase were average for each patient. Total oral pain medication use was gathered, converted into morphine equivalents, and analyzed.

The intended analysis was via *t*-test, however, it was discovered that distribution across the population was inconsistent depending on time point and interval (Table 16). Since this violated the assumption of normal distribution among groups, testing was via Wilcoxon-Mann-Whitney testing. Interestingly, no significant differences were noted between the treatment groups. During the initial 24 hour interval of the postoperative phase, the average dose of morphine equivalent administered to patients who received single-injection sciatic PNB (*Mdn* = 10.00) did not significantly differ from those who received continuous sciatic PNB (*Mdn* = 9.38), W_s = 241.5000, z = -0.8375, p = 0.4023. During the second 24 hour interval of the postoperative phase, the average dose of morphine equivalent administered to patients who received single-injection sciatic PNB (*Mdn* = 13.75) did not significantly differ from those who received continuous sciatic PNB (*Mdn* = 12.50), W_s = 259.5000, z = -0.1518, p = 0.8804. During the final 24 hour interval of the postoperative phase, the average dose of morphine equivalent administered to patients who received single-injection sciatic PNB (*Mdn* = 10.00) did not significantly differ from those who received continuous sciatic PNB (*Mdn* = 8.25), W_s = 251.5000, z = -0.4561, p = 0.6483. The average dose of morphine equivalent

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Table 16

Test of Normality for Postoperative Pain Medication Use (24 hour intervals and overall average)

Variable: pv_pod1

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.922777	Pr < W	0.0247
Kolmogorov-Smirnov	D	0.164254	Pr > D	0.0262
Cramer-von Mises	W-Sq	0.15803	Pr > W-Sq	0.0188
Anderson-Darling	A-Sq	0.962826	Pr > A-Sq	0.0144

Variable: pv_pod2

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.962576	Pr < W	0.3226
Kolmogorov-Smirnov	D	0.136796	Pr > D	0.1295
Cramer-von Mises	W-Sq	0.066119	Pr > W-Sq	>0.2500
Anderson-Darling	A-Sq	0.405752	Pr > A-Sq	>0.2500

Variable: pv_pod3

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.95084	Pr < W	0.1523
Kolmogorov-Smirnov	D	0.130698	Pr > D	>0.1500
Cramer-von Mises	W-Sq	0.074644	Pr > W-Sq	0.2394
Anderson-Darling	A-Sq	0.500474	Pr > A-Sq	0.2024

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Table 16 continued

Variable: pv

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.95116	Pr < W	0.1555
Kolmogorov-Smirnov	D	0.159133	Pr > D	0.0385
Cramer-von Mises	W-Sq	0.092895	Pr > W-Sq	0.1371
Anderson-Darling	A-Sq	0.523813	Pr > A-Sq	0.1761

administered over the 72 hour postoperative phase did not significantly differ either, with the average dose of morphine equivalent administered to patients who received single-injection sciatic PNB (*Mdn* = 35.00) being similar to those who received continuous sciatic PNB (*Mdn* = 29.38), $W_s = 248.0000$, $z = -0.5855$, $p = 0.5582$.

Hypothesis $H_{1.3}$ focused on unplanned admission due to poor pain control as a metric for determining pain control. No patients in this study were admitted to the hospital due to poor pain control during the postoperative period, therefore no statistical testing was performed for Hypothesis $H_{1.3}$.

Specific Aim Two. Questions remain as to the impact of of sciatic PNB on active knee flexion postoperatively. Specific Aim Two posited that the extended duration of action offered by continuous sciatic PNB does not delay active knee flexion during the 72 hour postoperative period following hamstring autograft harvest when compared to single-injection sciatic PNB.

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$H_{2.1}$. Active knee flexion during the initial 72 hours following hamstring autograft harvest will not be delayed in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.

Hypothesis $H_{2.1}$ focused on reported knee movement scores as a metric for determining the impact of continuous sciatic PNB on active knee flexion. Knee movement scores were collected from each patient enrolled in the study once every twelve hours for 72 hours following the completion of surgery. Chi-square testing was employed to analyze Hypothesis $H_{2.1}$ as the DV was ordinal in nature. No significant differences were found between treatment groups in relation to active knee flexion (Table 17). Distribution of responses followed a similar pattern for each treatment group at each time interval (Table 18). For each treatment group, the majority of answers regarding the ability to actively flex the knee improved from "too much pain to bend" to "able to bend, but with pain" at the 36 hour time interval.

Table 17

Summary of Chi-Square Analyses for Active Knee Flexion by Treatment Group

Time Interval	x^2	df	*p*
12	5.9429	2	0.0512
24	1.4	2	0.4966
36	0.1497	2	0.9279
48	0.4762	2	0.7881
60	0.3768	2	0.8283
72	0.1107	2	0.9461

Specific Aim Three. Pain control is often closely associated with patient satisfaction. Specific Aim Three posited that the extended duration of analgesia offered by continuous sciatic PNB will improve patient satisfaction during the 72 hour

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Table 18

Summary of Distribution of Active Knee Flexion Responses by Treatment Group for Each Time Interval

Time Interval	Randomization Group	Able to bend with no pain (n)	Able to bend, but with pain (n)	Too much pain to bend (n)
12	1	0	4	12
	2	5	3	8
24	1	1	6	9
	2	3	4	9
36	1	2	8	6
	2	2	9	5
48	1	1	11	4
	2	2	11	3
60	1	2	11	3
	2	1	12	3
72	1	3	10	2
	2	4	10	2

postoperative period following hamstring autograft harvest when compared to single-injection sciatic PNB.

