Title

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Journal

Anesthesia & Analgesia, 122(5)

ISSN

0003-2999

Authors

Monahan, Amanda M

Sztain, Jacklynn F

Khatibi, Bahareh

et al.

Publication Date

2016-05-01

DOI

10.1213/ane.0000000000001182

Peer reviewed

Continuous Adductor Canal Blocks: Does Varying Local Anesthetic Delivery Method (Automatic Repeated Bolus Doses Versus Continuous Basal Infusion) Influence Cutaneous Analgesia and Quadriceps Femoris Strength? A Randomized, Double-Masked, Controlled, Split-Body Volunteer Study

Amanda M. Monahan, MD,* Jacklynn F. Sztain, MD,* Bahareh Khatibi, MD,* Timothy J. Furnish, MD,* Pia Jæger, MD, PhD,†‡ Daniel I. Sessler, MD,‡§ Edward J. Mascha, PhD,‡‖¶ Jing You, MS,‡ Cindy H. Wen, BS,# Ken A. Nakanote, BA,** and Brian M. Ilfeld, MD, MS*‡

BACKGROUND: It remains unknown whether continuous or scheduled intermittent bolus local anesthetic administration is preferable for adductor canal perineural catheters. Therefore, we tested the hypothesis that scheduled bolus administration is superior or noninferior to a continuous infusion on cutaneous knee sensation in volunteers.

METHODS: Bilateral adductor canal catheters were inserted in 24 volunteers followed by ropivacaine 0.2% administration for 8 hours. One limb of each subject was assigned randomly to a continuous infusion (8 mL/h) or automated hourly boluses (8 mL/bolus), with the alternate treatment in the contralateral limb. The primary end point was the tolerance to electrical current applied through cutaneous electrodes in the distribution of the anterior branch of the medial femoral cutaneous nerve after 8 hours (noninferiority delta: −10 mA). Secondary end points included tolerance of electrical current and quadriceps femoris maximum voluntary isometric contraction strength at baseline, hourly for 14 hours, and again after 22 hours.

RESULTS: The 2 administration techniques provided equivalent cutaneous analgesia at 8 hours because noninferiority was found in both directions, with estimated difference on tolerance to cutaneous current of −0.6 mA (95% confidence interval, −5.4 to 4.3). Equivalence also was found on all but 2 secondary time points.

CONCLUSIONS: No evidence was found to support the hypothesis that changing the local anesthetic administration technique (continuous basal versus hourly bolus) when using an adductor canal perineural catheter at 8 mL/h decreases cutaneous sensation in the distribution of the anterior branch of the medial femoral cutaneous nerve. (Anesth Analg 2016;122:1681–8)

From the *Department of Anesthesiology, University of California San Diego, San Diego, California; †Department of Anesthesiology, Rigshospitalet, Copenhagen University Hospital, Copenhagen, Denmark; ‡Outcomes Research Consortium, Cleveland, Ohio; §Department of Outcomes Research, Anesthesiology Institute, The Cleveland Clinic, Cleveland, Ohio; Departments of ‖Quantitative Health Sciences and ¶Outcomes Research, The Cleveland Clinic, Cleveland, Ohio; #Department of Ophthalmology, University of California San Diego, San Diego, California; and **School of Medicine, University of California San Diego, San Diego, California.

Accepted for publication November 25, 2015.

Funding: This study was supported by the University of California San Diego Clinical and Translational Research Institute (San Diego, CA); the National Institutes of Health National Center for Research Resources grant UL1RR031980; Department of Anesthesiology, University California of San Diego (San Diego, CA); and Smiths Medical (St. Paul, MN). In addition, Smiths Medical provided the portable infusion pumps, and Teleflex Medical (Research Triangle Park, NC) provided the perineural catheters used in this investigation. Neither company had input into any aspect of study conceptualization, design, and implementation; data collection, analysis and interpretation; or manuscript preparation. The content of this article is solely the responsibility of the authors and does not necessarily represent the official views of the funding entities.

The authors declare no conflicts of interest.

Presented, in part, as a scientific abstract at the Annual Meeting of the American Society of Anesthesiologists in San Diego, CA, October 26, 2015.

