Adductor Canal Nerve Versus Femoral Nerve Blockade for Pain Control and Quadriceps Function Following Anterior Cruciate Ligament Reconstruction With Patellar Tendon Autograft: A Prospective Randomized Trial

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Purpose: To compare femoral nerve blockade (FNB) versus adductor canal nerve blockade (ACB) for postoperative pain control and quadriceps muscle function in patients undergoing anterior cruciate ligament (ACL) reconstruction with patellar tendon autograft. **Methods:** A randomized therapeutic trial of 90 patients undergoing ACL reconstruction with patellar tendon autograft was conducted comparing ACB versus FNB at 24 hours, 2 and 4 weeks, and 6 months postsurgery. Early outcome measures included average pain score and morphine equivalent units (milligrams) consumed, quadriceps surface electromyography, straight leg raise, and ability to ambulate without assistive devices. The 6-month outcome measures included knee range of motion (ROM), isokinetic knee extension peak torque, single-leg squat, and single-leg hop performance. Complications were recorded throughout the study for the development of anterior knee pain, knee extension ROM loss, deep vein thrombosis, and graft failure. Mixed-model analysis of variance and Mann-Whitney *U* tests were performed using an alpha of .05. **Results:** Quadriceps surface electromyography deficits were higher for FNB at 24 hours ($P < .001$) and 2 weeks ($P < .001$) when compared with the ACB group. There were no between-groups difference for subjective pain ($P = .793$) or morphine consumption ($P = .358$) within the first 24 hours of surgery. A higher percentage of patients in the ACB group met the full ambulation criteria at 4 weeks compared with the FNB group (100% vs 84.2%, $P < .001$). No between-group differences were observed at 6 months; however, the rate of knee extension ROM loss was higher for the FNB group versus the ACB group (21.1% vs 5.0%, $P = .026$), respectively. **Conclusions:** ACB was as effective as FNB at providing pain control while eliciting fewer quadriceps muscle activation deficits and fewer postoperative complications. Based on previous evidence and the results of this study, we recommend the use of ACB over FNB for the analgesic management of patients undergoing ACL reconstruction with patellar tendon autograft. **Level of Evidence:** Level I, prospective randomized controlled trial.

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The number of anterior cruciate ligament (ACL) reconstructions performed in outpatient centers has risen dramatically over recent decades. In 1994, for example, approximately 43% of all ACL reconstructions were performed in outpatient settings, whereas that estimate rose to just over 94% in 2014.[1] Because of these changes in surgical practice, the need to effectively manage postoperative pain is key to optimizing patient satisfaction and clinical outcomes. Furthermore, considering the detrimental effects that ACL reconstruction often has on quadriceps muscle function,[2-4] it is critical to explore means of restoring quadriceps strength after surgery owing to the muscle's inherent role in recovery and function.[5,6]

Traditional anesthesia protocols have relied on femoral nerve blockade (FNB) to manage postoperative pain after ACL reconstruction, and the evidence supports its ability to reduce pain and opioid consumption after knee surgery.[7] This procedure, however, is not without complications, which can range from minor quadriceps weakness to permanent and debilitating nerve palsies.[8,9] In patients undergoing total knee arthroplasty, previous studies suggest that FNB was responsible for persistent quadriceps muscle weakness and increased fall risk.[10] Considering the consistent reports of quadriceps muscle weakness[11-14] and high reinjury rates[15] associated with ACL reconstruction, it is imperative to explore potential ways to avoid these adverse events.[16]

Recently, the motor branch sparing adductor canal nerve blockade (ACB) has gained attention within the orthopedic and anesthesiology communities as a potential means of preserving quadriceps muscle strength after surgery.[17] Although early clinical trials comparing these 2 treatment options (FNB vs ACB) have shown varied results, no studies to date have observed pain control and quadriceps function collectively when comparing the relative benefits of these nerve blockades. The purpose of this study was therefore to compare FNB versus ACB for postoperative pain control and quadriceps muscle function in patients undergoing ACL reconstruction with patellar tendon autograft. We hypothesized that patients receiving ACB would exhibit improved quadriceps function and similar pain control when compared with patients receiving FNB.