$H_{3.1}$. Patient satisfaction with pain control during the initial 72 hours following hamstring autograft harvest will be improved in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.

Hypothesis $H_{3.1}$ focused on reported satisfaction scores as a metric for determining the impact of continuous sciatic PNB on patient satisfaction. Satisfaction scores were collected from each patient enrolled in the study once every twelve hours for 72 hours following the completion of surgery. In addition, satisfaction scores for each patient were averaged per each of the three 24 hour intervals observed during the postoperative phase. Satisfaction scores over the entire 72 hour postoperative phase were averaged for each patient as well. The distribution of satisfaction scores across

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the population was not normal (Table 19), indicating that non-parametric testing would be appropriate. As such, the Wilcoxon-Mann-Whitney test was employed to analyze satisfaction scores.

Table 19

Test of Normality for Satisfaction Scores

Variable: satisfaction_12

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.842626	Pr < W	0.0003
Kolmogorov-Smirnov	D	0.236293	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.303116	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	1.915763	Pr > A-Sq	<0.0050

Variable: satisfaction_24

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.847882	Pr < W	0.0004
Kolmogorov-Smirnov	D	0.213176	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.266317	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	1.733284	Pr > A-Sq	<0.0050

Variable: satisfaction_36

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.830486	Pr < W	0.0002
Kolmogorov-Smirnov	D	0.200717	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.296049	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	1.927452	Pr > A-Sq	<0.0050

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Table 19 continued

Variable: satisfaction_48

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.849884	Pr < W	0.0004
Kolmogorov-Smirnov	D	0.21875	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.332025	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	2.027425	Pr > A-Sq	<0.0050

Variable: satisfaction_60

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.808472	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.204723	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.362817	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	2.41014	Pr > A-Sq	<0.0050

Variable: satisfaction_72

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.750444	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.320219	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.513726	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	3.230695	Pr > A-Sq	<0.0050

As a whole, satisfaction scores between groups proved to be similar. The sole exception, however, was at the 72 hour interval. When compared between study groups, satisfaction scores 72 hours postoperatively of those randomized to receive single-injection sciatic PNB (*Mdn* = 4.00) significantly differed from those who received

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continuous sciatic PNB (*Mdn* = 4.50), W_s = 290.0000, *z* = 2.1456, *p* = 0.0319. Despite this finding, satisfaction scores per 24 hour interval and overall failed to be significantly different (Table 20).

Table 20

Summary of Wilcoxon-Mann-Whitney Analyses of Satisfaction Scores

Time Interval	Single-injection PNB median	Continuous PNB median	*Ws*	*z*	*p*
Initial 24 hour interval	3.75	4	267	0.0976	0.9222
Second 24 hour interval	3.5	4	305	1.763	0.115
Final 24 hour interval	4	4.5	306	1.6082	0.1078
Average over entire 72 hours	3.67	4	294.5	1.1483	0.2509

Chapter Summary

This chapter presented the statistical analyses and results of this study which aimed to answer the following research question: does single-injection sciatic PNB or continuous sciatic PNB provide more effective postoperative pain control following ACL reconstruction with a hamstring autograft in the adolescent population? Effective care is multifaceted. Accordingly, this study utilized a variety of measures of pain scores to best capture the impact duration of sciatic PNB may have on outcomes related to effective care. A variety of parametric and non-parametric statistical testing methods were employed to most appropriately analyze the data. The measures analyzed included postoperative medication requirements, rate of unplanned admission due to poor pain control, active knee flexion throughout the 72 hour postoperative phase, and satisfaction scores. Of these, postoperative pain scores were most impacted by duration of sciatic PNB. Chapter Five will discuss theoretical and practical implications

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of the results, limitations of the study, and will offer recommendations for future research.

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Chapter Five: Discussion

Chapter Introduction

This chapter reviews the findings of this study which explored a question clinicians providing care for adolescents undergoing ACL utilizing a hamstring autograft routinely encounter: What duration of sciatic PNB provides the most effective postoperative pain control? A brief synopsis of the clinical relevance, as well as the study design, methodology, ensuing analyses and findings, are discussed. This includes a discourse on the theoretical and practical implications of the findings, in addition to consideration of study-related limitations. Finally, recommendations for future research are offered.

Summary and Overview of the Problem

ACL reconstruction among the adolescent population has increased by over 400 percent in the last decade. With an ever increasing number of adolescents now routinely undergoing ACL reconstruction, the mean age of all patients scheduled for this surgery has decreased to 18 years of age (Silvers & Mandelbaum, 2007). Several surgical techniques for ACL reconstruction are commonly accepted, however, use of a hamstring autograft has emerged as the technique of choice for adolescents due to the decreased morbidity and proven long-term stability when compared to the other ligament replacement options (Mehta, Mandala, Foster, & Petsche, 2010; Pallis, Svoboda, Cameron, & Owens, 2012). The advantages of using a hamstring autograft

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over other techniques include the decreased incidence of graft failure, lower infection rate, decreased risk of disease transmission, a potential faster return to full activities, and a significant reduction in postoperative pain scores (Ryu & Provencher, 2011; Feller, Webster, & Gavin, 2001). Still, the pain attributed to hamstring autograft harvest is considered to be significant during the immediate postoperative phase and must be addressed accordingly.

