AMBULATORY PERINEURAL LOCAL ANESTHETIC INFUSION FOLLOWING TOTAL JOINT REPLACEMENT: A PILOT STUDY

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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I dedicate this master's thesis to my wife, **Jenny Kline Ilfeld**, MD, for her patience, sacrifices, and understanding during my training culminating in this body of work.

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Total joint arthroplasty results in severe postoperative pain historically requiring hospitalization to provide potent analgesia. "Perineural infusion" or a "continuous peripheral nerve block" is a relatively novel analgesic option. This technique involves the percutaneous insertion of a catheter directly adjacent to the peripheral nerves supplying the affected joint. Local anesthetic is then infused *via* the catheter providing potent, site-specific analgesia with minor, if any, side effects. Unlike epidural catheters, perineural catheters may be used with new anticoagulants. Furthermore, perineural infusion does not require hospitalization, as do epidural infusion and intravenous opioids. Combining perineural catheters with portable infusion pumps, outpatients may experience the same level of analgesia previously afforded only to those remaining hospitalized. These attributes, along with others, make perineural infusion a potentially effective treatment for the debilitating and limiting pain following major joint replacement. This pilot study investigated the feasibility of converting total shoulder

arthroplasty (TSA) into an outpatient procedure and total knee (TKA) and hip (THA) arthroplasty into overnight-stay procedures using ambulatory perineural local anesthetic infusion.

Preoperatively, patients received a perineural catheter. Postoperatively, perineural ropivacaine, 0.2%, was delivered with a portable infusion pump for 4-6 days. Patients were discharged home when they met specific, prospectively-defined discharge criteria. The investigation was divided into two phases. The first phase allowed protocol optimization while having patients remain in the controlled environment of the hospital (1 night for TSA, 3 nights for TKA and THA). Twenty-two patients completed this phase, 15 of whom were ready for discharge on POD 0 (TSA) or 1 (TKA and THA). For the second phase, patients were allowed to be discharged home earlier than is current standard-of-care: directly from the recovery room for TSA, and on POD 1 for TKA and THA.

Of 16 phase 2 patients, 5 of 6 were discharged directly from the PACU following TSA, 5 of 5 were discharged on POD 1 following TKA, and 4 of 5 were discharged on POD 1 following THA. The remaining patients were discharged the subsequent day. For all patients, postoperative pain was well-controlled, oral opioid requirements and sleep disturbances were minimal, range-of-motion consistently reached surgeon-defined goals (TSA) or ambulation was greater than 30 m (TKA and TKA), and patient satisfaction was high. These results suggest that TSA, TKA, and THA may be performed on an outpatient or overnight basis using ambulatory perineural local anesthetic infusion. Additional data are required to define the appropriate subset of patients, assess the incidence of complications, and determine the degree of benefits associated with this practice.

INTRODUCTION

Osteoarthritis is the most common cause of disability and limitation of activity in mid and late life, with over 16 million Americans suffering from this incurable process.[1-4] Although medications may temporarily relieve discomfort, surgery remains one of the only long-term treatments for osteoarthritis. Over a half-million major joint replacement surgeries are performed annually in the United States alone.[5-7] Yet, while these procedures reduce chronic joint pain, the period of recovery extends up to a year and the prostheses rarely return patients to a level of function enjoyed by a non-arthritic person. A primary factor in the ultimate success of joint replacement is optimal rehabilitation in the postoperative period. Unfortunately, patients' ability to engage in physical therapy is usually severely limited by pain that increases with joint motion. For lower extremity procedures, epidural analgesia has been recognized as a satisfactory method of pain control, but is quickly becoming obsolete because of its contraindication with the use of potent new anticoagulants given for thromboprophylaxis (e.g. low molecular weight heparin). Alternatively (and for upper extremity procedures), intravenous opioids may be used, but often cause multiple undesirable side effects. Both epidural and intravenous options require hospitalization, greatly lengthening the hospital stay in order to provide adequate pain relief. New, improved analgesic techniques are needed to maximize patient well-being, postoperative rehabilitation, and ultimate surgical outcome.

Perineural Local Anesthetic Infusion

"Perineural local anesthetic infusion" or a "continuous peripheral nerve block" is a relatively novel analgesic option. This technique involves the percutaneous insertion of a catheter directly adjacent to the peripheral nerves supplying the affected joint. Local anesthetic is then infused *via* the catheter providing potent, site-specific analgesia with minor, if any, side effects. Unlike epidural catheters, perineural catheters may be used with new anticoagulants. Furthermore, perineural infusion does not require hospitalization, as do epidural infusion and intravenous opioids. Combining perineural catheters with portable infusion pumps, outpatients may experience the same level of analgesia previously afforded only to those remaining hospitalized. These attributes, along with others, make perineural infusion a potentially effective treatment for the debilitating and limiting pain following major joint replacement. The aim of this research was to determine if perineural local anesthetic infusion in the immediate postoperative period reduced discomfort, length of stay, and cost following total joint replacement surgery for osteoarthritis.

Background

The number of joint replacements has doubled for each of the past two decades, and is expected to continue to increase as the population ages.[5,6,8,9] These surgeries are among the most expensive hospital procedures, costing an average of $25,000 per case, and totaling over $12 billion annually in the United States.[6,10,11] Yet, while these procedures improve patients' functional status and reduce chronic joint pain, the prostheses rarely restore functional performance to a normal level.[12-15] Reflecting this, a NIH Consensus Conference found that, "potential capabilities of the [joint replacement]

patients are not being fully developed," and concluded that "future research should focus on… determining optimal short- and long-term rehabilitation strategies."[16]

Postoperative Rehabilitation

Physical therapy following surgery is a critical component of rehabilitation following shoulder, hip, and knee replacement.[17-23] Therapy is important to reverse the effects of immobilization on muscles and synovial joints, including muscular and cartilage atrophy, ligament weakening, and adhesion formation.[24] Because these damaging changes begin immediately following surgery, physical therapy is initiated as soon as possible, usually the day following surgery,[25] and often within a few hours of leaving the operating room.[21,26,27] Unfortunately, joint replacement is exceptionally painful, and inadequate analgesia severely limits patients' ability to adhere to their essential frequent and intensive physical therapy regimens.[28,29] To date, the most common analgesic methods include epidural infusion for lower extremity surgery and intravenous (IV) opioids for upper extremity procedures.

Epidural infusion of local anesthetic and/or opioids provides potent analgesia for lower extremity joint replacement.[30,31] Epidurals are associated with a decrease in postoperative pain and improvements in knee range-of-motion and time needed to reach therapy milestones.[19,30,32-34] However, epidural catheters have significant limitations: they limit ambulation by affecting both legs, cause urinary retention, and result in sympathectomy-induced hypotension.[30] But perhaps the most important factor leading to the growing obsolescence of epidural catheters is their contraindication for use with new anticoagulants.[35] These new anticoagulants, particularly low molecular weight heparin (e.g. enoxaparin), are given in the postoperative period to decrease the risk of

thromboembolism.[36-38] Unfortunately, these medications are associated with a high risk of epidural hematoma formation when administered with an epidural catheter in place.[39,40] This is a potentially catastrophic complication in which blood accumulates around the spinal cord at the location of the catheter may result in permanent paraplegia.[41] Because of the high risk of thromboembolism—estimated at up to 0.1%—following joint replacement procedures, the new potent anticoagulants are now routinely used, limiting their use for analgesia.[42]

Without epidural infusion, IV opioids are currently the analgesic standard-of-care. Unfortunately, this method provides inadequate pain relief during physical therapy in the immediate postoperative period.[43] The relatively new technique of perineural local anesthetic infusion provides potent, site-specific analgesia with minor, if any, side effects.[44-47] Unlike epidural catheters, perineural catheters may be used with new anticoagulants. Perineural infusion therefore offers the potential of fundamentally improving rehabilitation by providing potent analgesia in the immediate postoperative period.

Shoulder replacement. For shoulder replacement procedures, a perineural catheter is placed along the brachial plexus in an interscalene position. This procedure allows local anesthetic to be introduced to the nerves that innervate the shoulder girdle and capsule. Borgeat et al. demonstrated that interscalene perineural infusion provides superior analgesia to IV opioids following shoulder replacement.[48,49] Cohen et al. reported procedural success in a retrospective review of 100 patients who received interscalene perineural infusion following various shoulder procedures,[50] while other studies have examined different aspects of this technique, such as the optimal local

anesthetic delivery regimen.[51-56] However currently no investigations have been published which evalaute the potential effect of perineural infusion on hospitalization duration or postoperative physical therapy outcomes following shoulder replacement.

Hip replacement. Singelyn et al. demonstrated that a perineural infusion *via* a "lumbar plexus" catheter following hip replacement provides superior analgesia to IV opioids.[57,58] Additional investigations have examined different aspects of this technique, such as the optimal insertion technique.[59,60] As with shoulder replacement, no current data are available regarding the potential affect of perineural infusion on hospitalization duration or postoperative physical therapy outcomes following hip replacement.

Knee replacement. For knee replacement, a catheter is placed along the femoral nerve near the inguinal ligament, and three studies demonstrate that perineural infusion provides superior analgesia compared with IV opioids.[30,34,61] Unlike catheters following shoulder and hip replacement, some reports now suggest that femoral infusion improves postoperative rehabilitation.[30,34] Both Capdevila (France) and Singelyn (Belgium) demonstrated that compared with IV opioids, perineural infusion results in an additional 10-15° of knee flexion for up to 12 weeks following surgery,[30,34] but current physical therapy regimens in the United States emphasize functional outcomes such as independence in bed-to-bathroom transfers and ambulation distance.[25,29,62] These regimens enable patients to function independently at home and increase patient mobility, thereby decreasing the risk of thromboembolism and muscle atrophy. While Capdevila and Singelyn demonstrated that perineural infusion can influence postoperative rehabilitation, these studies failed to demonstrate a *functional* benefit for patients, and therefore have had little influence on clinical practice within the United States. Singelyn

did report that patients with perineural infusion ambulated nearly one day earlier than patients receiving IV opioids (3.5 ± 0.6 vs 4.3 ± 0.7 days, p = 0.02).[30] But, unfortunately, the distance walked was not reported, and patients in the United States ambulate within 24 hours of surgery—not 3-4 days later as reported in this study of patients in Belgium.