Methods

A randomized therapeutic trial was conducted at the University of Texas at Houston, which adheres to the Consolidated Standards of Reporting Trials Guidelines (Table 1). Institutional review board approval was received through the University of Texas Medical School, Houston, Texas. Verbal and written consent were obtained for all eligible participants undergoing ACL reconstruction with patellar tendon autograft from a single board-certified orthopedic surgeon (W.R.L.) between February 2016 and January 2017. Participants followed a standardized weightbearing rehabilitation protocol supervised by a licensed physical therapist that included cryotherapy and a progressive strengthening, balance, and agility program. All participating physical therapists completed protocol training for the standardized rehabilitation program and were blinded to patient group.

Table 1. Baseline Patient Demographics

Variable	FNB (n = 38)	ACB (n = 40)	*P*
Age, yr	24.4 ± 8.8	21.0 ± 7.3	.151
Gender, % men	52.6	57.5	.228
Height, in.	68.3 ± 3.8	69.0 ± 3.9	.500
Weight, lb	162.8 ± 34.4	169.4 ± 32.7	.537
Body mass index	24.5 ± 4.2	24.9 ± 4.7	.944
Meniscus repair, %	76.3	80.0	.621
Cartilage injury, %	5.3	10.0	.370
Injury to surgery, wk	3.2 ± 1.9	2.9 ± 2.2	.846

NOTE. Values reported as mean ± standard deviation. Statistical significance at $\alpha = .05$.

Participants

Patients between the ages of 15 and 50 were screened for eligibility before surgery in the outpatient surgical center (Table 1). Those agreeing to participate were assigned to 1 of 2 parallel treatment groups (ACB vs FNB) by use of an electronic random number generator (Microsoft Excel; Microsoft, Redmond, WA). Exclusion criteria for participation were revision ACL reconstruction, ACL repair, multiple-ligament reconstruction, and full-thickness cartilage defects that prevented adherence to the immediate weightbearing and range of motion rehabilitation protocol. Patients with concomitant meniscus body repairs were included because this did not alter the postoperative rehabilitation and was considered among the baseline surgical demographics between groups. Patients were examined at 24-hours, 2- and 4-week, and 6-month postoperative time frames to determine the early and late effects of nerve blockade after surgical reconstruction.

Nerve Blockade

A board-certified anesthesiologist (J.W.) performed all nerve blocks in the preoperative holding area with the patient supine. Ultrasound-guided FNB (30 mL of 0.2% ropivacaine with 100 mcg clonidine using a 22-gauge 40-mm ProBloc II insulated needle [Kimberly-Clark, Roswell, GA]) was introduced below the inguinal ligament using a high-frequency linear 6- to 15-MHz ultrasound transducer (X-porte; Fuji-Film SonoSite, Bothell, WA) with stimulator confirmation. Similarly, ultrasound-guided ACB (15 mL of 0.2% ropivacaine with 100 mcg clonidine using a 22-gauge 80-mm ProBloc II insulated needle; Kimberly-Clark) was performed at the midthigh with the probe positioned in cross-section of the saphenous nerve at the midpoint between the patella and the inguinal crease.

Surgical Procedure

An anatomic single-bundle ACL reconstruction was performed as previously described by Brown et al[18] using an autologous bone-patellar tendon-bone graft harvested from patients' ipsilateral knee. Blunt dissection of the central one-third of the patellar tendon was performed using an oscillating bone saw (Stryker, Kalamazoo, MI) and a one-quarter inch curved osteotome. The femoral tunnel was drilled independently of the tibial tunnel within the center of the native ACL footprint[19] through the accessory anteromedial portal. The anteromedial tibial

tunnel was drilled using a retro-reamer (Arthrex, Naples, FL) through the residual tibial footprint.[20] The graft was shuttled into the joint by retrieving the suture loop in the femoral tunnel and looping the passing sutures from the ACL graft through the suture loop and out the lateral thigh. The femoral side of the graft was fixated using an interference screw; the tibial side was fixated with either aperture (interference screw) or suspensory fixation (6.5 × 25 mm post). Before tibial fixation, the graft was tensioned between 10 and 20 N, the knee was cycled 15 times, and the graft was retensioned if necessary. Once the graft was tensioned, the arthroscope was inserted into the joint to ensure that wall and roof impingement did not occur.

Pain control was assessed after surgery by a registered nurse blinded to group in the postanesthesia care unit (PACU) using a self-reported numeric pain rating scale (NPRS)[21,22] and tracking consumption of all oral and intravenous morphine equivalents (milligrams). Both variables were recorded hourly until the patient was discharged from the PACU. Mean pain scores (0-10) and morphine equivalent units (milligrams) consumed throughout the PACU stay were used for statistical comparison.