Reprints will not be available from the authors.

Address correspondence to Brian M. Ilfeld, MD, MS, Department of Anesthesiology, 200 West Arbor Dr., MC 8770, San Diego, CA 8770. Address e-mail to bilfeld@ucsd.edu.

DOI: 10.1213/ANE.0000000000001182

Continuous adductor canal blocks provide pain control after surgical procedures of the knee, but there is growing evidence that they provide less-potent analgesia, at times, than continuous femoral nerve blocks.[1,2] Because perineural adductor canal infusions induce far less quadriceps femoris muscle weakness than their femoral counterparts, they may be preferable if the cause(s) of the inferior analgesia can be identified and corrected. A potential cause of inferior analgesia is due to the neuroanatomy of the adductor canal (an intermuscular space within the anterior thigh).[3–5] The saphenous nerve enters the adductor canal at the apex of the femoral triangle, contributes to the innervation of the knee, and then innervates the medial leg below the knee and the ankle capsule.[6,7] Because adductor canal perineural catheters are located within the canal itself, local anesthetic introduced through the catheter presumably reaches the saphenous and other nerves passing through the canal, which is deep to the sartorius muscle.

In contrast, nerves that innervate much of the skin around the knee do not pass through the adductor canal: the medial femoral cutaneous nerve branches from the anterior branch of the femoral nerve approximately 4 cm distal to the inguinal ligament, crosses anterior to the femoral artery, and then further divides into posterior and anterior branches.[6,8] The anterior branch runs close to the deep fascia superficial to

the sartorius muscle—never entering the adductor canal—and innervates the skin of the medial and lateral knee.[8–10]

Conduction studies confirm that the anterior branch of the medial femoral cutaneous nerve contributes to the innervation of the skin over the medial side of the thigh extending to the middle of the patella and distal to the inferior border of the patella.[11] Therefore, this branch often contributes to the innervation of the surgical site for various procedures of the knee yet does not traverse the adductor canal. Indeed, 1 clinical trial suggests that a basal infusion of local anesthetic through a perineural catheter in the adductor canal does not appear to affect the anterior branch of the medial femoral cutaneous nerve, therefore, compromising postoperative analgesia after knee surgery.[12]

It seems likely, however, that a sufficient local anesthetic bolus administered within the adductor canal might extend proximally and reach the anterior branch of the medial femoral cutaneous nerve, thus enhancing analgesia to the knee. Therefore, first, we tested the primary hypothesis that scheduled bolus anesthetic administration is superior or noninferior to a continuous infusion on cutaneous knee analgesia after 8 hours of treatment. Second, we evaluated noninferiority of cutaneous analgesia and muscle strength at other time points within 22 hours of beginning treatment.

METHODS

Enrollment

This study followed Good Clinical Practice and was conducted within the ethical guidelines outlined in the Declaration of Helsinki. The trial was registered prospectively at clinicaltrials.gov (NCT02219438). The University of California San Diego IRB (San Diego, California) approved all study procedures and provided oversight of the data and safety issues for the duration of the trial. Written informed consent was obtained from all participating subjects.

Healthy adult male and female volunteers (18 years and older) were recruited by the use of an established University of California San Diego IRB–approved volunteer database. Exclusion criteria included daily analgesic use, opioid use within the previous 4 weeks, any neurologic or muscular deficit involving the lower extremities, body mass index exceeding 35 kg/m^2, pregnancy, or incarceration. The study was conducted at the University of California San Diego Clinical and Translational Research Institute (San Diego, California).

Perineural Catheter Insertion

Bilateral adductor canal catheters were inserted in each volunteer. Subjects were positioned supine with the knee slightly flexed and the hip externally rotated. Insertion sites were prepared with chlorhexidine gluconate/isopropyl alcohol solution and sterile drapes. The catheter insertion level was identical on each leg, determined by the use of a ruler at half the distance between the anterior superior iliac spine and the superior aspect of the patella.[13] Standard American Society of Anesthesiologists monitors were applied, and oxygen was administered by nasal cannula at 3 L/min. IV midazolam (1 mg) and fentanyl (50 μg) were administered.