Primary endpoints. In contrast, this research study investigated *functional* rehabilitation outcomes following total joint replacement. For knee and hip replacements, the primary outcome variable was ambulatory distance in the afternoon following surgery (details follow in "Methods" chapter). Following shoulder replacement, no functional rehabilitation outcome measures exist since *active* motion of the shoulder joint is strictly prohibited for 2 - 6 weeks postoperatively to avoid capsular damage.[21,26] Therefore, the primary outcome variable was *passive* external rotation, with passive elevation a secondary variable. Optimizing these two motions is critical to avoid capsular and soft-tissue adhesions which limit the ultimate joint range-of-motion.[21,23,26] If perineural infusion improves patients' ability to perform their physical therapy regimen following shoulder, hip, and knee replacement, this procedure will help optimize ultimate joint function.[19-23] Additional benefits may follow, including reductions in hospitalization duration as well as a decreased incidence of deep venous thrombosis and pulmonary embolism.[63,64]

Hospitalization Duration

In the United States, the median duration of hospitalization for joint replacement procedures is 5 days, according to the American Academy of Orthopaedic Surgeons.[6,10,11] However, the range of hospital stay duration varies dramatically, up to 19 days in some reports.[27,65-67] Hospitalizations of more than one day primarily result from (1) intractable

pain requiring potent analgesia; (2) inability to function at home secondary to postoperative disability; and (3) patient comorbidities.[29,66-69] This research examined the impact of perineural infusion on the first two: postoperative pain and functional mobility. Although the effects of perineural infusion for patients with major cardiovascular comorbidities were not directly investigated, over 60% of patients presenting for joint replacement are reported to be free of moderate or severe illness.[66]

As noted previously, joint replacement results in severely debilitating pain that is exacerbated by the frequent and intensive physical therapy required for postoperative rehabilitation.[28,29] Consequently, patients are required to remain hospitalized for either epidural or IV opioid analgesics. In contrast to these forms of analgesia, perineural infusion does not require patients to remain hospitalized. Combining a perineural catheter with a portable infusion pump, an outpatient may theoretically experience the same level of analgesia previously afforded only to those remaining hospitalized. However, advancements in portable pump technology have only recently allowed for ambulatory perineural infusion.[70] The possibility of decreasing hospitalization duration following joint replacement using this new technique has not previously been investigated.

Additionally, patients' inability to function independently results in extended hospital stays. Home discharge criteria following hip and knee replacement in the United States usually include the requirements that patients ambulate 100 feet (30.3 m), move from a supine to standing position, and achieve bed-to-bathroom transfers independently.[25,29,62,67,69] Munin et al. reported a decrease of three days in hospital stay following hip and knee replacements by initiating rehabilitation on postoperative day 3

rather than day 7 (12 ± 2 vs. 15 ± 2 days, $p<0.001$).[67] These findings are consistent with the proposition of the present research: if perineural infusion improves patients' ability to perform their physical therapy and decreases the duration of time to reach functional therapy milestones, then hospital stays may be shortened.

Benefits of a shortened hospitalization are numerous for individual patients and society in general. The Centers for Disease Control and Prevention estimate nosocomial infections affect over 2 million patients annually, and cost more than $4.5 billion in 1992.[71,72] Other investigators report such infections to be the eighth leading cause of death in the United States.[73] Similarly, the Institute of Medicine estimated that there are 44,000 to 98,000 deaths annually due to error-prone institutional systems and mistakes by individual health care workers during patient hospitalization.[74] Other investigators have provided evidence to support this finding.[75,76] *For patients, shortening hospitalization and thereby decreasing the risk of nosocomial infection and harmful medical error is significant.*

For society, the potential cost-savings are enormous. Each joint replacement costs an average of $25,000, so the total health-care related annual cost exceeds $12 billion.[5,6,10,11,67] Charges for the joint implants and physician services encompass 27% of this total, but the remaining 73% covers hospitalization and ancillary services.[10,11] With the per diem hospital cost estimated at $3,000, the potential savings to society of shortening hospital stays must be estimated in the hundreds of millions of dollars (Table 1).[6,10,11,67]

Indeed, Mahoney et al. demonstrated a reduction in hospital stay of 2 days (18%) following knee replacement using epidural vs. IV opioid.[33] The present research used

portable pumps to allow patients to be discharged home with the analgesic benefits of perineural infusion which, unlike epidurals, may be administered on an outpatient basis. Capdevila et al. found that using femoral perineural infusion for 72 hours following knee replacement decreased stays in a rehabilitation center from 50 to 40 days ($p<0.05$).[34] Similarly, Singelyn et al. using lumbar plexus perineural infusion for 48 hours, reported a decrease in hospital stay from 21 to 17 days ($p<0.001$).[30] However, both studies were conducted in Europe where hospitalization is dramatically longer than in the United States. Additionally, as previously noted by two leaders in the specialty of Anesthesiology, since the average institutional stay of patients in the United States is less than a week, the European data do not suggest that hospitalizations in this country may be reduced with the use of perineural infusion.[77] Also, the effects of perineural infusion following shoulder and hip replacement on hospitalization duration have not been investigated. Therefore, the relationship between in- and out-patient perineural local anesthetic infusion and hospital length-of-stay remains unexamined for all joint replacement procedures.

Table 1. Potential annual hospital cost reduction for U.S. joint replacements.

Percentage of U.S. Procedures for which Perineural Infusion Applicable	Projected Cost Savings in U.S. Dollars Based on the Number of Hospitalization Days Reduced for Each Admission			
	1 Day	**2 Days**	**3 Days**	**4 Days**
10%	182,500,000	365,000,000	547,500,000	730,000,000
20%	365,000,000	730,000,000	1,095,000,000	1,460,000,000
30%	547,500,000	1,095,000,000	1,642,500,000	2,190,000,000
40%	730,000,000	1,460,000,000	2,190,000,000	2,920,000,000
50%	912,500,000	1,825,000,000	2,737,500,000	3,650,000,000

Calculations based on the following estimates: 500,000 procedures/yr, 5 days/ procedure, $25,000/procedure, hospital costs 73% of total charges. All figures in U.S. Dollars.

Ambulatory Total Joint Replacement

Previous investigations have demonstrated that perineural local anesthetic infusion may be provided to patients at home using small, portable infusion pumps. However, without exception, these studies have involved outpatients undergoing far less painful and invasive procedures compared with joint replacement.[44-46,78-81] Providing perineural infusion following joint replacement procedures has been described, but exclusively in patients remaining hospitalized for the duration of the infusion. The feasibility of converting joint replacement surgery into an overnight or ambulatory procedure using perineural local anesthetic infusion and a portable infusion pump has not been investigated.

This pilot study was designed to evaluate the feasibility of converting shoulder replacement into an ambulatory procedure and hip and knee replacement into an overnight hospitalization using perineural infusion and portable infusion pumps. Additional primary endpoints included postoperative ambulatory ability and shoulder joint mobility. Secondary endpoints included postoperative pain scores, oral and IV opioid requirements, sleep disturbances, and patient satisfaction.

METHODS

The investigation was divided into two phases. The first, or *Hospitalization* phase, required patients to remain as inpatients for the current minimum stay consistent with standard-of-care. The purpose of this phase was to evaluate and improve the protocol to allow for successful ambulatory or infusion, while having patients remain in the controlled environment of the hospital for at least one night (three following hip and knee replacement). To move from this phase to the next, five subjects with each type of joint replacement had to undergo successful infusion. "Successful infusion" was defined as a patient (1) receiving acceptable analgesia as measured using a numeric rating pain scale (NRS < 4) throughout POD 5 (7 for shoulder patients); (2) avoiding hospital readmission; (3) ambulating > 30 m; and following shoulder replacement, (4) achieving at least 50% of the surgeon's shoulder elevation and external rotation goals (defined below) in the recovery room and on POD 1 and 3.[82] The second, or *Ambulatory* phase, allowed patients to be discharged home earlier than is currently possible, if it was medically appropriate. For both phases, the collected data was analyzed separately for each joint.

Investigation Protocol

Enrollment

Subjects were patients undergoing total knee, hip, or shoulder replacement. The study was presented to eligible patients by the orthopedic surgery nurse facilitator in a preoperative visit within one week prior to surgery. As this health-care provider came into contact with the patient through routine clinical care, HIPAA requirements were met. If a patient expressed interest in study participation, the patient was provided with verbal

and written information regarding the investigation and written, informed consent was obtained. Selection for inclusion was not based on gender, race, or socioeconomic status.