Early Postoperative Outcome Measures

A blinded physical therapist with more than 10 years of clinical and research experience conducted all postoperative outcome assessments. Quadriceps muscle activation, straight leg raise, and ambulation status were assessed at the 24-hour, 2-week, and 4-week postoperative time frames. Quadriceps muscle activation was examined using surface electromyography (sEMG; Win Health Medical, Alnwick, UK) of the vastus medialis oblique muscle using previously reported methods.[23] Peak sEMG activity was recorded in microvolts on the surgical and contralateral limbs while performing 5 maximal effort isometric contractions in full knee extension. Measurement sensitivity was 0.1 μV root mean square with an accuracy of 4% ± 0.3 μV at a sampling rate of 200 Hz. Intrarater reliability was acceptable using these methods (intraclass correlation = .77; standard error of the mean = 7.6 μV). Statistical analysis was performed using the quadriceps EMG deficit (microvolts) of the contralateral limb minus the surgical limb.

The straight leg raise assessment was performed in a standardized long-sitting position with well knee flexed to 90°. Patients were asked to complete 30 repetitions of straight leg raises with a small bolster supporting the heel using the following criteria: (1) perform with no visible quad lag, (2) reach the height of the opposite tibial tubercle, and (3) maintain a controlled rate of 30 Hz for the ascending and descending phases. Subjects were given verbal instruction before performing the test according to the criteria previously outlined; 1 verbal warning was allotted during the assessment. If the subject was unable to comply with the instructions, the test was stopped and the total number of successful repetitions was recorded. The examination was performed on the surgical limb only and the absolute number of successful repetitions was used for group comparisons.

Ambulation status was recorded during each of the postoperative testing sessions. Patients were required to meet the criteria of our institution to successfully achieve full ambulatory status. These criteria included (1) symmetry or ≥0° of passive knee extension, (2) successfully maintain balance on the surgical limb for ≥20 seconds,[24,25] and (3) symmetrical gait without an assistive device as determined by the research physical therapist. Ambulation status was recorded as a dichotomous variable (yes/no), and the total percentage of patients within each group was used for analysis.

Six-Month Outcome Measures

Subjective knee function was assessed at 6 months using the International Knee Disability Committee-2000 survey (0-87).[26] Clinical outcomes included bilateral knee ROM, isokinetic knee extension peak torque (60°/second, 180°/second, 300°/second), and single-leg squat reach distance. Knee flexion and extension ROM were assessed passively using reliable methods[27] and reported as the absolute deficit when compared with the uninvolved limb (°). Single-leg squat performance was assessed using the y-balance anterior reach test[28] and recorded as a deficit (centimeters). Knee extension peak torque was assessed at 60°/s, 180°/s, and 300°/s and recorded as limb symmetry index, which is the relative percentage of the surgical limb compared with the uninvolved limb (percentage).[29] Last, adverse events were tracked over the 6-month study period for conditions that required additional surgeon intervention. Adverse events were documented and included patellar tendonitis, extension ROM loss, deep vein thrombosis, and graft rupture. Knee extension ROM loss was defined as an asymmetric deficit >5° observed at the 3-month postoperative time frame that required additional intervention. Percentages of each complication category were used for statistical comparisons between groups.

Statistical Analysis

Sample size estimates were based on minimal detectable change and standard error of measure values for quadriceps sEMG activity as the primary outcome variable. To achieve a power of $\beta = .80$ and an alpha level of .05 for the risk of a type I error a total sample of 72 subjects (36 per group) was projected (G*Power, v3.0.10). To conservatively account for an estimated 20% dropout rate, we planned to enroll 90 subjects for the study. Baseline demographics and surgical

procedures were compared between groups using a Student t test for continuous variables or Mann-Whitney U for nonparametric variables when indicated. Patients lost to follow-up were accounted for using an intention-to-treat analysis. The primary and secondary outcomes were compared between groups over time using a mixed-model analysis of variance with Tukey post hoc analysis. IBM SPSS 24 was used for all statistical analyses; statistical significance was set a priori at $\alpha = .05$.

Results

Participants

Ninety consecutive patients were screened for participation before surgery. Four patients refused participation, 1 was excluded after surgery for receiving a primary ACL repair, and 1 did not undergo ACL reconstruction (Fig 1). No differences were observed for patient or surgical demographics between groups (Table 1).