While it is accepted that sciatic PNB best palliates hamstring donor site pain, controversy remains as to the appropriate duration of sciatic PNB. It has been reported that hamstring donor site pain may persist up to 48 hours postoperatively, but definitive studies regarding the duration of hamstring donor site pain are lacking (Frost, et al., 2000). This void in the literature yields a lack of evidence-based practice, forcing clinicians to rely upon anecdotal experiences to guide their decision making when choosing between single-injection and continuous sciatic PNB. As a result, there remains no consensus as to the duration of sciatic PNB required to effectively control donor site pain throughout the postoperative period (Tran, Ganley, Wells, Ganesh, Minger, & Cucchiaro, 2005; Bushnell, Sakryd, & Noonan, 2010).

Both single-injection and continuous sciatic PNB elicit concerns making it challenging for clinicians to discern best practice. Advocates of single-injection sciatic PNB, which can last up to 24 hours or longer, note that in adult studies sciatic PNB offered significant advantages in postoperative pain control only during the initial 24 hours following knee surgery (Wegener et al., 2011). Furthermore, concerns regarding increased risk of falls, decreased active knee movement and the masking of compartment syndrome often preclude the routine use of continuous sciatic PNB (Liu &

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Wu, 2007). Proponents of continuous sciatic PNB assert that the extended duration of analgesia afforded by this technique improves overall pain control postoperatively and decreases the need for supplemental pain medications (Ganesh & Cucchiaro, 2007). In addition, it has been reported that the duration of action of single-injection sciatic PNB may fail to outlast that of hamstring donor site pain (Ganesh & Cucchiaro, 2007).

The choice between single-injection and continuous sciatic PNB is important, as patient outcomes may be greatly affected based on the technique chosen to employ. Should postoperative pain be mismanaged, negative physiological, psychological, and economic consequences often result (Agin & Glass, 2005). Failure to address pain may lead to future impairment in functioning as well as heighten anxiety and fear, which in turn may further increase the perception of pain (Matthews, 2011). Suffering secondary to protracted pain can lead to detrimental derangements in lifestyle and personality (Beales, Holt, Keen & Mellor, 1983). Furthermore, poorly managed pain may impede recovery, resulting in increased healthcare-related costs and time away from school and work (Twycross, 2002). Ultimately, the profound impact duration of sciatic PNB may have on patient outcomes merits investigation as there remains a lack of comparative effectiveness studies exists in the literature regarding the ideal duration of sciatic PNB following hamstring autograft harvest to guide clinical practice.

Purpose of the Study

Despite the exponential increase in adolescents undergoing ACL reconstruction with a hamstring autograft, there is not an accepted standard of care addressing postoperative pain control stemming from hamstring autograft harvest. The purpose of this research was to compare the effect of single-injection sciatic PNB to continuous

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sciatic PNB on 1) postoperative pain control as measured by self-reported pain scores, pain medication use, and unplanned hospital admission due to poor pain control, 2) active knee flexion, and 3) patient satisfaction with pain control following ACL reconstruction with a hamstring autograft. The results of this research have the potential to impact clinical decision making regarding pain control management when caring for adolescents undergoing ACL reconstruction with a hamstring autograft.

Review of Theory and Research Question

Melzack and Wall (1965) introduced the most renowned theory of pain control several decades ago. While much regarding the human neuromatrix has been uncovered since that time, the tenets of the gate control theory continue to guide pain-related research around the globe. The gate control theory of pain proposed that small neuronal C fibers activate excitatory systems that subsequently excite output cells which enhances pain. Conversely, it was suggested that large neuronal A fibers mediate inhibitory processes and descending control systems from the central nervous system, thereby mitigating further enhancement of pain by excited output cells (Dickenson, 2002). Melzack and Wall (1965) suggested that pain could be modulated or "gated" not only in the dorsal horn, but also at a number of points in the pain pathway. The ability to inhibit excitatory influences and enhance inhibitory influences within the pain pathway provides the theoretical foundation for alleviating pain via sciatic PNB. Successful modulation of the pain pathway following a painful insult, such as a ACL reconstruction with a hamstring autograft, should theoretically lead to reductions in the perception of pain and subsequently the need for supplement opioids. If true, it follows

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that overall patient satisfaction levels should rise as many of the deleterious opioid-related side effects that often derail recovery from surgery could be averted.

The gap in knowledge regarding management of hamstring autograft donor site pain in adolescents is demonstrated by a lack of literature of the same. While improvements in pain control for adolescents have given rise to improved patient outcomes postoperatively, many questions remain as to appropriate resource management and utilization, as both the cost and duration of action vary greatly between single-injection and continuous PNB techniques. This study was designed to answer the research question: Does single-injection sciatic PNB or continuous sciatic PNB provide more effective postoperative pain control following ACL reconstruction with a hamstring autograft in the adolescent population?