Inclusion and Exclusion Criteria

Inclusion criteria for the trial were (1) undergoing unilateral primary knee, primary hip, or primary/revision shoulder replacement; (2) age 18 – 80 years; (3) postoperative analgesic plan that included perineural local anesthetic infusion; and (4) the availability of a "caretaker" who would remain with the patient from home discharge until perineural catheter removal. *Exclusion criteria* for the trial were (1) morbid obesity as defined by a body mass index > 40 (BMI=weight in kg / [height in meters]^2); (2) renal insufficiency (preoperative creatinine > 1.5 mg/dL); (3) chronic opioid use (use within the 2 weeks prior to surgery and duration of use > 4 weeks); (4) allergy to study medications (other than NSAIDs and acetaminophen); (5) history of opioid abuse; (6) inability to communicate with the investigators; (7) any known cardiopulmonary disease for shoulder patients; and (8) any comorbidity which results in moderate or severe functional limitation (as defined by an American Society of Anesthesiology Physical Status Classification > 2).[83] Of note, the American Society of Anesthesiology Physical Status Classification (ASA) has been used worldwide by anesthesia providers as an assessment of the preoperative physical health of patients since its inception in 1961.[83,84] This system is the standard instrument for classification of prognostic comorbidity, and has been used in nearly every clinical trial reported in the anesthesiology literature for over three decades.[85] ASA Class 1 is defined as "a normal healthy patient;" ASA Class 2 is defined as "a patient with mild systemic disease and no functional limitations;" and ASA

Class 3 is defined as "a patient with moderate to severe systemic disease that results in some functional limitation."[85]

Recruitment Feasibility

The orthopedic surgery nurse facilitator and the principal investigator have experience in prospectively recruiting individuals prior to total joint replacement surgery, as evidenced by previous preliminary studies. (provide a ref or state, unpublished data) In addition, the author was successful in recruiting over 200 patients for prior investigations involving ambulatory perineural local anesthetic infusion.[44-46,52,81,86-88] The orthopedic surgeon, Peter Gearen, MD, involved with the knee and hip replacements is also the Chairman of the Department of Orthopedic Surgery. The orthopedic surgeon, Thomas Wright, MD, involved with the shoulder replacements is a national leader involving this procedure. They both have had a continuously-growing surgical volume for the more than 20 years since joining the University of Florida faculty.

Knee and hip recruitment. Based on the past five years, the projected annual surgical volume for primary, unilateral hip and knee replacements is 120 patients, with approximately 80 patients of these meeting inclusion and exclusion criteria (divided equally between knee and hip replacements). And based on prior experience, the projected recruitment rate was approximately 50-60%, allowing enrollment of at least 25-30 subjects within the first year of study initiation.

Shoulder recruitment. Based on the past five years, the projected annual surgical volume for primary and revision, unilateral shoulder replacements is 40 patients, with approximately 30 patients of these meeting inclusion and exclusion criteria. And based on prior experience, the projected recruitment rate was approximately 50-60%, allowing

enrollment of at least 15-18 subjects per year and recruitment to be completed within the first year of study initiation.

Preoperative Management

Following written, informed consent, baseline pain scores were recorded using a Numeric Rating Pain Scale (NRS; 0-10, 0= absence of pain, 10= worst imaginable pain).[89] Prior to surgery, patients had a perineural catheter placed on the operative side. The anatomic location of the catheter depended upon the joint being replaced: a femoral catheter for knee replacement, psoas compartment catheter for hip replacement, or interscalene catheter for shoulder replacement. Standard noninvasive monitors were applied, and oxygen administered *via* a facemask. IV midazolam and fentanyl were titrated for patient comfort, while ensuring that patients remained responsive to verbal cues. The area that was subsequently covered by the catheter dressing was prepared with chlorhexidine gluconate and isopropyl alcohol (ChloraPrep One-Step, Medi-Flex Hospital Products, Inc., Overland Park, KS, USA), and then shaved with a surgical safety razor, if necessary.

Femoral catheter placement.[90] Patients were placed in a supine position. After sterile preparation and draping, a local anesthetic skin wheal was raised 1 cm lateral to the femoral arterial pulse along the inguinal crease. With the bevel directed cephalad, an 8.89 cm, 17 gauge, insulated needle (StimuCath, Arrow International, Reading, PA, USA) was inserted with the long axis of the needle in the parasagittal plane and 45º to the transverse and coronal planes. This needle was connected to a nerve stimulator (Stimuplex-DIG, B. Braun Medical, Bethlehem, PA, USA) initially set at 1.2 mA, 0.1 ms, and 2 Hz. Once the needle tip was through the skin and immediate underlying fascia, the

stylet was removed to allow for identification of a penetrated vessel. The needle was redirected, as needed, until quadriceps contractions were elicited with a current between 0.30 and 0.50 mA.

The 19 g catheter was then placed through the length of the needle and the nerve stimulator transferred from the needle to the catheter, which had a conducting wire through its length delivering current to its tip. The stimulating current was increased to 0.80 mA if necessary to retain muscle motion, and the catheter advanced 5 cm beyond the needle tip. If quadriceps motion decreased as the stimulating catheter was advanced, the catheter was withdrawn into the needle, the needle redirected or rotated, and the catheter readvanced. If there was resistance during catheter withdrawal, the needle was withdrawn until the catheter resistance resolved. If resistance impeded catheter advancement following 10 attempts, the catheter was removed from the needle and 20 mL of preservative-free D_5W was injected following a negative aspiration. If the catheter could not be placed following this maneuver the patient was withdrawn from the study.

Once a catheter had been successfully advanced 5 cm past the needle tip, the needle itself was withdrawn over the catheter, the catheter stylet removed, and the catheter tunneled subcutaneously cephalad to the inguinal ligament using the included needle stylet and 17 g insulated needle. The injection port was attached to the end of the catheter, the nerve stimulator attached to the injection port, and the minimum current resulting in muscle contraction noted. The catheter was secured with sterile liquid adhesive, an occlusive dressing, and an anchoring device (StatLock, Venetec International, San Diego, CA, USA) to affix the catheter hub to the patient.

Following negative aspiration, 40 mL of anesthetic solution was injected *via* the catheter with gentle aspiration between divided doses (3-5 mL/dose). The injectate contained mepivacaine, 1.5%, and epinephrine, 100 µg. After 30 min, terminal nerve blockade was evaluated and considered successful with a decreased sensation to cold temperature of the skin over the ipsilateral quadriceps muscle (measured with an alcohol swab comparing both thighs). Patients with a successful nerve block were retained in the study and taken to the operating room.

Psoas compartment catheter placement.[59] Patients were placed in the lateral recumbent position with their operative side up. After sterile preparation and draping, a skin wheal of local anesthetic was raised at the point of needle entry. This point was determined as follows. Two parallel lines were drawn: the first over the lumbar spinous processes, and a second through the posterior superior iliac spine. The intercrystal line was drawn connecting the two iliac crests. The intercrystal line was then divided into thirds between the two parallel lines. The point of entry was along this latter line at the intersection of the middle and lateral thirds. With the bevel directed caudad, a 102-mm, 18-gauge, insulated stimulating needle (Contiplex, B. Braun Medical, Bethlehem, PA) was inserted through the skin wheal perpendicular to all planes of the skin. This was connected to a nerve stimulator (Stimuplex-DIG) that was initially set at 1.2 mA, 0.1 ms, and 2 Hz. Continuous aspiration was applied to the syringe and the needle advanced until the forth lumbar transverse process was identified. The needle was then withdrawn 3 cm and redirected slightly caudad within the parasagittal plane to pass between the forth and fifth lumbar transverse processes. The insertion endpoint was quadriceps contraction (femoral nerve stimulation) elicited with a current between 0.30 and 0.40 mA. Fifteen

milliliters of D_5W was injected *via* the needle, and then a polyamide, nonsimulating catheter was inserted 2 cm past the needle tip. The needle was removed, leaving the catheter *in situ.*

Once a catheter was been successfully advanced 2 cm past the needle tip, the needle itself was withdrawn over the catheter, the catheter stylet removed, and the catheter tunneled subcutaneously medially past the line over the spinous processes using a 16 g angiocatheter.[91] The injection port was attached to the end of the catheter, the catheter itself was secured with sterile liquid adhesive, an occlusive dressing, taped up the back to the ipsilateral shoulder, and the catheter hub affixed to the patient using an anchoring device (StatLock).

Following negative aspiration, 15 mL of anesthetic solution was injected *via* the catheter with gentle aspiration between divided doses (3-5 mL/dose). The injectate contained mepivacaine, 1.5%, and epinephrine, 37.5µg. After 30 min, terminal nerve blockade was evaluated and considered successful with a decreased sensation to cold temperature of the skin over the ipsilateral quadriceps muscle (measured with an alcohol swab comparing both thighs). Patients with a successful nerve block were retained in the study and taken to the operating room.

Interscalene catheter placement.[52] Patients were placed in the supine position, with their heads turned slightly away from the operative side. After sterile preparation and draping, a local anesthetic skin wheal was raised over the groove between the anterior and middle scalene muscles, at the cephalad-caudad level of the cricoid cartilage. With the bevel directed anteriolaterally, an 8.89 cm, 17 gauge, insulated needle (StimuCath) was inserted with the long axis of the needle 45º to the parasagittal,

transverse, and coronal planes. This needle was connected to a nerve stimulator (Stimuplex-DIG) initially set at 1.2 mA, 0.1 ms, and 2 Hz. Once the needle tip was through the skin and immediate underlying fascia, the stylet was removed to allow for identification of a penetrated vessel. The needle was redirected, as needed, until deltoid or biceps motion is elicited with a current between 0.30 and 0.70 mA.

The 19 g catheter was then placed through the length of the needle and the nerve stimulator transferred from the needle to the catheter. If necessary, the stimulating current was increased to 0.80 mA to retain muscle contractions, and the catheter advanced 3-5 cm beyond the needle tip. If biceps or deltoid contractions decreased as the stimulating catheter was advanced, the catheter was withdrawn into the needle, the needle redirected or rotated, and the catheter readvanced. If there was resistance during catheter withdrawal, the needle was withdrawn until the catheter resistance resolves. If resistance impeded catheter advancement following 10 attempts, the catheter was removed from the needle and 20 mL of preservative-free D_5W was injected following a negative aspiration. If the catheter could not be placed following this maneuver the patient was withdrawn from the study.

Once a catheter was successfully advanced 3-5 cm past the needle tip, the needle itself was withdrawn over the catheter, the catheter stylet removed, and the catheter tunneled subcutaneously caudad towards the sternal notch using the included needle stylet and 17 g insulated needle. The injection port was attached to the end of the catheter, the nerve stimulator attached to the injection port, and the minimum current resulting in muscle contractions noted. The catheter was secured with sterile liquid

adhesive, an occlusive dressing, and an anchoring device (StatLock) to affix the catheter hub to the patient.