No differences were observed in mean postoperative pain rating scores (mean ± standard deviation, 2.5 ± 1.9 vs 2.6 ± 2.0, $P = .793$) or morphine consumption (14.8 mg ± 8.3 mg vs 16.0 mg ± 7.4 mg, $P = .358$) between FNB and ACB groups, respectively, following surgery. Table 2 lists the results for the 24-hour and 2- and 4-week functional comparisons (Fig 2). There was a significant group by time interaction for sEMG deficits ($P = .03$). Tukey post hoc testing indicates greater sEMG deficits for the FNB block group compared with the ACB group (Fig 3) at 24 hours ($P < .001$) and 2 weeks ($P < .001$). Additionally, there was a significant

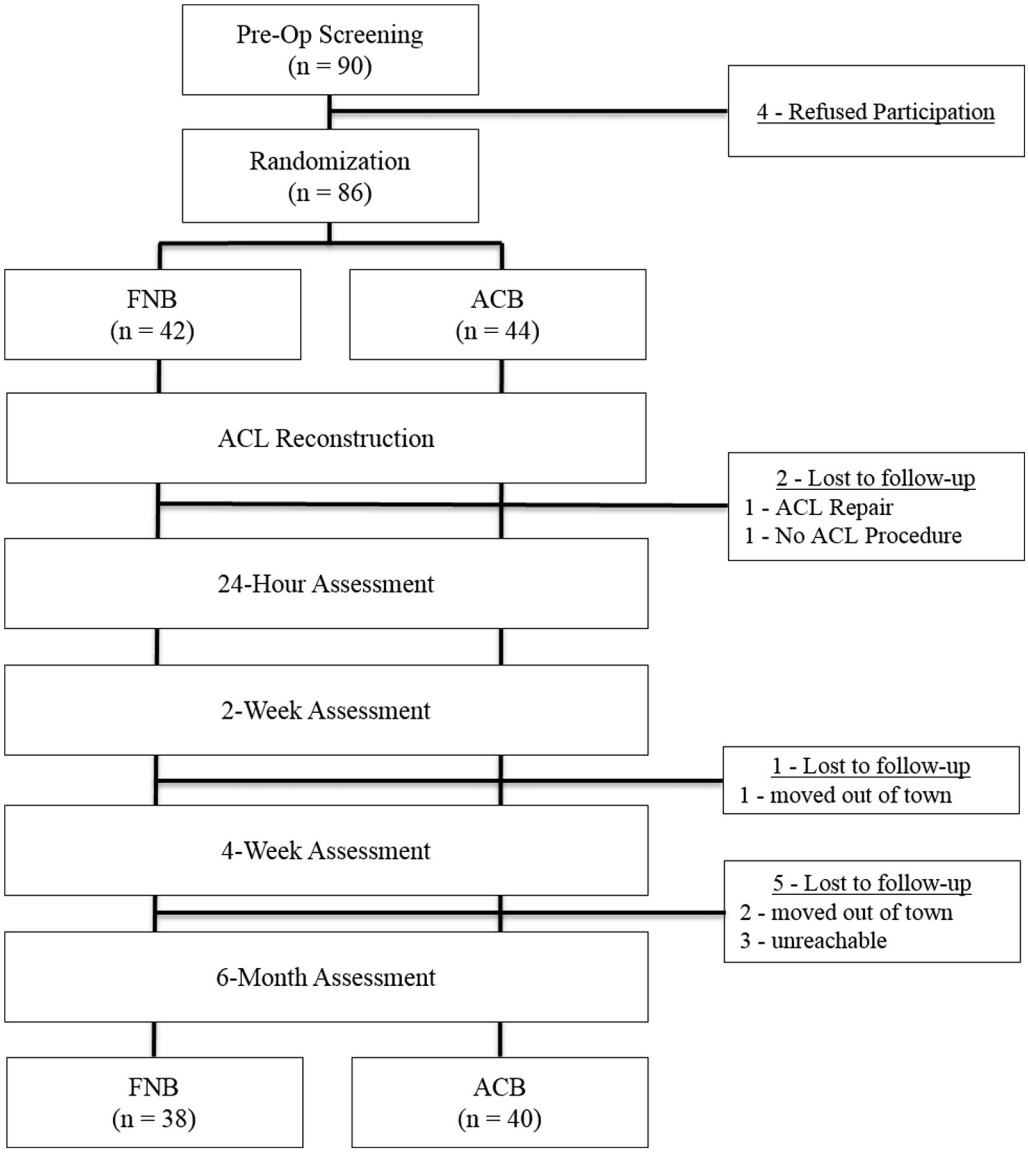

Fig 1. Consolidated Standards of Reporting Trials study design. (ACB, adductor canal nerve blockade; ACL, anterior cruciate ligament; FNB, femoral nerve blockade.)