The adductor canal was visualized with a 13 to 6 MHz 38-mm linear array transducer (M-Turbo, SonoSite, Bothell, WA) in a short-axis view. A skin wheal was placed with 1% lidocaine and a noninsulated, 17-gauge, 8.89-cm long Tuohy needle was advanced in plane toward the canal. Normal saline was used for hydrodissection, up to 15 mL. A flexible 19-gauge epidural catheter (FlexBlock, Teleflex Medical, Research Triangle Park, NC) was advanced 1 cm beyond the needle tip, and the needle withdrawn over the catheter. Air (0.5 mL) was injected through the catheter, under ultrasound visualization, to confirm catheter tip location within the adductor canal. The skin entry site was covered with a sterile, clear occlusive dressing, and the sterile drape was removed. Sterile, clear occlusive dressings were used to secure the catheter up the thigh, and an anchoring device was affixed to the anterior thigh.

Treatment Group Assignment

The Investigational Drug Service created a computer-generated randomization table in blocks of 2, with a 1:1 ratio, stratified by sex. The dominant leg of each subject was randomized to receive 1 of 2 administration regimens of 0.2% ropivacaine: a continuous basal infusion (8 mL/h) or automated, hourly boluses (8 mL/bolus delivered over 115 s). The contralateral leg received the alternative treatment. This split-body study design enabled subjects to act as their own controls. Investigational Drug Service personnel prepared all ropivacaine reservoirs and infusion pumps. The electronic, programmable infusion pumps (CADD-Solis, Smiths Medical, St. Paul, MN) are capable of providing automated, bolus doses and a continuous basal infusion. Each subject had 2 infusion pumps, one programmed to deliver automated bolus doses and the other a continuous basal infusion. The ends of the tubing were labeled "dominant" and "contralateral." For each subject, the tubing from each of the 2 infusion pumps were wound gently about each other at least 5 rotations and covered with opaque tape, masking treatment allocation to investigators and subjects.

After catheter connection to the subject, both infusion pumps were activated, and local anesthetic administration was initiated at hour 0. After 8 hours of administration, medical personnel removed the perineural catheters.

End Points

Outcome measurements were evaluated dominant side first at baseline (before local anesthetic administration) and every hour through hour 14 and again at hour 22 before patient discharge.

Tolerance to Transcutaneous Electrical Stimulation

Electrocardiogram electrodes were placed over the proximal patella and quadriceps tendon 1 cm medial of midline at the time of baseline measurements and left in situ until following the final measurement at hour 22. This location was chosen to evaluate the anterior branch of the medial femoral cutaneous nerve (as opposed to the saphenous nerve).[8,11] A nerve stimulator (EZstimII, Model ES400; LifeTech, Stafford, TX) was connected to the electrodes. Current was delivered as a tetanic stimulus (50 Hz) slowly increased from 0 mA until the first reported perception of discomfort, at which point the current was recorded and the nerve stimulator was turned off.[14–17]

Quadriceps Muscle Strength

Quadriceps muscle strength was assessed by measurement of maximum voluntary isometric contraction (MVIC).[13,18,19] In the sitting position, without using accessory muscle groups, subjects performed maximum forceful knee extension against an electromechanical dynamometer (MicroFET2, Lafayette Instrument Company, Lafeyette, IN). The subject sat at the side of the bed with legs dangling. The device was placed against the anterior tibia just above the malleoli between the subject and a nonelastic 5-cm wide fabric band that was affixed to the gurney to stabilize the dynamometer during flexing of the quadriceps femoris muscle. Subjects were instructed to come to maximum force of knee extension over 2 seconds, hold this force for 5 seconds, and then relax. The maximum force was recorded, and the results are reported relative to the preinfusion baseline measurement (i.e., percent of baseline).

Statistical Analysis

We assessed noninferiority of the bolus method (hourly 8-mL boluses of 0.2% ropivacaine) compared with basal infusion (0.2% ropivacaine 8 mL/h continuous infusion) on the primary end point of tolerance to cutaneous current at 8 hours using a 1-tailed noninferiority *t* test at the 0.025 significance level with an a priori–specified noninferiority delta of 10 mA. Noninferiority was claimed if the lower limit of the 95% confidence interval (CI; 0.025 in the hypothesized direction) for the difference in means was more than the noninferiority delta of −10 mA.