Following negative aspiration, 40 mL of anesthetic solution was injected *via* the catheter with gentle aspiration between divided doses (3-5 mL/dose). The injectate contained mepivacaine, 1.5%, and epinephrine, 100 µg. After 30 min, terminal nerve blockade was evaluated and considered successful with a decreased sensation to cold temperature of the skin over the ipsilateral deltoid muscle (measured with an alcohol swab comparing both shoulders). Patients with a successful nerve block were retained in the study and taken to the operating room.

Intraoperative Management

Patients received a standardized general anesthetic with sevoflurane in N_2O and O_2 These gasses were titrated for a Bispectral Index of 40-60 in order to provide adequate anesthesia while minimizing postoperative recovery duration.[92] Esmolol and hydralazine were used to provide hemodynamic stability, and opioids administered if necessary (fentanyl in 25 µg increments). The OR pharmacy provided the local anesthetic (ropivacaine 0.2%) used for the perineural infusion. The ropivacaine infusion (knees and hips: basal rate 8 mL/h, bolus dose 4 mL, lock-out period 30 min; shoulders: basal rate 7 mL/h, bolus dose 3 mL, lock-out period 60 min) was initiated using a portable infusion pump attached to the perineural catheter (knees and hips: Pain Pump II, Stryker Corporation, Kalamazoo, MI; shoulders: CADD-Legacy, Smiths Medical, St. Paul, MN). Just prior to emergence, a standard antiemetic (ondansetron, 4 mg, IV) was administered and IV morphine was titrated for a respiratory rate of 14. Upon emergence, patients were taken to the recovery room and then to the General Clinical Research Center (GCRC).

Postoperative Protocol: *Hospitalization* Phase

Medical management and physical therapy during hospitalization and following discharge home did not differ from the current standard-of-care. Vital signs and pain scores were recorded every 4 hours by GCRC nursing staff, except when the patients were sleeping.

Postoperative Analgesia

For the duration of the study, *all* patients received the current usual and customary oral and IV analgesics. These included scheduled oral acetaminophen (975 mg QID), and a nonsteroidal anti-inflammatory medication, or NSAID (knees/hips: enteric-coated aspirin at 650 mg QD; shoulders: celecoxib 100 mg BID) beginning the evening of postoperative day (POD) 0 and continuing for one week. For knee replacement patients, an oral time-release opioid was added beginning the evening of POD 0 (Oxycontin 10 mg BID). Additional analgesics, if needed for break-through pain, were dependent upon the NRS. Within the anesthesia literature, an NRS < 4 is considered mild pain, while an NRS = 4-5 is moderate, and an NRS > 5 is severe.[30,34,44-46,52,58,61,81,86-88] Therefore, for an NRS < 4 (mild pain) a low dose of immediate-release oral opioid was provided if the patient desired additional analgesia (oxycodone 5 mg q 30 min). For an NRS of 4 - 5 (moderate pain) a higher dose of immediate-release oral opioid was provided (oxycodone 10 mg q 30 min). And for an NRS > 5 (severe pain) IV morphine was administered (2-4 mg q 10 min).[82,93]

Physical Therapy

Patients underwent twice daily physical therapy sessions at 16:00 and 08:00 beginning the evening of surgery following shoulder replacement, and beginning at 08:00 the morning of POD 1 following knee and hip replacement.

Shoulder replacement. Both patients and their caretakers received instruction on rehabilitation exercises from a physical therapist. The primary indicator of functional outcome following shoulder replacement was range-of-motion, specifically elevation and external rotation.[50] For the first 2-6 weeks following surgery, patients underwent *passive* elevation and external rotation up to surgeon-defined maximums—or "goals"—to avoid damaging the rotator cuff.[21,26] These goals were defined intraoperatively with the repaired subscapularis muscle under direct vision to determine the maximum motion possible without suture line damage. For elevation, the patient's arm against the side of the body defined 0º, and elevation increased as the arm was raised (without elbow flexion) in the sagittal plane.[21,26] For external rotation, the measurement was performed with the elbow at the patient's side and the forearm at a 90º angle with the upper arm. The patient's hand directly in front of the patient defined 0º, and external rotation increased with lateral hand motion.[21,26] During range-of-motion measurement after surgery, patients were instructed to tell the therapist "when to stop" as determined by comfort level, and to always stop prior to an NRS > 8. Maximum-tolerated passive shoulder elevation and external rotation were recorded. Since patients' surgeon-defined "goals" differed, joint range-of-motion was analyzed as the percentage of the "goal" each individual patient achieved. For example, if the set goal was 30º, and the patient achieved 15º, then the variable used for analysis would equal 50%.

Knee and hip replacement. On POD 1, patients were instructed in an active/active-assisted exercise program that included ankle dorsiflexion/plantarflexion, isometric quadriceps sets, gluteal sets and knee flexion. Hip abduction/adduction, straight leg raises, supine short arc quadriceps, and seated long arc quadriceps exercises

were added in subsequent sessions. Transfer and bed mobility training was initiated along with gait training and activities of daily living with concentration on correct and safe technique, use of assistive equipment, and encouraging appropriate weight bearing. The goal was to ensure safe and independent transfers and ambulation in the home setting with the appropriate assistive device (four-leg walker). Strict hip precautions to ensure the stability of the hip joint require extensive caregiver training, and the observation of patient adherence to hip precautions is ongoing (following hip replacement).

Home discharge criteria following knee and hip replacement in the United States usually include the requirement that patients are able to ambulate at least 100 feet (30.3 m) to demonstrate adequate mobility to function within their own home.[25,29,62,67,69] The 6-minute walking test (6-MWT) was selected as the instrument to measure ambulation ability. The 6-MWT measures the maximum distance that a patient can walk in 6 min.[94] A 10 meter course was marked in a level, enclosed corridor and a chair placed at each end. Patients were transported to the start of the course by wheelchair and assisted into a standing position. Patients were instructed to walk from end to end at their own pace while attempting to cover as much ground as possible in six minutes. Patients were allowed to use their usual mobility aids, which for this study included a four-leg walker that is the standard device used following all knee and hip replacements.[25] A specifically-trained physical therapist from the Shands Hospital Department of Physical Therapy and Rehabilitation administered the 6-MWT using a stopwatch. Simple verbal encouragement may improve patient performance, therefore, the therapist encouraged patients every 30 seconds in a standardized manner, facing the patient and using one of two phrases: “You’re doing well” or “Keep up the good work.”[94,95] Patients were

allowed to slow or stop and rest during the walk, but were asked to resume walking as soon as they feel they were able. After six minutes, the distance walked was measured by the therapist and recorded on the data form within patients' medical charts.

The 6-MWT was originally developed as a measure of cardiovascular status.[96,97] The test has subsequently been used extensively and validated as a measure of functional mobility specifically following knee and hip replacement.[98-104] Multiple previous studies involving patients with osteoarthritis undergoing joint replacement have demonstrated that analgesia is a unique factor and that the 6-MWT is a valid and responsive measure of functional mobility specifically following knee and hip replacement.[98-104]

The 6-MWT has been demonstrated to have excellent test-retest reliability, with intraclass correlation coefficients from 0.94-0.96, and a low coefficient of variation (10.4%).[95,105-108] There are a number of other performance tests that may be used to measure functional mobility, but the 6-MWT is safer, easier to administer, better tolerated, and does not require extensive patient training.[94,105,109-111] For these reasons, the 6-MWT is the preferred test of functional mobility following knee and hip replacement for osteoarthritis.[98-104]

Hospital Discharge

Patients remained in the GCRC until they met specific, predefined discharge criteria, and were then discharged home, as early as the morning of POD 1 (shoulders) or 3 (knees and hips). Discharge criteria included an NRS < 4,[89] requiring no IV opioids in the previous 12 h, the ability to ambulate 30 m without assistance or dizziness, tolerating oral liquids without nausea or vomiting, SpO_2 > 95% on room air at a respiratory rate < 20, stable vital signs, and having no medical issues requiring continuing admission. In

addition, shoulder patients had to be able to reach >50% of their surgeon-defined maximum external rotation and elevation. Upon discharge, patients were given prescriptions for their oral analgesics and asked to fill these at a pharmacy prior to arriving at home.

Home Management

Patients were telephoned each evening until the night following catheter removal, as is standard practice for all ambulatory patients with a perineural infusion.[44-46,52,81,87,88] Information collected included pain scores (least, average, and worst NRS), oral opioid use, sleep quality, and analgesia satisfaction (scale of 0-10, "0"="very unsatisfied" and "10"="completely satisfied"). Gross sensory and motor functions of the operative extremity were reviewed. Patients were also questioned about symptoms of local anesthetic toxicity and infection, as well as the appearance of the catheter site/dressing. Also following discharge, a physical therapist provided home therapy once each day until POD 7 for hip and knee patients, and then once every-other day for two (hips) to four (knees) weeks, as is the current standard-of-care at the University of Florida. No outcome variables were measured during these home therapy sessions. Following shoulder replacement, patients received twice-daily physical therapy from their caretakers until their two-week postoperative visit with the orthopedic surgeon.

Perineural infusion continued until the evening of POD 4 (hips and knees) or 6 (shoulders), at which time the infusion was stopped and patients' caretakers removed the catheter with instructions from a physician *via* the telephone. Home removal has been used successfully for hundreds of previous patients,[44-46,52,81,87,88] and in a recent survey over 95% of patients responded that catheter removal was "easy" and that they would not

have preferred to return for removal.[112] However, if the patient desired, the patient could return to the hospital for catheter removal by the GCRC staff.

Postoperative Protocol: *Ambulatory* Phase

The purpose of the *Ambulatory* phase was to evaluate the feasibility of providing joint replacement on an ambulatory or 23-hour stay basis. The protocol was identical to the *Hospitalization phase* with one important exception: rather than remaining in the hospital for 1-5 days to receive perineural infusion, patients who meet all discharge criteria in the recovery room (shoulders) or in the morning of POD 1 (hips and knees) were discharged home.