Table 2. Early Postoperative Outcomes

Time Point	FNB (n = 38)	ACB (n = 40)	*P*
Quadriceps Muscle Activation Deficit, μV			
24 h	266.5 ± 52.4	212.5 ± 65.1	.001*
2 wk	183.2 ± 41.8	126.5 ± 48.9	.001*
4 wk	109.1 ± 32.2	94.1 ± 33.2	.389
Straight Leg Raises Performed, Repetitions			
24 h	3.2 ± 6.1	6.2 ± 8.0	.434
2 wk	23.3 ± 10.6	24.2 ± 10.9	.823
4 wk	29.7 ± 1.4	30 ± 0.0	.599
Ambulation Status, %			
24 h	0	0	>.99
2 wk	26.3	27.5	.846
4 wk	84.2	100	.001*

NOTE. Values reported as mean ± standard deviation.

ACB, adductor canal block; FNB, femoral nerve block; NPRS, numeric pain rating scale.

*Statistical significance at $\alpha = .05$.

main effects difference for "time," indicating that both groups significantly improved sEMG activation over the 4-week testing period. There was also a significant group × time interaction for ambulation status ($P = .04$). Post hoc analysis shows that more patients in the ACB group met the ambulation criteria at the 4-week time frame (84.2% vs 100%, $P < .001$). There were no group differences in straight leg raises performance at any of the testing time frames ($P > .05$).

A total of 78 (87%) patients (FNB, n = 38; ACB, n = 40) were available for 6-month follow-up testing. Table 3 shows the mean outcome scores and complication rates for both groups at the 6-month follow-up assessment. There were no differences between FNB and ACB groups for any of the function variables of knee ROM, single-leg squat anterior reach distances, or isokinetic knee extension peak torque at 60°/second, 180°/second, or 300°/second ($P > .05$). The percentage of patients treated for knee extension ROM loss was statistically higher for the FNB group versus the ACB group (21.1% vs 5.0%, $P = .026$). There were no other differences in complication rates between groups ($P > .05$).

Discussion

Our results favor ACB for providing similar pain control, with greater quadriceps muscle activation symmetry, and lower rates of ROM loss with respect to FNB following outpatient ACL reconstruction with patellar tendon autograft. Specifically, at 2 weeks, patients receiving ACB exhibited fewer quadriceps muscle sEMG deficits, reported similar NPRS pain scores, and consumed similar morphine equivalent units compared with their FNB counterparts. At 4 weeks, sEMG deficits were not statistically different between groups; however, ambulation rates were higher for the ACB group. Functional comparisons completed at 6 months showed no differences between groups with respect to knee ROM, single-leg squat performance, or isokinetic strength (Fig 4); however, the incidence of knee extension ROM loss requiring additional interventions