A value of 10 mA was a priori considered to be the smallest difference that would be clinically important between groups. This value was considered the minimally clinically relevant current because it approximates the tolerated electrical current range at baseline of the general population—in other words, similar to natural variability in the population, and therefore, a relatively small amount of current to detect.[20]

Our secondary analysis assessed noninferiority of bolus dosing to continuous infusion on mean tolerance to cutaneous current across all time points measured by the use of a noninferiority delta of −10 mA, as discussed previously. In this repeated-measures setting, noninferiority was assessed in the context of a linear mixed model with adjustment for the within-subject correlation (by the use of an autoregressive correlation structure).[21] If the group-by-time interaction was nonsignificant ($P > 0.20$), we would assess noninferiority collapsing over time and construct a 1-tailed noninferiority *t* test (with noninferiority delta of 10 mA) based on the model-based treatment effect for bolus versus basal infusion. In the presence of a group-by-time interaction, noninferiority would be assessed separately at each time point and a Bonferroni correction made for multiple comparisons to maintain the hypothesis-wise type I error at 0.025.

We also assessed noninferiority of bolus to basal infusion on the secondary end point of quadriceps femoris MVIC (22 hours total) by using a mixed-effects model as described previously. Noninferiority was claimed if the lower limit of the 95% CI was more than the noninferiority delta of −20%.

The rejection region for a noninferiority test includes superiority by definition (i.e., "not worse" implies either equivalent or better). Therefore, if a bolus was found to not only be noninferior but also superior, we would be able to claim superiority. This would be evidenced by the 95% CI for the difference between means falling above 0. Although we hypothesized that the bolus method was noninferior to basal infusion, it is possible that basal infusion would be noninferior to bolus. Therefore, we also conducted the aforementioned tests assessing noninferiority of basal infusion to bolus. If noninferiority was found in both directions, we would claim equivalence at ±10 mA at the overall 0.025 significance level (no Bonferroni adjustment for testing in 2 directions because both required to claim equivalence). SAS software 9.3 (SAS Institute, Cary, NC) was used for all analyses.

Sample-Size Calculations

Sample size calculations were based on the primary aim of determining the relationship between perineural ropivacaine delivery technique (basal versus bolus) and continuous adductor canal nerve block effects. To this end, we performed a noninferiority trial with the primary end point designated as the maximum tolerance to transcutaneous electrical stimulation at hour 8. With 24 subjects, we had approximately 90% power (88%) at the 0.025 significance level to detect noninferiority of bolus ropivacaine to basal infusion ropivacaine on mean tolerance to transcutaneous electrical stimulation at hour 8 using an a priori noninferiority delta of −10 mA and conservatively assuming, based on the previously published data, a SD of tolerance difference between legs of 15 mA.[20,22]

RESULTS

Twenty-four subjects enrolled and all had bilateral perineural adductor canal catheters placed per protocol. All were then randomized to receive hourly boluses ($n = 13$) or a continuous infusion ($n = 11$) on their dominant side. Subject characteristics were similar between the groups (Table 1). For the primary end point after 8 hours of treatment, average (SD) tolerance to electrical current for limbs receiving hourly boluses was 26.6 (12.1) versus 27.1 mA (14.5) for those with a continuous basal infusion. The estimated difference on the tolerance to cutaneous current at hour 8 was −0.6 mA (95% CI, −5.4 to 4.3) for bolus minus basal, after we adjusted for the tolerance at baseline, dominant side, and the within-subject correlation. Noninferiority was found in both directions (both $P < 0.001$, with 95% CI, within ± 10 mA), so that the bolus method and the basal infusion at hour 8 were found to be equivalent at ± 10 mA (Figs. 1 and 2).

The effects of the bolus method were consistent over time (group-by-time interaction $P = 0.96$). The overall difference across all measurements was −0.9 mA (95% CI, −4.1 to 2.1)

Table 1. Subject Characteristics

Dominant side randomized to	Continuous basal ($n = 11$)	Hourly boluses ($n = 13$)
Age (y)	38 (16)	41 (15)
Sex (female)	60	80
Height (cm)	175 (10)	173 (8)
Weight (kg)	79 (14)	74 (12)
Body mass index (kg/m^2)	26 (3)	25 (3)
Dominant side (right)	100	100

Values are reported as mean (SD) or percentage of subjects.