RESULTS

Shoulder Replacement

Hospitalization Phase

Eight patients were enrolled in this phase and all had an interscalene catheter placed successfully. Five patients (63%) met all discharge criteria both in the recovery room and on POD 1, and were discharged home on POD 1. Three patients (37%) did not meet discharge criteria in the recovery room. The first because of an NRS=7 that required 4 mg IV morphine to reduce to an NRS=3. This patient met discharge criteria the following morning and was discharged home on POD 1. The second patient had an estimated blood loss of 2400 mL and therefore exceeded the maximum allowable for recovery room discharge. When first brought to a seated position in the GCRC following admission, the patient experienced dizziness and then lost consciousness for one minute, subsequently experienced no adverse events, and was discharged home on POD 2. The third patient had a history of asthma, but was erroneously included in the study (exclusion criteria: lung disease). Postoperatively, she did not meet recovery room discharge criteria with an oxygen saturation of 91% with supplemental oxygen. During the first postoperative evening she experienced an asthma exacerbation, developed a unilateral pleural effusion on the side of the perineural catheter, had her catheter subsequently removed, and was withdrawn from the protocol (data following catheter removal excluded from analysis). By POD 3 her effusion had resolved, and although she

continued to require IV opioids for analgesia without a perineural infusion, she chose to return home where only oral opioids were available.

Of the remaining seven subjects, two required IV morphine during their hospital admission (4 mg each). Following discharge, pain was well controlled for all patients without the use of IV opioids (Figure 1). Postoperative oral opioid requirements and sleep disturbances were minimal (Table 2). During physical therapy sessions, patients always reached at least 50% of the surgeon-defined range-of-motion goals, and often reached the maximum-allowed elevation and external rotation (Figure 2). Mean patient satisfaction with postoperative analgesia was 9.6 ± 1.1 on POD 1 (scale: 0-10, 10=completely satisfied) and 9.9 ± 0.2 on POD 7. All subjects underwent successful perineural infusion at home until their catheters were inadvertently dislodged (n=1, POD 4) or removed (n=6, POD 6).

Ambulatory **Phase**

Of the subsequent 6 patients enrolled in this second phase, all met discharge criteria in the recovery room following surgery. One patient was admitted overnight after operating room delays resulted in surgery completion in the late evening. She required no medical interventions overnight and was discharged home the following morning. The remaining five patients were all discharged home directly from the recovery room. Postoperative pain was well-controlled (Figure 1), oral opioid requirements and sleep disturbances were minimal (Table 2), *range-of-motion consistently reached surgeon-defined goals (Figure 2)*, and patient satisfaction was 9.9 ± 0.2 on POD 1 and 9.9 ± 0.2 on POD 7. All subjects underwent successful perineural infusion at home until their catheters were inadvertently dislodged (n=1, POD 4) or removed (n=5, POD 6).

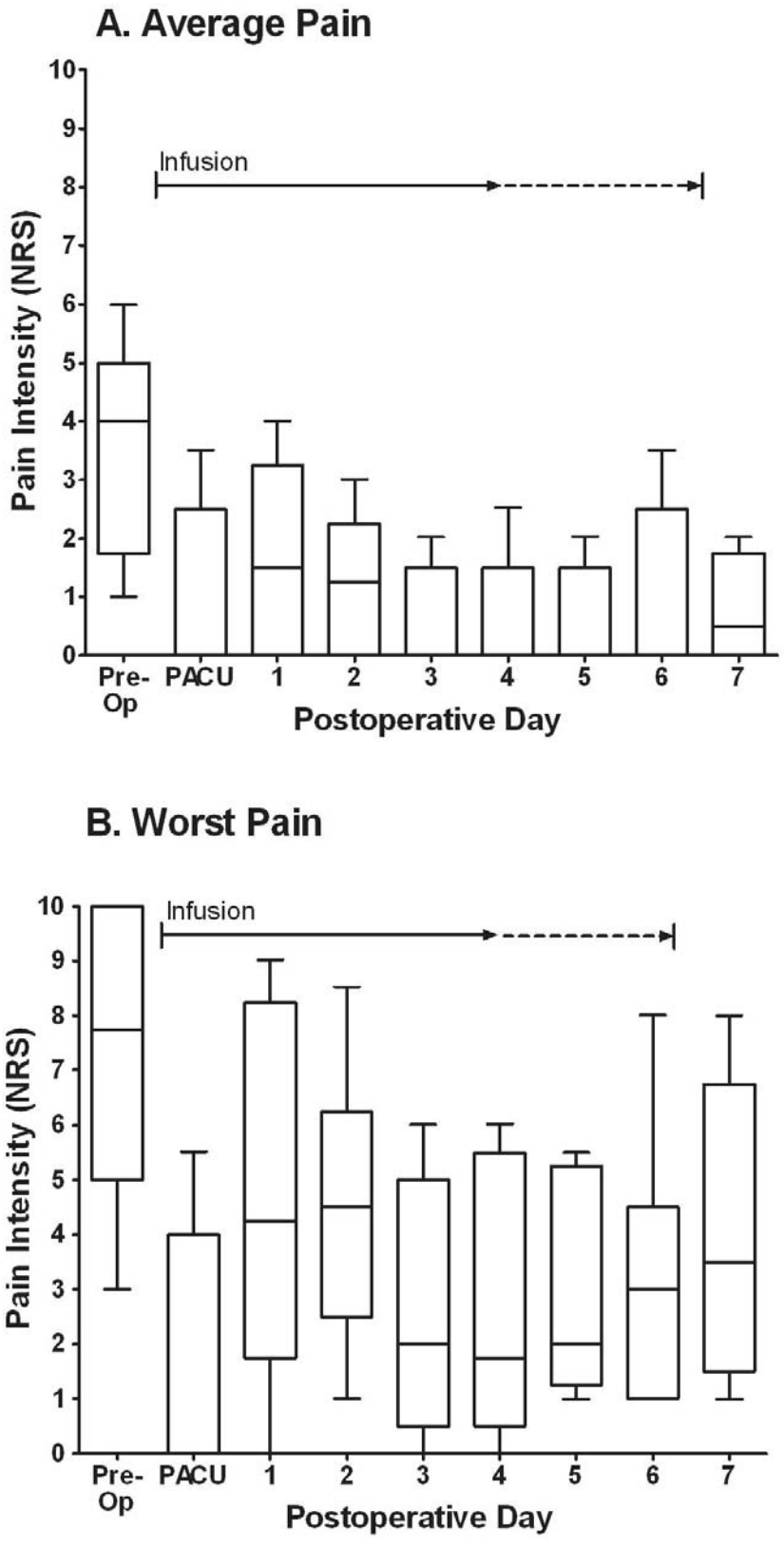

Figure 1. Numerical Rating Pain Scores Following Total Shoulder Replacement.

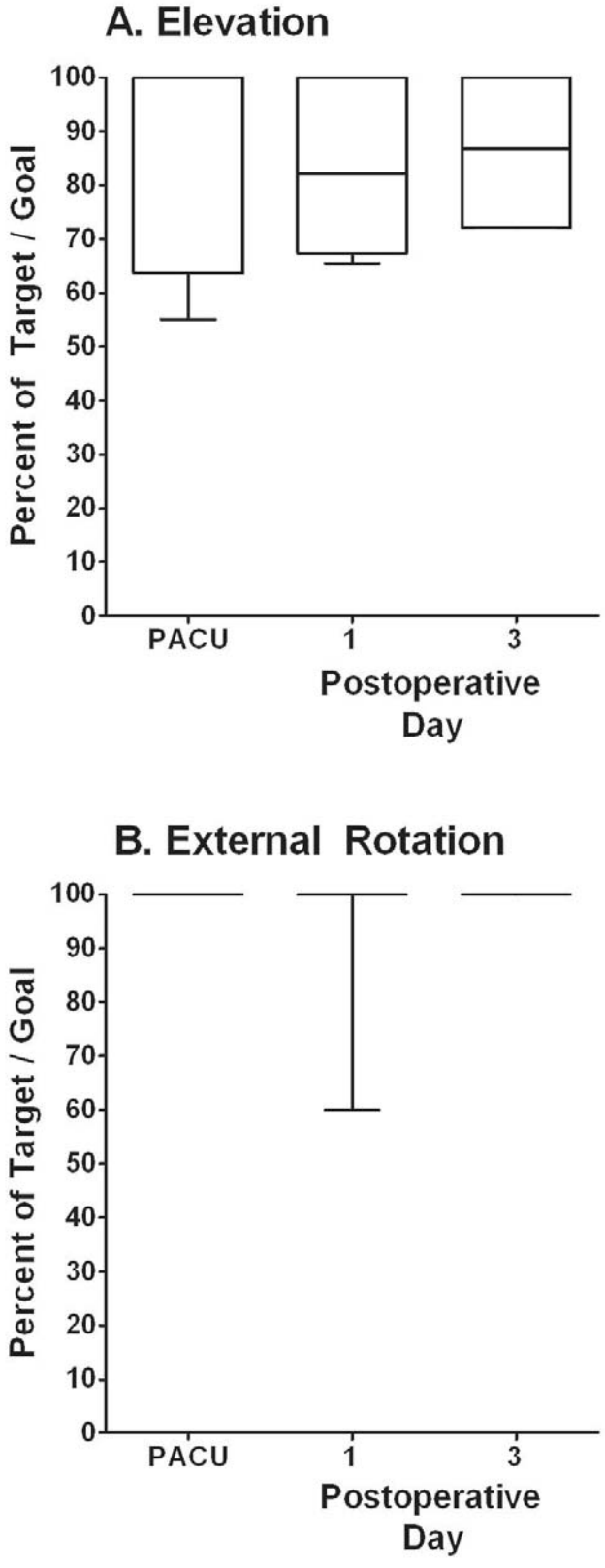

Figure 2. Shoulder Mobilization Following Total Shoulder Replacement

Caretakers for patients in both groups reported no difficulty removing catheters at home. There were no pump malfunctions or alarms and all infusion pumps were returned to the hospital *via* the postal service.