Methodology

An experimental posttest-only design with repeated follow-up was employed for this study. Following receipt of IRB approval from both CCHMC and VCU, patients from a convenience sample were enrolled into the study and allocated to one of two treatment groups in a prospective, randomized manner. Once data was collected from the predetermined number of patients necessary for interim analysis, study enrollment ceased to allow for data analysis. Descriptive statistics were used to assess whether or not the data set would be adequate to address the hypotheses. Following initial review of the data, it was determined that the data set was appropriate to address the proposed hypotheses. Subsequently, analysis commenced with Pearson correlation, the Wilcoxon-Mann-Whitney test, the independent samples *t*-test, and the chi-square

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test serving as the predominate analytic tests used to address the hypotheses of this study.

Study Findings

Hypotheses. Following analysis, it was discovered that only two of the five proposed hypotheses were supported.

$H_{1.1}$. Pain scores during the initial 72 hours following hamstring autograft harvest will be lower in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB. Analysis of multiple data points confirmed that pain scores throughout the 72 hour postoperative phase were significantly lower for patients who received continuous sciatic PNB when compared to those who received single-injection sciatic PNB. This included significant differences being reported 24, 48, and 54 hours postoperatively, with those who received continuous sciatic PNB reporting much lower pain scores in reference to the posterior aspect of their knee. Additionally, when posterior knee scores were averaged, patients receiving continuous sciatic PNB reported significantly lower pain scores for each of the three 24 hour postoperative intervals for which data was gathered. Over the course of the 72 hour postoperative phase the overall average posterior knee pain score was found to be significantly lower for those who received continuous sciatic PNB.

$H_{1.2}$. The use of oral pain medication during the initial 72 hours following hamstring autograft harvest will be lower in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB. Over the course of the 72 hour postoperative phase, at no point was a significant difference in pain medication use noted on analysis. Wilcoxon-Mann-Whitney testing determined that patients who

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received single-injection sciatic PNB required similar doses of oral pain medication during the initial 72 hours following hamstring autograft harvest to those who received continuous sciatic PNB.

$H_{1.3}$. The incidence of unplanned admission to the hospital due to poor pain control during the initial 72 hours following hamstring autograft harvest will be lower in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB. This hypothesis was not supported as the rate of unplanned admission due to poor pain control for patients enrolled in this study was the same for each treatment group. No patients in this study were admitted due to poor pain control, therefore no statistical testing was performed in regards to Hypothesis $H_{1.3}$.

$H_{2.1}$. Active knee flexion during the initial 72 hours following hamstring autograft harvest will not be delayed in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB. The results of the analyses supported this hypothesis. Chi-square testing was employed to analyze whether significant differences existed between treatment groups in relation to active knee flexion during the 72 hour postoperative phase. No statistically significant differences were found. In fact, the distribution of responses in each treatment group followed a similar pattern throughout the 72 hour postoperative phase, with the majority of patients reporting that their ability to actively flex the knee improved from “too much pain to bend” to “able to bend, but with pain” at the 36 hour time postoperative interval.

$H_{3.1}$. Patient satisfaction with pain control during the initial 72 hours following hamstring autograft harvest will be improved in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB. Analysis via the

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Wilcoxon-Mann-Whitney test failed to support this hypothesis as satisfaction scores between groups were found to be similar. The sole exception, however, was satisfaction scores reported at the 72 hour postoperative interval. When compared between study groups, satisfaction scores 72 hours postoperatively of those randomized to receive continuous sciatic PNB were significantly lower than those who received single-injection sciatic PNB. Despite this finding, however, satisfaction scores per 24 hour interval and overall failed to be significantly different implying that the singular finding of significance may have been a spurious result of analysis given the small sample sized being analyzed.

Application to the Literature

Despite the frequency of ACL reconstruction with a hamstring autograft in the adolescent, there is a dearth of information pertaining to how to most effectively manage pain at the hamstring donor site postoperatively. Furthermore, few studies have been reported in the literature comparing the impact of single-injection sciatic PNB with continuous sciatic PNB following knee surgery.

Jansen, Miller, Arretche, and Pellegrini (2009) investigated whether the addition of sciatic PNB following ACL reconstruction would improve postoperative pain control. This study failed to address duration of sciatic PNB, however, as the study compared the outcomes of patients who received single-injection sciatic PNB with those who did not receive sciatic PNB. It should also be noted that the study failed to specifically address hamstring donor site pain as the grafts included in the study varied, ranging from patellar tendon grafts, to semitendinosus grafts, to allograft. Nonetheless, following analysis it was reported that the addition of sciatic PNB improved

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postoperative analgesia. It was offered that sciatic PNB should be include as part of anesthetic care plans going forward to facilitate improved patient-reported outcomes (Jansen et al., 2009). This study builds upon the study presented by Jansen et al. as it explores the impact of sciatic PNB following ACL reconstruction in greater depth. In addition to comparing the impact secondary to the varying durations single-injection and continuous sciatic PNB offer, outcome measures relating to effective care were more clearly defined. This included measures beyond pain scores such as opioid requirements, admission rates due to poor pain control, the impact duration of sciatic PNB has on active knee flexion, and patient satisfaction scores.