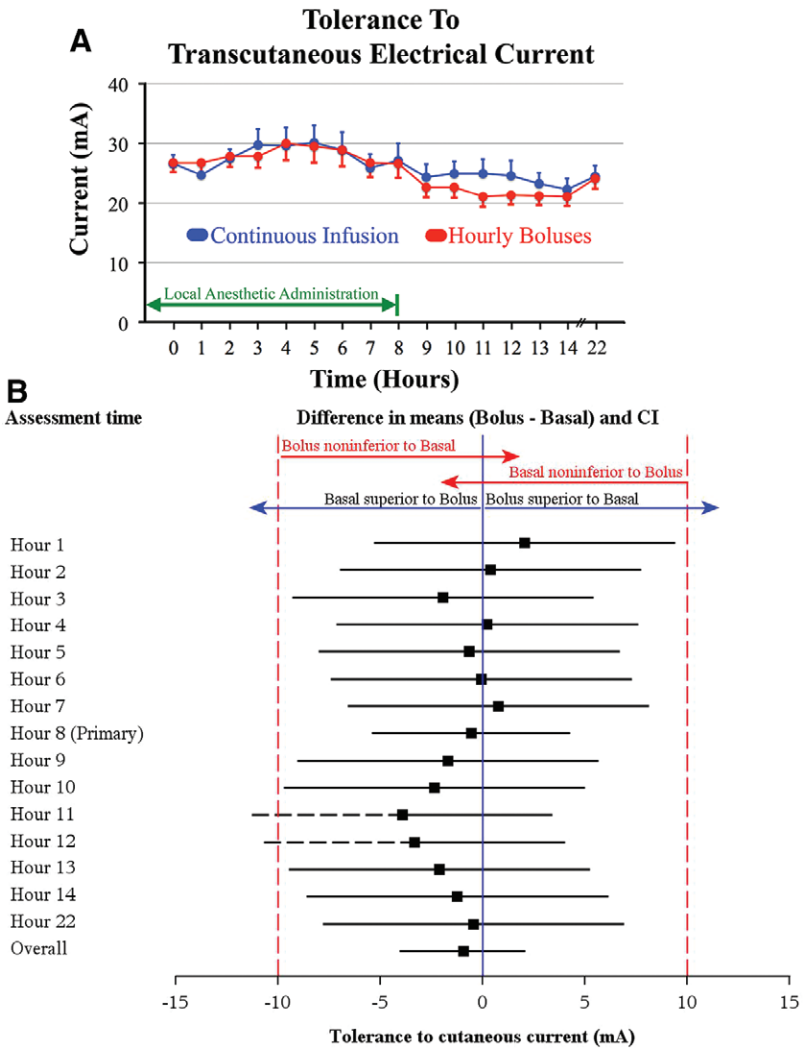

Figure 1. Effects of local anesthetic administration technique (continuous basal infusion versus automatic hourly bolus doses) on tolerance to transcutaneous electrical current in the nerve distribution of the anterior branch of the medial femoral cutaneous nerve. The 2 techniques were equivalent at hour 8 and across all the assessments at ±10 mA, except at hours 11 and 12. Panel A, Mean (SE) values are illustrated. Panel B, The difference in means of tolerance to cutaneous current was estimated with a mixed-effects model with repeated measures. A 95% 2-sided confidence interval (CI) for the primary analysis at hour 8 and the overall assessment for the secondary analysis and 99.7% CI for other times (Bonferroni correction) were estimated. Bolus was claimed noninferior to basal if the lower limit of the 95% CI for the difference in means (bolus – basal) was greater than the noninferiority delta of −10 mA and basal noninferior to bolus if the difference was <10 mA. If noninferiority was found in a particular direction, superiority was also tested in that direction. Equivalence was claimed if noninferiority was found in both directions, with CI within ±10 mA.