Table 2. Oral opioid consumption and sleep disturbances following shoulder replacement.

	Postoperative Day							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Oral opioid tablet consumption*	0 ± 0	0.5 ± 2.5	0 ± 2.9	0 ± 2.9	0 ± 3.5	0 ± 3.2	0 ± 2.4	3 ± 1.7
Patients reporting difficulty sleeping	2	1	0	0	1	0	1	
Awakenings for each patient	0 ± 2.7	0 ± 0.8	0 ± 0	0 ± 0.9	0 ± 1.4	0 ± 0	0 ± 0	

Figures are presented as mean ± SD. * Opioid tablets consisted of oxycodone 5 mg.

Knee Replacement

Hospitalization Phase

Seven patients were enrolled in this phase and all had a femoral catheter placed successfully. Five patients (71%) met all discharge criteria by the afternoon of POD 1, and were discharged home on POD 3, per protocol. Two patients (29%) did not meet discharge criteria on POD 1. Knee pain limiting ambulation to less than 30 m was the limiting factor for both patients. However, for one patient it was determined that her hospital-based infusion pump had malfunctioned and she had not received any local anesthetic for all of POD 1 (note that there were no malfunctions of the portable infusion pumps). Both patients ambulated more than 30 m by the morning of POD 2.

Following discharge, pain was well controlled for all patients without the use of IV opioids (Figure 3). Postoperative oral opioid requirements and sleep disturbances were minimal (Table 3). During physical therapy sessions, once patients reached the 30 m threshold, they never fell back below this distance during subsequent attempts (Figure 4).

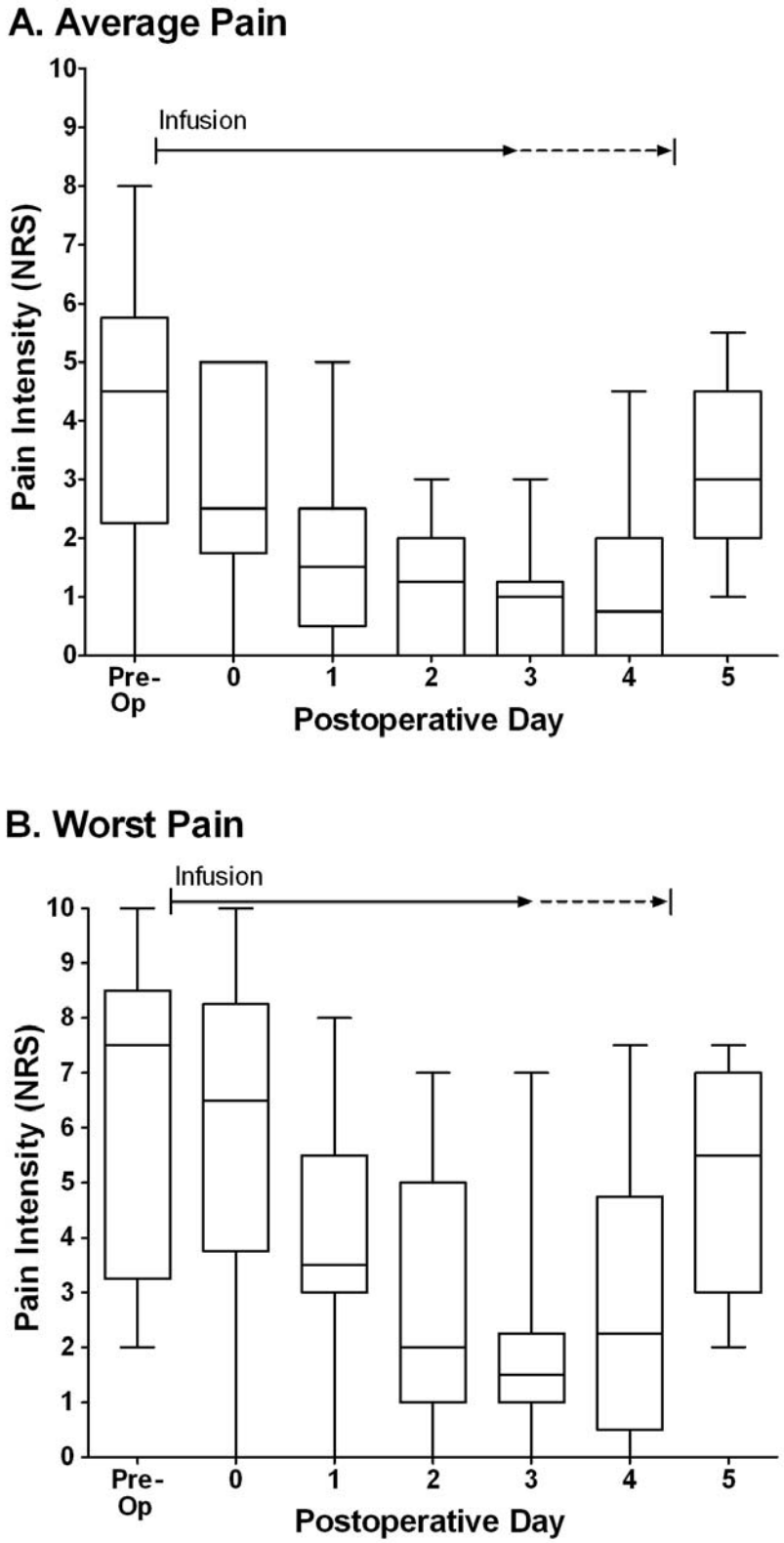

Figure 3. Numerical Rating Pain Scores Following Total Knee Replacement.

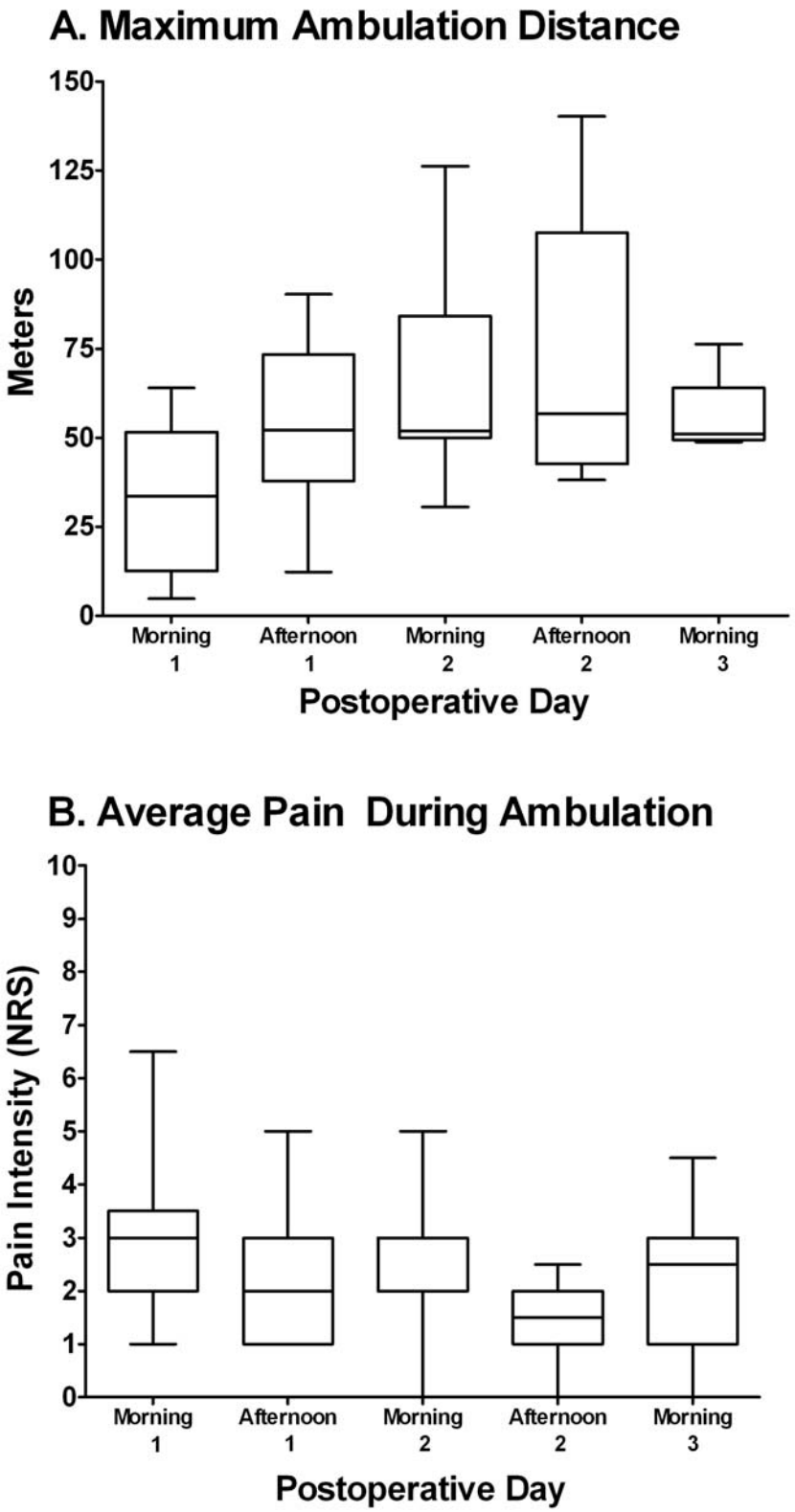

Figure 4. Rehabilitation Outcomes Following Total Knee Replacement.

Mean patient satisfaction with postoperative analgesia was 9.6 ± 1.0 on POD 1 and 9.0 ± 1.7 on POD 5. All subjects underwent successful perineural infusion at home until their catheters were removed on POD 4. Since 6 of 7 patients in this phase had limited ambulation the morning of POD 1 as a result of dizziness upon standing (presumably secondary to hypovolemia), the intraoperative protocol was altered for the following phase: a colloid—hetastarch—was infused for all patients (15 mL/kg).