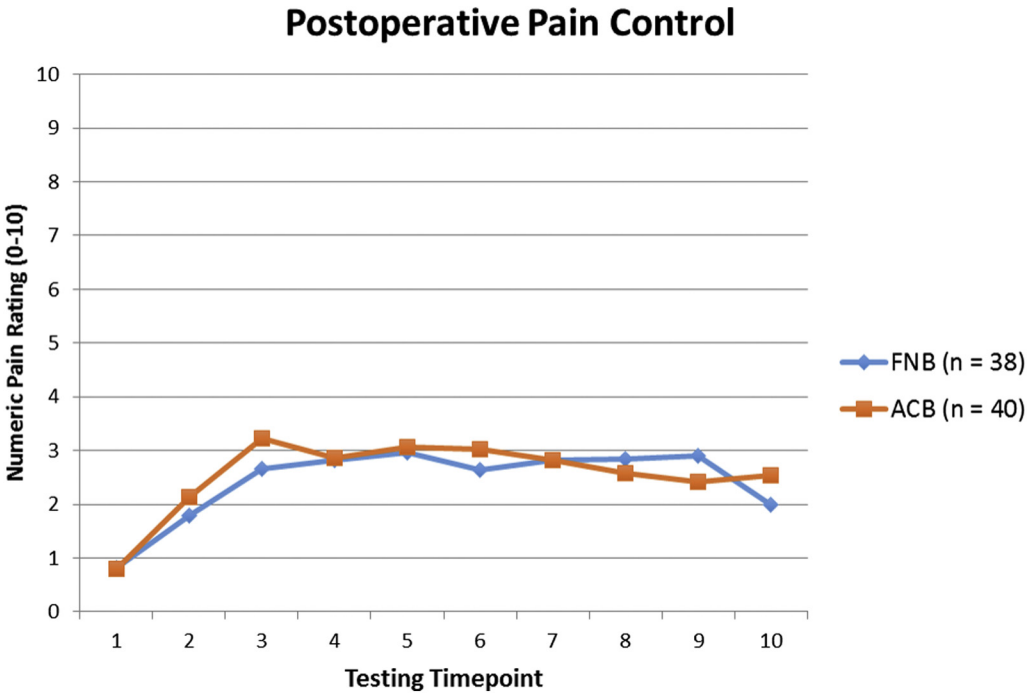

Fig 2. The mean numeric pain rating scale of patients within the first 24 hours of surgery ($F = .061$, $P = .806$). (ACB, adductor canal nerve blockade; FNB, femoral nerve blockade.)

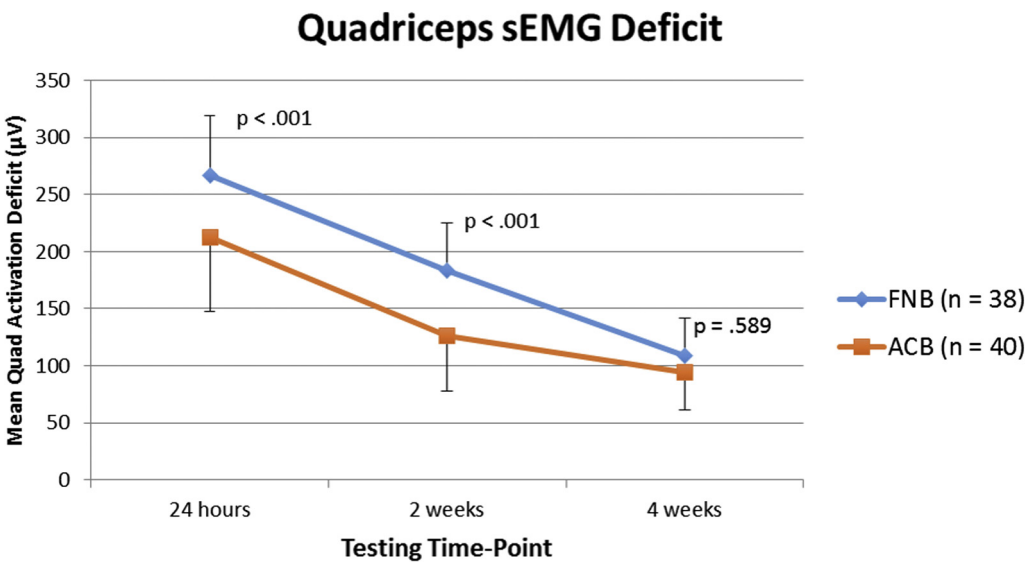

Fig 3. Quadriceps muscle activation deficits. Significant between-group differences at testing time-points 24 hours and 2 weeks. (ACB, adductor canal nerve blockade; ACL, anterior cruciate ligament; FNB, femoral nerve blockade.)

was significantly higher for the FNB group (21.1% vs 5.0%, $P < .001$).

Restoring quadriceps muscle function is key to safely returning athletes to sport and has been strongly associated with the subsequent risk of ACL reinjury. Work from the Delaware-Oslo group[16] reported a statistically higher reinjury rate at 2 years for patients who were unable to achieve at least 90% symmetry in quadriceps muscle strength by 12 months after ACL surgery (33.3% vs 12.5%). Furthermore, quadriceps muscle strength symmetry for patients who suffered a reinjury was significantly lower compared with athletes who did not sustain a reinjury (84.4% ± 15.2 vs 75.0% ± 16.7, $P < .03$). With these relationships in mind, surgeons and rehabilitation professionals should explore methods that optimize quadriceps muscle activation and strength throughout all phases of rehabilitation. The 24-hour and 2-week postoperative data indicate that higher quadriceps muscle activation was achieved within the ACB group compared with FNB, perhaps limiting the negative effects associated with this surgical procedure. These differences did resolve, however, at the 6-month testing time frame, at which isokinetic strength symmetry was similar between groups.