Wegener et al. (2011) previously investigated the impact of single-injection and continuous sciatic PNB following total knee arthroplasty. Although Wegener et al. attacked a significant problem, the aims of the study were poorly delineated. It was difficult to discern what the true *primary* aim of the study was: to investigate the impact duration of sciatic PNB had on pain control, the impact duration of sciatic PNB had on rehabilitation, the ability of continuous sciatic PNB to decrease time-to-discharge readiness or the ability of continuous sciatic PNB to decrease overall length of admission postoperatively. As a result, the study failed to offer solid guidance in regards to determining the ideal duration of sciatic PNB following knee surgery. Readdressing many of the same questions in a clearly delineated manner, this study furthers the work of Wegener et al. by thoroughly investigating the impact duration of sciatic PNB has on postoperative outcomes. The findings of this research contribute to the understanding clinicians have in regards to the impact duration of sciatic PNB has

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on pain control, movement, and satisfaction following ACL reconstruction with hamstring autograft harvest.

Implications

Theoretical implications. The gate control theory suggest that pain signals can be modulated modulated or "gated" not only in the dorsal horn, but also at a number of points in the pain pathway. The ability to inhibit excitatory influences and enhance inhibitory influences within the pain pathway provides the theoretical foundation for alleviating pain via sciatic PNB. The results of this study only partially support Melzack and Wall's theory. While reported pain scores were significantly lower for those randomized to receive continuous sciatic PNB, opioid requirements did not significantly differ between treatment groups. The results of this study suggest that the ability of sciatic PNB to inhibit excitatory influences in this study was not absolute. While a lower concentration of local anesthetic was used in this study achieve sensory blockade, rather than motor blockade, complete inhibition of excitatory influences should have been present. This suggests additional influences following ACL reconstruction with a hamstring autograft contribute to the experience of pain. Additionally, the results of this study dispel the contention that lower pain scores result in a decrease in opioid requirements.

Practical implications. From a practical standpoint, the use of continuous sciatic PNB seemingly benefits patients and improves reported outcomes without detriment to patients' postoperative course. While only two of the five hypotheses were supported by the results of the analyses, this limited study suggests that the use of continuous sciatic PNB improves reported pain scores without impeding recovery

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following ACL reconstruction with a hamstring autograft. To the contrary, the use of continuous sciatic PNB did not preclude active knee flexion among the patients enrolled in this study.

It can be hypothesized that the use of continuous sciatic PNB may lead to improved postoperative metrics among the adult population. Physical therapy and rehabilitation for many knee surgeries typically commences either the day of surgery or the morning of postoperative day one. The literature supporting early initiation of rehabilitation following joint surgery is robust and well founded. One of the primary limiting factors during the initiation of physical therapy, however, is the pain associated with movement of the newly reconstructed joint. Given the significantly lower pain scores and retained ability to actively flex the knee, it is feasible that the utilization of continuous PNB may facilitate early initiation of rehabilitation.

It is of no surprise that the extended analgesia offered by continuous sciatic PNB significantly improved postoperative pain scores during the 72 hour postoperative phase of this study. The lower pain scores, however, did not translate to a decrease in opioid administration or improved satisfaction scores. As there were not significant wide spread improvements in most of the metrics analyzed, some clinicians may continue to find the increased costs associated with continuous sciatic PNB prohibitive. Further analysis of a larger sample is required to determine if the additional costs associated with continuous sciatic PNB are justified. Should further significant improvements in outcomes be identified, it may be easier to persuade clinicians to utilize continuous sciatic PNB to facilitate pain control following ACL reconstruction with a hamstring autograft. Significant improvements in satisfaction scores would be especially

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persuading, as reimbursement for health care will be largely based on patient satisfaction scores in the near future.

Limitations

Threats to internal validity. Several threats to internal validity of this study were recognized during the design of this study. At that time all levels of measurement were reassessed to confirm that the tool aligns with the constructs within the design of the study. Nonetheless, it is recognized that this study continues to have several limitations.

Criterion-related validity remains supported, as the utilization of sciatic PNB for pain control following hamstring autograft is grounded in the literature. The study was designed to offer predictive validity, as the study was designed to differentiate between the efficacy of single-injection sciatic PNB and continuous sciatic PNB following hamstring autograft harvest. Adherence to study protocols by the clinicians involved was essential to safeguarding intervention fidelity. Were study protocols not followed, variability due to the intervention may have been suppressed and variability due to other factors may have been inflated, possibly leading to erroneous conclusions. While suggested guidelines regarding PNB and opioid administration were offered to all clinicians providing direct patients care, adherence to these guidelines was not monitored or enforced.

Patients enrolled in this study were randomized to treatment group via a computer-generated randomization scheme taking into consideration three key demographic variables; age, gender, and ASA physical status. While randomization allows for control of individual characteristics and removes selection bias, in addition to

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decreasing the chance for homogeneity, it fails to completely control for all inherent traits of the study population that may be detrimental to the results of this study (Polit & Beck, 2012). One such example is design contamination leading to compensatory rivalry. Upon awaking from surgery, it was apparent to the patient and their guardian which treatment group they were randomized to as patients were not blinded to the treatment group. It is possible that those randomized to the single-injection sciatic PNB group unknowingly altered their responses as part of a compensatory mechanism. Pain is a unique experience that is dealt with in a multitude of ways, one of which is rationalization. By convincing one's self that they received the "ideal" intervention, patients may have unknowingly skewed outcome data.