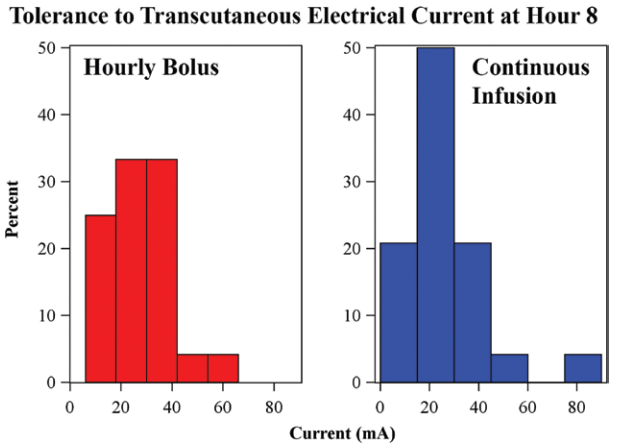

Figure 2. Histograms of the raw data for the tolerances to cutaneous current at hour 8.

for bolus minus basal after adjustment for the tolerance at baseline, dominant side, and the within-subject correlation. Given noninferiority in both directions ($P < 0.001$ in both directions), we can claim that the 2 methods were equivalent across all time points measured at ±10 mA (Table 1 and Fig. 1). Furthermore, the 2 methods were found equivalent at each individual measurement time, except at hours 11 and 12 (Table 2).

Also, we found that the bolus method and the basal infusion were equivalent on MVIC at hour 8 and across all time points (group-by-time interaction $P = 0.76$) at ±20% of baseline. The estimated difference in percent of baseline MVIC was −0.1% (95% CI, −12.4% to 12.2%) at hour 8 and 0.5% (−9.4% to 10.4%) across all measurements for bolus minus basal after adjusting for baseline MVIC, dominant side, and the within-subject correlation (Table 3 and Figs. 3 and 4). There were no protocol violations or adverse events.

DISCUSSION

This randomized, double-masked, controlled, split-body volunteer trial suggests that for 0.2% ropivacaine administered at 8 mL each hour through a perineural catheter inserted into the adductor canal, automatic hourly bolus doses provide cutaneous analgesia and motor strength equivalent to a continuous basal infusion. Therefore, we found no evidence that replacing a basal infusion with repeated bolus doses at the volume/rate studied improves cutaneous analgesia coverage during adductor canal

Table 2. Primary Analysis—Effects of Bolus Method (Versus Basal Infusion) on Tolerance to Cutaneous Current