Few studies are currently available that compare the effects ACB and FNB following ACL reconstruction. Among the existing studies is the work of Abdallah et al.,[17] who compared ACB and FNB over the first 24 hours in patients undergoing ACL reconstruction with multiple graft types. Before surgery, the investigators examined isometric quadriceps muscle

Table 3. Six-Month Comparisons and Adverse Events

Variable	FNB (n = 38)	ACB (n = 40)	*P*
6-Month Clinical Outcomes			
IKDC-2000 survey, 0-87 range	74.9 ± 13.1	76.7 ± 10.5	.815
Extension ROM deficit, °	3.1 ± 2.4°	1.8 ± 2.4°	.057
Flexion ROM deficit, °	5.6 ± 4.4°	4.4 ± 4.1°	.994
Single-leg squat deficit, cm	2.8 ± 3.1 cm	2.5 ± 2.8 cm	.612
Knee extension peak torque (LSI), 60°/s	66.9 ± 16.3%	69.4 ± 13.5%	.439
Knee extension peak torque (LSI), 180°/s	73.4 ± 15.8%	77.7 ± 10.2%	.369
Knee extension peak torque (LSI), °/s	79.9 ± 13.0%	84.3 ± 10.8	.880
Adverse Events, %			
Anterior knee pain, % (n)	18.4 (7)	20.0 (8)	.779
Knee extension loss, % (n)	21.1 (8)	5.0 (2)	.026*
DVT, % (n)	0 (0)	2.5 (1)	.743
Reinjury, % (n)	2.6 (1)	0 (0)	.698

NOTE. Values reported as mean ± standard deviation.

ACB, adductor canal block; DVT, deep vein thrombosis; FNB, femoral nerve block; IKDC, International Knee Documentation Committee; LSI, limb symmetry index; NPRS, numeric pain rating scale; ROM, range of motion.

*Statistical significance at $\alpha = .05$.

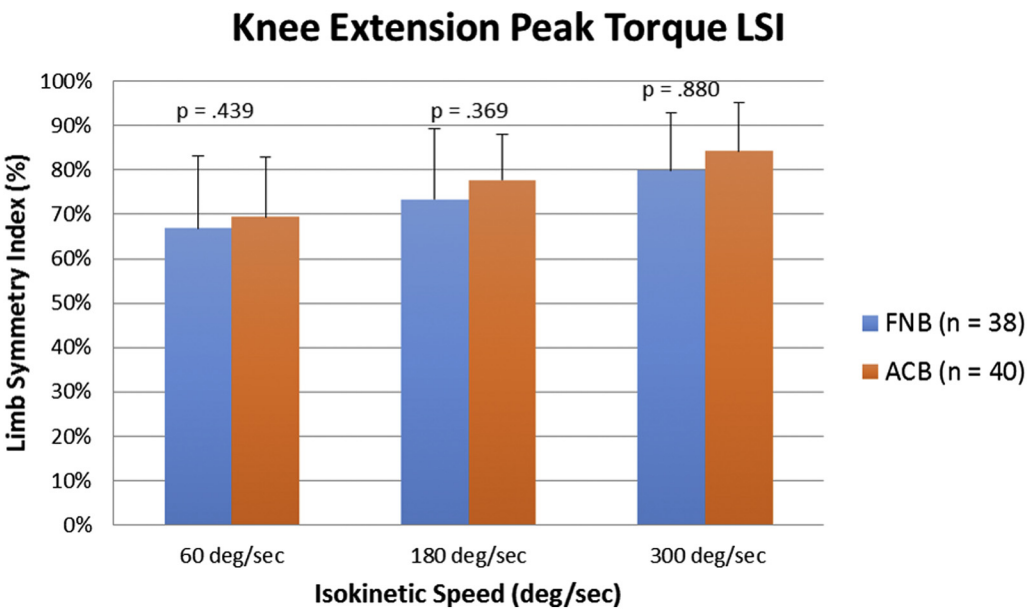

Fig 4. Six-month comparison of isokinetic knee extension peak torque. (ACB, adductor canal nerve blockade; FNB, femoral nerve blockade; LSI, limb symmetry index.)