The potential threat of history was not assessed during the preoperative phase. Many patients have a family member, friend, or classmate who have previously undergone ACL reconstruction or received PNB. Conversations with those with prior experience may have had undue influence on the results reported by those enrolled in this study. However, while the threat of history exists, it is acknowledged that it likely affected both treatment groups in the study and had minimal to no effect on outcomes.

Temporal ambiguity was not a concern, as the focus of the study is the efficacy of single-injection sciatic PNB in controlling pain at the hamstring autograft donor site, mandating that the cause of pain (hamstring autograft harvest) preceded any perceived effect (postoperative pain control secondary to sciatic PNB). However, in assessing postoperative pain, we failed to adequately assess the origins of pain. Not all ACL injuries are equal and the degree of collateral damage secondary to the injury can be

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quite variable. It is within reason then to anticipate increased pain for more extensive repairs when compared to ACL reconstructions with less extensive damage.

Maturation, not in relation to age but in relation to time, may have impacted the scoring of the self-reported measures. Just as one's performance decreases with fatigue, patients enrolled in this study may have grown weary of recording data points once every six hours for a 72 hour period. A lack of interest or effort on the part of the patients enrolled in the study may have ultimately resulted in erroneous results and conclusions.

Pain following ACL reconstruction with a hamstring autograft is associated with cutaneous distributions of the femoral, sciatic, obturator, and lateral femoral cutaneous nerves. For this study, we chose to decrease the level of complexity and focused on the two primary nerve distributions associated with ACL reconstruction; the femoral and sciatic nerve distributions. The contribution of the lateral femoral cutaneous nerve to postoperative pain following ACL reconstruction is minimal at best. However, pain over the lateral femoral cutaneous nerve distribution increases as tourniquet times and tourniquet pressures rise. The same holds true for the cutaneous innervation of the obturator nerve, although the cutaneous distribution of the obturator nerve is far more variable. Because of the inherent variability, it is often not considered in regards to tourniquet pain. The obturator nerve plays a role in hamstring autograft donor site pain, however, as it provides partial sensory innervation to the gracilis muscle which is sometimes harvested as part of the hamstring autograft. The influence of pain derived from the sensory distribution of the lateral cutaneous femoral and obturator nerves was not controlled for in this study.

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Finally, while attrition during the postoperative phase was anticipated, the actual attrition rate was higher than expected (13.5%). During analysis it was found that patient attrition was largely due to the inability to contact patients and families postoperatively. Prior to enrollment, point of contact information was gathered from patients and/or their parents, however, it was not verified if the provided contact information was valid and/or operating.

Threats to external validity. Several threats to the external validity of this study have been recognized. First, this study was performed as a single-center trial, with all of the patients recruited from a convenience sample. Choosing this sampling method has significant inherent limitations in terms of external validity. Convenience sampling ultimately may not produce a sample typical of the population with regard to critical variables. It was anticipated, however, that the study sample would be diverse and representative of patients who comprise the target population.

While the sample population in this study was representative of the target population in many aspects, several key factors were not accounted for such as home environment following surgery. After some reflection, it was recognized that this study assumes that adolescents undergoing ACL reconstruction on an outpatient basis will have the appropriate support, means, and faculties to achieve optimal outcomes. This does not hold true for all adolescents nationally. Perhaps to say that the results of this study are generalizable to suburban youth would be more appropriate.

Additional patient-related factors, such as the genetic variability relating to morphine metabolism, should be considered. Over the last decade much has been discovered regarding the genetic variability that guides opioid transport and metabolism.

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It is now accepted that genetics play a significant role in postoperative opioid requirements. These are but a few examples of patient-related variables that were not accounted for that may impact the outcomes of interest in this study.

It is acknowledged that the techniques and protocols employed clinicians at CCHMC are not universal. Regional influence and individual training background both guide clinical practice. In regards to this study, it should be recognized that regional influence impacts both anesthetic and orthopedic practice. While PNB is routinely part of the anesthetic plan at CCHMC, not all facilities are comfortable with performing PNB on patients under general anesthesia, thereby limiting its utility in the pediatric and adolescent population. Likewise, not all orthopedic surgeons performing ACL reconstruction for the adolescent population prefer to use a hamstring autograft, which potentially limits the significance of the results of the study. Moreover, it would be ill-advised to report the results of this study as generalizable given the results were from the interim analysis of a much larger study.

Conclusions and Recommendations for Future Research

The addition of continuous sciatic PNB may improve patent-reported outcome measures after ACL reconstruction with a hamstring autograft in the adolescent population, but the benefits of this approach remain uncertain. Wegener et al. (2011) reported that continuous sciatic PNB lead to the reduction of pain scores during the initial 24 hours following total knee arthroplasty, but failed to demonstrate a significant impact beyond that time. Though drawn from a limited sample, the results of the study demonstrate that continuous sciatic PNB significantly reduces postoperative pain scores

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for 72 hours postoperatively when compared to those of patients who received single-injection sciatic PNB without further impeding active knee flexion.

Although the choice to perform continuous sciatic PNB should be based on the individual case and each institution's policy, continuous sciatic PNB appears to be worthwhile in the adolescent population undergoing ACL reconstruction with a hamstring autograft. Further studies with a larger sample are warranted to better discern the impact duration of sciatic PNB has following hamstring autograft harvest. In addition, studies are needed to understand the relationship between pain scores, opioid requirements following surgery, and patient satisfaction scores as the relationship between the three variables does not seem to be linear.