***Ambulatory* Phase**

Of the subsequent 5 patients enrolled in this second phase, all met discharge criteria in the morning of POD 1 and were discharged home at that time. Postoperative pain was well-controlled (Figure 3), oral opioid requirements and sleep disturbances were minimal (Table 3), and patient satisfaction was 9.8 ± 0.4 on POD 1 and 9.8 ± 0.5 on POD 5. All subjects underwent successful perineural infusion at home until their catheters were removed on POD 4. Caretakers for patients in both groups reported no difficulty removing catheters at home.

Table 3. Opioid requirements and sleep disturbances following knee replacement.

	Postoperative Day					
	PACU	**1**	**2**	**3**	**4**	**5**
Oral opioid tablet consumption (tabs)*	1 ± 0	10 ± 2.5	7 ± 3.4	6 ± 2.9	4 ± 1.5	12.5 ± 3.2
IV morphine consumption (mg)	20 ± 8.9	0 ± 10	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Patients reporting difficulty sleeping	3	1	0	0	2	
Awakenings for each patient	0 ± 2.7	0 ± 0	0 ± 3.0	0 ± 0	0 ± 4.0	

Figures are presented as mean ± SD.

* Oral opioid tablets consisted of oxycodone 5 mg (this excludes the regularly-scheduled Oxycontin, 10 mg, which all patients received twice each day).

Hip Replacement

Hospitalization Phase

Seven patients were enrolled in this phase and all had a psoas compartment catheter placed successfully. Five patients (71%) met all discharge criteria by the afternoon of POD 1, and were discharged home on POD 3, per protocol. Two patients (29%) did not meet discharge criteria on POD 1. Hip pain limiting ambulation to less than 30 m was the limiting factor for both patients. Both patients ambulated more than 30 m by the morning of POD 2.

Following discharge, pain was well controlled for all patients without the use of IV opioids (Figure 5). Postoperative oral opioid requirements and sleep disturbances were minimal (Table 4). During physical therapy sessions, once patients reached the 30 m threshold, they never fell back below this distance during subsequent attempts (Figure 6). Mean patient satisfaction with postoperative analgesia was 9.6 ± 0.9 on POD 1 and 9.6 ± 0.9 on POD 5. All subjects underwent successful perineural infusion at home until their catheters were removed on POD 4. Since 5 of 7 patients in this phase had limited ambulation the morning of POD 1 as a result of dizziness upon standing (presumably secondary to hypovolemia), the intraoperative protocol was altered for the following phase: a colloid—hetastarch—was infused for all patients (15 mL/kg).

Ambulatory Phase

Of the subsequent 5 patients enrolled in this second phase, all met discharge criteria in the morning of POD 1, and all but one were discharged home at that time. One patient had a childcare provider cancel at the last minute, and so his spouse asked that he not be discharged until she could get help in caring for their three young children. This patient

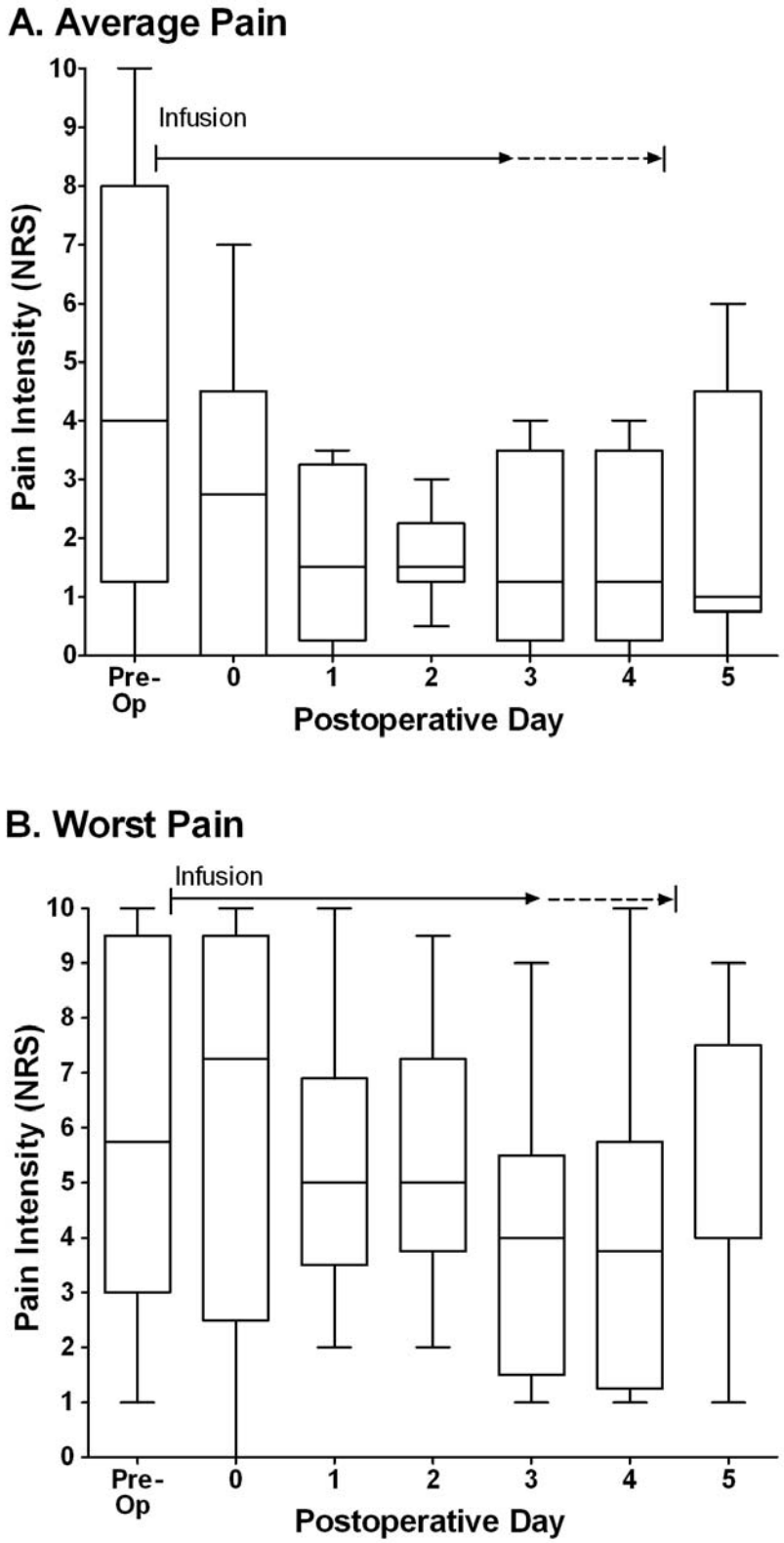

Figure 5. Numerical Rating Pain Scores Following Total Hip Replacement.

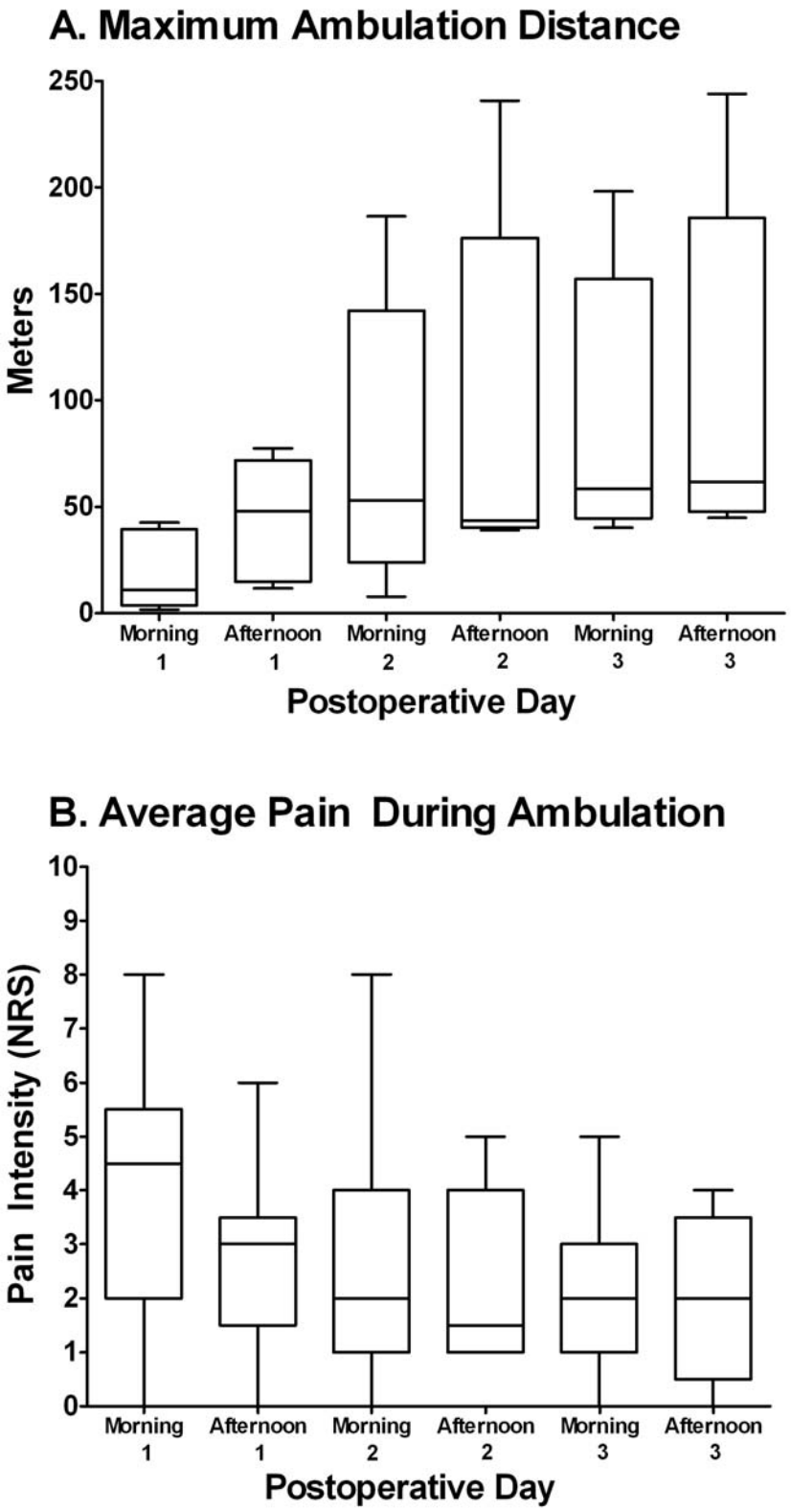

Figure 6. Rehabilitation Outcomes Following Total Hip Replacement.

required no medical interventions during his hospitalization and was discharged home on POD 3. For all five patients, postoperative pain was well-controlled (Figure 5), oral opioid requirements and sleep disturbances were minimal (Table 4), and patient satisfaction was 9.3 ± 1.0 on POD 1 and 9.9 ± 0.3 on POD 5 All subjects underwent successful perineural infusion at home until their catheters were removed on POD 4. Caretakers for patients in both groups reported no difficulty removing catheters at home.