strength after nerve blockade was administered and found statistically greater strength deficits in the FNB versus the ACB group, respectively ($P < .01$). Considering the motor-sparing quality of ACB versus FNB, these results are not surprising, and although intriguing, they cannot be compared with our sample because of the differences in timing and graft selection. We consider the use of a single graft source to be a strength of our study; however, we recommend that similar methodology be undertaken to determine whether these relationships are maintained across other graft sources such as allograft or quadriceps and hamstring autograft. The results observed between groups within our sample showed that early postoperative muscle activation was higher for patients receiving ACB; however, these deficits did resolve over time. Further examination is needed to determine the underlying mechanisms and potential long-term effects of these differences.

Similar study designs have been performed comparing FNB with control groups receiving no peripheral nerve blockade for ACL reconstruction. In 2017, Magnussen et al.[30] reported that patients receiving FNB had significantly greater quadriceps muscle strength deficits (13.6%, $P < .01$) at 6 weeks compared with a control group; however, these group differences were not detected at 6 months. Our findings were similar to the Magnussen study, because patients in the FNB group displayed greater deficits at 24 hours and 2 weeks compared with the ACB group, with no obvious quadriceps muscle strength differences at 6 months. The increased rate of subsequent interventions (arthroscopic lysis of adhesions) required to restore knee extension within the FNB group in our study may have influenced these outcomes, however.

The outcomes observed for postoperative pain control between our patient groups are consistent with previous studies. The investigation by Abdallah et al.[17] reported similar pain control between groups receiving ACB and FNB using a visual analog scale and morphine consumption at 24 hours following ACL reconstruction ($P < .01$). In addition, these investigators noted preoperative strength differences between the groups that were consistent with our postoperative investigation. In sum, the existing data for ACB appear to be equivocal to FNB, specifically for pain control within the 24 hours after ACL reconstruction. As a result, we advocate for its use over FNB for pain management in outpatient ACL surgery with consideration to the motor-sparing characteristics of the ACB.

Previous work comparing local liposomal bupivacaine versus FNB[31] for ACL reconstruction showed increased pain for the patients receiving local anesthetic between 5 and 8 hours following surgery (6.3 ± 2.0 vs 4.8 ± 2.6; $P = .01$), respectively, although these group differences did not extend beyond the initial 24-hour period. Six patients within the FNB group also suffered prolonged quadriceps muscle inhibition or sensory disturbances, and collectively were more likely to call the surgeon the following day after surgery because of pain (29% vs 8%, $P = .04$). Considering these results, ACB may provide a suitable alternative to improve the pain control limitations of local bupivacaine and detrimental complications of FNB; however, future work is needed to compare these treatment modalities to confirm these hypotheses.

An unanticipated discovery of our results was the higher rate of knee extension loss for patients receiving FNB compared with other forms of analgesia. Although we are unable to establish definitive relationships, we assume that the early differences in quadriceps sEMG within the FNB group may have, in some part, contributed to the differences observed for knee extension loss. Postoperative knee extension loss following ACL surgery is not uncommon and can have serious long-term consequences. Previous work by Werner et al.[32] reported the incidence of lysis of adhesions or manipulation under anesthesia for knee extension loss using the PearlDiver database of >13,000 ACL reconstructions performed within the United States. The authors discovered an average incidence of up 6% following these surgical procedures, which was similar to the rate observed within our study. A recent longitudinal study of lysis of adhesions after ACL reconstruction[33] at an average of 18.7 years reports that the incidence of knee osteoarthritis is significantly higher when ROM deficits are present. Considering these data and the results of this study, we would recommend the use of ACB over FNB to potentially reduce the risk of knee extension loss after ACL reconstruction.

Limitations

Our study is subject to several limitations, including the lack of a control group not receiving regional nerve blockade for direct comparisons. Although beneficial for methodological considerations, this was not feasible at our institution because nerve blockade is considered standard of care for outpatient ACL reconstruction. Additionally, the homogenous sample of patellar tendon autografts limits extrapolation of these data to other graft sources and should be carefully considered when interpreting these results.

Conclusions

ACB was as effective as FNB at providing pain control while eliciting fewer quadriceps muscle activation deficits and fewer postoperative complications. Based on previous evidence and the results of this study, we recommend the use of ACB over FNB for the analgesic management of patients undergoing ACL reconstruction with patellar tendon autograft.

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