In summary, pain is an individual experience. While every patient has a unique perception of pain, it is a reasonable expectation that evidence-based protocols exist to guide pain control following surgery. Given the frequency ACL reconstruction is performed in the adolescent population, it is imperative further studies are done to determine the most effective duration of sciatic PNB to effectively manage pain following hamstring autograft harvest. This study has answered several questions, but has given rise to many more. There remains much to be learned about optimizing pain control so that negative physiological, psychological, and economic consequences are avoided in the future.

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Appendix A

Person Loading Chart

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Name	Role	Percent Effort	Budget Request	Contribution						
				Design	Writing	Recruitment	Data Collection	Preliminary Analyses	Analyses	Dissemination
James Furstein, DNAP, CRNA, CPNP-AC	PI	20	In kind	X	X	X	X	X	X	X
Suzanne Wright, PhD, CRNA	Co-Investigator	5	In kind	X	X			X	X	X
Diane Dodd-McCue, DBA	Co-Investigator	5	In kind	X				X	X	
Senthilkumar Sadhasivam, MD, MPH	Co-Investigator	5	In kind	X				X	X	X
Susan Glynn, CCRP	Research Coordinator	15	$6000.00			X	X			
Statistician (TBN)	Consultant	20 hours total	Department Supported	X				X	X	

Key Personnel

James Furstein, DNAP, CRNA, CPNP-AC (PI: 24.0 calendar months, 20% effort) is Lead Certified Registered Nurse Anesthetist (CRNA) of the Liberty Campus of Cincinnati Children's Hospital Medical Center (CCHMC). He has worked as a pediatric CRNA since 2005, with much of his career focused on regional anesthesia for pediatric and adolescent patients. Dr. Furstein is an Adjunct Faculty member of the University of Cincinnati, College of Nursing, for the Nurse Anesthesia Program and is responsible for the didactic component of the curriculum covering pain, pain management and regional anesthesia, in addition to providing hands-on instruction to students in a simulation

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environment. Currently, he is PI at CCHMC for multiple on-going IRB-approved studies focusing on regional anesthesia and is Co-Investigator on several others. Dr. Furstein has authored articles for peer-reviewed journals such as the *AANA Journal*, *Pediatric Anesthesia* and *International Anesthesiology Clinics*. He has presented both locally and nationally, including at the American Association of Nurse Anesthetists annual meeting, the Ohio State Association of Nurse Anesthetists annual meeting, the Society of Pediatric Anesthesia annual meeting, and was the Keynote Speaker at the 2012 University of California-Irvine Educational Symposium. Dr. Furstein is responsible for the design of the study, collaboration with the research coordinator to ensure data collection, and will also hold primary responsibility for manuscript preparation and dissemination of any knowledge gained.

Suzanne Wright, PhD, CRNA (Co-Investigator: 24.0 calendar months, 5% effort) is the Director of Doctoral Education for the Nurse Anesthesia Program in the School of Allied Health at Virginia Commonwealth University, as well as Director of the Center for Research in Human Simulation. Her research interests in simulation in education, clinical decision-making and patient safety have culminated in publications in the *AANA Journal*, *Airway Management*, and *Simulation in Education*. Dr. Wright is a past recipient of the AANA Foundation Doctoral Fellowship and is well versed in study design and implementation. Dr. Wright will aid in study design and preliminary exam of the data.

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Diane Dodd-McCue, DBA (Co-Investigator: 6.0 calendar months, 5% effort) is an Associate Professor in Virginia Commonwealth University's Program in Patient Counseling, and is responsible for coordinating research activities and teaching research methods in the department's Master's Program. In addition, she teaches core research methods courses in the School of Allied Health PhD program. Dr. Dodd-McCue was Principal Investigator of several grant projects funded by Health and Human Services (HRSA), National Association of Transplant Coordinators, and the Jessie Ball duPont Fund. Her articles have appeared in *Inquiry, Progress in Transplantation, American Journal of Critical Care, Journal of Nursing Administration, Chaplaincy Today, Journal of Pastoral Care and Counseling, Journal of Health Administration Education, and Human Relations*. Dr. Dodd-McCue will aid in study design and preliminary exam of the data.

Senthilkumar Sadhasivam, MD, MPH (Co-Investigator: 24.0 calendar months, 5% effort) is Associate Professor in Anesthesia and Pediatrics and Director of Acute and Perioperative Pain Service at Cincinnati Children's Hospital Medical Center. Dr. Sadhasivam has a strong research background in analgesia management, receiving multiple research awards including the Society of Ambulatory Anesthesia Research Award, the Laasberg/Johnson Research Award, the Clinical Center of Excellence Award, and the Young Investigator Award from the American Academy of Pediatrics. Dr. Sadhasivam has received funding as a PI from the Thrasher Foundation and Research Innovation and Pilot Funds, in addition to serving as co-investigator on several other funded studies. His work has been published in *Pediatrics*, *Journal of*

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Opioid Management, *Current Opinions in Anesthesiology*, *Anesthesiology*, *Anesthesia and Analgesia*, and the *Journal of Clinical Anesthesia*. Dr. Sadhasivam will aid in study design and preliminary exam of the data.