Table 4. Opioid requirements and sleep disturbances following hip replacement

	Postoperative Day					
	PACU	**1**	**2**	**3**	**4**	**5**
Oral opioid tablet consumption (tabs)*	2.0 ± 1.0	10.0 ± 4.5	7.0 ± 5.5	6.0 ± 4.0	4.0 ± 1.5	8.5 ± 3.5
IV morphine consumption (mg)	20 ± 7.0	0.0 ± 2.0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Patients reporting difficulty sleeping	3	0	0	0	2	
Awakenings for each patient	0 ± 1.9	0 ± 0	0 ± 0	0 ± 0	0 ± 3.0	

Figures are presented as mean ± SD.
* Oral opioid tablets consisted of oxycodone 5 mg.

DISCUSSION

This pilot study was designed to evaluate the feasibility of converting shoulder replacement into an ambulatory procedure and hip and knee replacement into an overnight hospitalization using perineural local anesthetic infusion and portable infusion pumps. Additional primary endpoints included postoperative ambulatory ability and shoulder joint mobility. Secondary endpoints included postoperative pain scores, oral and IV opioid requirements, sleep disturbances, and patient satisfaction.

Early Home Discharge

The results of this pilot study suggest that for patients free of cardiopulmonary disease, total shoulder replacement on an ambulatory basis is possible when perineural interscalene infusion is provided for analgesia. In addition, these results suggest that total knee and hip replacement may be performed with a single overnight hospital stay by providing perineural femoral or psoas compartment infusion, respectively. Postoperative pain was well-controlled with baseline and breakthrough pain intensity below levels previously reported for much smaller ambulatory orthopedic procedures (NRS<4) .[113] This degree of analgesia was attained without the need for IV opioids, and contributed to a low incidence of sleep disturbances and high level of patient satisfaction.

Postoperative Shoulder Mobility and Ambulatory Ability

Following total shoulder replacement, patients achieved greater than 50% of the surgeon-defined maximum elevation and external rotation without exception at all time

points, and often reached 100% of this goal. Following total knee and hip replacement, patients ambulated over 30 meters the day following surgery in nearly all cases. The patients of this pilot study attained more than 3 times the degree of shoulder mobility and ambulatory distance compared with historic institutional control subjects, and this degree of mobility was achieved with pain scores less than half of historic controls.[114,115] Therefore, the results of this pilot study suggest that perineural infusion may not only decrease hospitalization duration, associated costs, and potentially reduce the risk nosocomial infection, but may also improve patients' ability to perform their postoperative rehabilitation and optimize ultimate joint function.

Appropriate Patient Selection

While this evidence demonstrates that joint replacement may be performed as an ambulatory or 23-hour procedure, it does not define the appropriate subset of patients and incidence of complications associated with this practice. For this investigation, patients with any known heart or lung disease, or a baseline oxygen saturation of less than 96% were excluded from the shoulder study since interscalene perineural infusion has been shown to cause frequent ipsilateral diaphragm paralysis,[116] although the effect on overall pulmonary function may be minimal for relatively healthy patients receiving a dilute ropivacaine infusion.[54] Related to this, one patient with a history of asthma was erroneously enrolled in the present study. She developed a pleural effusion on the same side as her perineural infusion that resolved with infusion discontinuation. Similar pulmonary complications have previously been associated with interscalene perineural infusion in hospitalized and ambulatory patients.[117,118] In using the strict exclusion criteria of this study, it is not the author's intention to suggest that inclusion of patients with any cardiopulmonary disease is an unsafe practice. Rather, the author prefers

cautious application of this technique until additional investigation of hospitalized, medically supervised patients documents its safety.[119] Because not all patients desire, or are capable of accepting, the extra responsibility that comes with the catheter and pump system, appropriate patient selection will be crucial for safe ambulatory local anesthetic infusion.

In this pilot study, there were no medical complications attributable to providing perineural infusion at home following joint replacement. However, the small number of patients does not permit us to draw definite conclusions about its relative safety. The technical complication of inadvertent catheter dislodgement occurred in two patients with interscalene catheters on POD 4, and both reported subsequent increases in baseline and breakthrough pain, oral opioid requirements, and pain during physical therapy. These patients reported that they could not reach the same elevation and external rotation following dislodgement as they had the day prior to dislodgement. However, since dislodgement occurred following the final objective measurement of elevation and external rotation by an investigator on POD 3, to what degree infusion termination affected shoulder mobilization remains unknown. Should a catheter dislocation or infusion pump malfunction occur earlier, patients may be at high risk of experiencing severe surgical pain unresponsive to oral opioids, requiring hospital readmission. For this reason, we required patients to remain within two hours of the hospital for the first week following surgery. Related to this issue, patients with heart disease were excluded from participation out of concern that acute, severe pain could trigger an adverse cardiac event.

As with most surgical procedures, postoperative pain following joint replacement decreases with time. The benefits of providing improved early analgesia with perineural

infusion must be balanced against the associated risks. While baseline and breakthrough pain did increase following catheter removal/dislodgement on POD 4-6, the increases were minimal (Figures 1, 3, and 5). Therefore, the optimal infusion duration following joint replacement remains undetermined. Similarly, we based our choice of local anesthetic[53] and infusion pump settings on published data involving bupivacaine infusion[51] and less-extensive/invasive ambulatory orthopedic procedures[52] At this time, the optimal ropivacaine concentration, basal rate, bolus dose volume, and lockout time all remain unexamined following joint replacement.

Future Research

As a pilot feasibility study, a control group was not included in the investigative design. Considering the well-documented acute pain experienced by patients following joint replacement and the results of the present study, there is little doubt that perineural local anesthetic infusion provided analgesia allowing discharge directly from the recovery room or on POD 1. What remains unknown is the degree of sustained benefit that perineural infusion will provide following joint replacement For example, based on our experience, the amount of elevation and external rotation achieved by subjects of the present study far exceeds the mobility of previous patients using IV opioids as their primary analgesic.[114,115] To document and quantify this improvement requires a randomized, double-masked, placebo-controlled study. The research from this pilot study led to the implementation of three such randomized clinical trials that are currently ongoing at the University of Florida (Appendix).

Conclusion

The results of this pilot feasibility study suggest that shoulder, knee, and hip replacement may be performed on an outpatient or overnight basis. Furthermore,

perineural infusion provides potent analgesia which allows for increased patient shoulder mobility and ambulatory capability. Additional data are required to define the appropriate subset of patients and assess the incidence of complications associated with this practice. Further research is necessary to define the specific benefits of this treatment modality.

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BIOGRAPHICAL SKETCH

My interest in clinical research began during my undergraduate education at Pomona College. My dual major of anthropology and public policy analysis exposed me to investigations involving the social sciences, and my thesis involving nonverbal communication between the sexes was my first practical research experience. Following graduation with Phi Beta Kappa and cum laude honors, I was admitted to the University of California at San Francisco for medical school. During a clinical elective in a rural central Oregon town, I encountered a recently introduced prenatal-care program for low-income women. I initiated an independent research project investigating the relationship between prenatal care and birth outcomes, comparing birth outcomes prior to and then following the program's inception. This retrospective cohort study led to a thesis commensurate with the master's degree, and I graduated with the "MD with Thesis" degree, with honors.

Although residency in anesthesiology at the University of California at San Francisco trained me to administer all types of anesthesia, my passion for regional anesthesiology and academic medicine led me to pursue post-doctoral training. My specific interest in perineural local anesthetic infusion, or "continuous peripheral nerve blocks," brought me to the University of Florida where Dr. Kayser Enneking is a leader in developing this relatively new analgesic technique. It was during this fellowship year that my enthusiasm for research was matched with clinical opportunity. Although the fellowship requirements included work on one academic endeavor, I initiated multiple

projects during this year in addition to my intensive clinical training. Working closely with Dr. Enneking, I designed and completed multiple randomized clinical investigations and a laboratory study.

After joining the faculty at the University of Florida as an Assistant Professor, I continued the research that I had started during my fellowship year involving perineural infusion. These previous studies involving perineural infusion led me towards outcomes-oriented rehabilitation research. I was fortunate to find two mentors with an enormous amount of expertise in this area: Drs. Pamela Duncan and Krista Vandenborne, both with the University of Florida. Their guidance has proven invaluable to both my education and clinical research following my fellowship.

While my experiences at the University of Florida confirmed my passion for clinical research, they also illuminated my lack of formal preparation for this endeavor. I therefore applied, and was accepted, to the university's Advanced Postgraduate Program in Clinical Investigation (APPCI) with Dr. Vandenborne as my mentor. This program is supported by a Clinical Research Curriculum Award (K30) from the NIH, and includes three years of didactic and related clinical work resulting in a master,s degree in medical sciences with a concentration in clinical investigation.

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