Susan Glynn, CCRP (Research Coordinator: 18.0 calendar months, 15% effort) has worked on a variety of investigator-initiated studies at Cincinnati Children's Hospital Medical Center, ranging from retrospective chart reviews to prospective, randomized, to blinded studies. Currently, she serves as lead CRC for several studies, including a multi-center foundation-funded prospective, observational study evaluating the association between specific genotypes and phenotypes, as defined by pain and analgesic response, in children following adenotonsillectomy. Mrs. Glynn also coordinates several studies evaluating the effectiveness of pain management techniques. Mrs. Glynn will aid in screening the operating room schedule for potential study candidates, consenting patients and/or their guardian(s), collecting data pertinent to the study and completing all postoperative data collection via telephone conversations with study participants and the designated scoring guardian(s). Mrs. Glynn will be supervised by the PI throughout the course of the study.

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Appendix B

Sample Post-Discharge Data Collection Instrument

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PAIN CONTROL:

Keep track of your pain score and location of pain:

Pain score: 0 = no pain, 10 = worst pain Pain location: F = front of knee, B = back of knee, X = both front & back			
6 hours		**42 hours**	
12 hours		**48 hours**	
18 hours		**54 hours**	
24 hours		**60 hours**	
30 hours		**66 hours**	
36 hours		**72 hours**	

Date and time the leg was no longer numb behind the knee:_____

Pain medicine prescribed (circle one): Vicodin Percocet Other:_____

Write down every time pain medication is taken:

Time/date	Type of medicine	Number of pills

ACTIVE KNEE MOVEMENT:

Rate the ability to bend the knee that was operated on:

Knee Movement	12 hours	24 hours	36 hours	48 hours	60 hours	72 hours
0 = Able to bend with no pain **1 = Able to bend, but with pain** **2 = Too much pain to bend**						

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SATISFACTION:

Rate your overall satisfaction score with pain management:

Satisfaction Score	12 hours	24 hours	36 hours	48 hours	60 hours	72 hours
0 = Not satisfied at all **1 = Not satisfied** **2 = Partially satisfied** **3 = Satisfied** **4 = Highly satisfied**						

From your perspective, have you encountered any unexpected postoperative experiences?

_____

_____

_____

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Appendix C

Aims, Variables, Analyses Table

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Aim 1: Explore the impact of sciatic PNB technique on hamstring donor site pain control postoperatively.

Objective(s)	Hypothesis	Variable(s)	Analyses
1. Assess pain control following hamstring autograft harvest, comparing the efficacy of single-injection and continuous sciatic PNB.	*1.1 Pain scores during the initial 72 hours following hamstring autograft harvest will be lower in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.*	*Self-reported pain scores (DV), sciatic PNB technique (IV)*	*Pearson correlation, Wilcoxon-Mann-Whitney test*
	1.2 The use of oral pain medication during the initial 72 hours following hamstring autograft harvest will be lower in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.	*Self-reported oral pain medication use (DV), sciatic PNB technique (IV)*	*Independent samples t-test*
	1.3 The incidence of unplanned admission to the hospital due to poor pain control during the initial 72 hours following hamstring autograft harvest will be lower in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.	*Unplanned admission due to poor pain control (DV), sciatic PNB technique (IV)*	*Chi-square test*

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Aim 2: Explore the impact of sciatic PNB technique on active knee flexion postoperatively.

Objective(s)	Hypothesis	Variable(s)	Analyses
2. Assess impact of sciatic PNB technique on active knee flexion.	*2.1 Active knee flexion during the initial 72 hours following hamstring autograft harvest will not be delayed in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.*	*Active knee flexion (DV), sciatic PNB technique (IV))*	*Chi-square test*

Aim 3: Explore the impact of sciatic PNB technique on patient satisfaction with postoperative pain control.

Objective(s)	Hypothesis	Variable(s)	Analyses
3. Assess the impact of sciatic PNB technique on patient satisfaction with postoperative pain control following ACL reconstruction with a hamstring autograft.	*3.1 Patient satisfaction with pain control during the initial 72 hours following hamstring autograft harvest will be improved in patients receiving continuous sciatic PNB when compared to those receiving single-injection sciatic PNB.*	*Patient satisfaction (DV), sciatic PNB technique (IV)*	*Wilcoxon-Mann-Whitney test*

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Vita

James Scott Furstein was born in Rockville, Connecticut. He earned his Bachelor of Science in Nursing at the University of Cincinnati in 2001, his Master of Science in Nursing at the University of Cincinnati in 2004, his Doctorate of Nurse Anesthesia Practice at Virginia Commonwealth University in 2011, and his Post-Master's Certificate for Master of Science in Nursing at the University of Cincinnati in 2015. James has practiced as a Certified Registered Nurse Anesthetist at Cincinnati Children's Hospital Medical Center since 2005. Currently, he is the Lead Nurse Anesthetist at the Liberty Campus of Cincinnati Children's Hospital Medical Center. In addition, he is Adjunct Faculty for the University of Cincinnati Nurse Anesthesia Program. In 2015, James was awarded the Alice Magaw Outstanding Clinical Practitioner Award by the American Association of Nurse Anesthetists.

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