Tolerance to cutaneous current (mA)	Bolus (*N* = 24)	Basal (*N* = 24)	Difference in means (CI)[a] (Bolus − basal)		NI H_1: Bolus − basal > −10 mA SUP H_1: Bolus − basal >0		NI H_1: Basal − bolus > −10 mA SUP H_1: Basal − bolus >0	
			Unadjusted[b]	Adjusted[c]	NI *P* value[a]	SUP *P* value[a]	NI *P* value[a]	SUP *P* value[a]
Baseline	26.7 ± 7.6	26.6 ± 7.2	—	—	—	—	—	—
Hour 1	26.8 ± 8.8	24.7 ± 7.8	2.13 (−5.40 to 9.65)	2.06 (−5.31 to 9.42)	<0.001	0.20	0.001	0.80
Hour 2	27.9 ± 9.0	27.4 ± 8.2	0.46 (−7.32 to 8.23)	0.39 (−6.97 to 7.75)	<0.001	0.44	<0.001	0.56
Hour 3	27.8 ± 9.6	29.7 ± 13.3	−1.88 (−12.4 to 8.60)	−1.94 (−9.31 to 5.42)	0.001	0.79	<0.001	0.21
Hour 4	30.0 ± 14.0	29.7 ± 14.6	0.29 (−12.6 to 13.2)	0.22 (−7.14 to 7.59)	<0.001	0.46	<0.001	0.54
Hour 5	29.5 ± 13.7	30.1± 14.5	−0.58 (−13.3 to 12.1)	−0.65 (−8.02 to 6.71)	<0.001	0.60	<0.001	0.40
Hour 6	29.0 ± 14.0	29.0 ± 14.8	0.00 (−13.0 to 13.0)	−0.07 (−7.43 to 7.29)	<0.001	0.51	<0.001	0.49
Hour 7	26.8 ± 12.1	25.9 ± 11.3	0.83 (−9.72 to 11.4)	0.76 (−6.60 to 8.13)	<0.001	0.38	<0.001	0.62
Hour 8 (primary)	26.6 ± 12.1	27.1 ± 14.5	−0.5 (−12.6 to 11.6)	−0.57 (−5.41 to 4.28)	<0.001	0.59	<0.001	0.41
Hour 9	22.7 ± 8.8	24.3 ± 10.6	−1.63 (−10.5 to 7.20)	−1.69 (−9.06 to 5.67)	<0.001	0.75	<0.001	0.25
Hour 10	22.6 ± 8.6	24.9 ± 10.5	−2.29 (−11.0 to 6.37)	−2.36 (−9.72 to 5.00)	0.001	0.83	<0.001	0.17
Hour 11	21.1 ± 8.4	25.0 ± 12.1	−3.88 (−13.3 to 5.53)	−3.94 (−11.3 to 3.42)	0.007[d]	—[d]	<0.001	0.05
Hour 12	21.3 ± 7.8	24.6 ± 12.7	−3.25 (−12.8 to 6.27)	−3.32 (−10.7 to 4.04)	0.003[d]	—[d]	<0.001	0.09
Hour 13	21.2 ± 7.4	23.2 ± 9.4	−2.04 (−9.70 to 5.61)	−2.11 (−9.47 to 5.25)	0.001	0.80	<0.001	0.20
Hour 14	21.1 ± 7.9	22.3 ± 8.8	−1.17 (−8.71 to 6.38)	−1.24 (−8.60 to 6.13)	<0.001	0.69	<0.001	0.31
Hour 22	24.1 ± 8.8	24.5 ± 9.0	−0.38 (−8.44 to 7.69)	−0.44 (−7.81 to 6.92)	<0.001	0.57	<0.001	0.43
Overall				−0.92 (−4.06 to 2.08)	<0.001	0.75	<0.001	0.25

The effects of bolus method were consistent over time (group-by-time interaction, $P = 0.96$).

CI = confidence interval; NI = noninferiority; SUP = superiority.

[a]We tested on both directions. For a particular direction, the noninferiority and superiority testing were conducted at 0.025 (0.05/2, Bonferroni correction). Thus, 95% 2-sided CI was estimated for the primary analysis at hour 8 and the overall assessment for the secondary analysis. The significance criterion was further adjusted for multiple comparisons to maintain the hypothesis-wise type I error at 0.025 (0.025 in the hypothesized direction); thus, at each assessment time, the significance criterion was 0.0017 (i.e., 0.025/15, Bonferroni correction), and 99.7% CI was estimated.

[b]Effects were estimated using Student *t* test (unadjusted) with repeated measures by the use of an autoregressive correlation structure, with adjustment for the tolerance at baseline, dominant side, and the within-subject correlation.

[c]Effects were estimated using a mixed-effects model with repeated measures by the use of an autoregressive correlation structure, with adjustment for the tolerance at baseline, dominant side, and the within-subject correlation.

[d]Superiority was not assessed because noninferiority was not claimed.

Table 3. Secondary Analysis—Effects of Bolus Method (Versus Basal Infusion) on MVIC

MVIC	Bolus (*N* = 24)	Basal (*N* = 24)	Difference in means (CI)[a] (Bolus − basal)		NI H_1: Bolus − basal > −20% SUP H_1: Bolus − basal >0		NI H_1: Basal − bolus > −20% SUP H_1: Basal − bolus >0	
			Unadjusted[b]	Adjusted[c]	NI *P* value[a]	SUP *P* value[a]	NI *P* value[a]	SUP *P* value[a]
Baseline	188 ± 65	188 ± 78						
	% baseline							
Hour 1	84 ± 27	88 ± 36	−3.59 (−32.5 to 25.3)	0.18 (−18.4 to 18.8)	0.001	0.49	0.001	0.51
Hour 2	89 ± 21	87 ± 30	2.05 (−21.7 to 25.8)	0.23 (−18.4 to 18.9)	0.001	0.49	0.001	0.51
Hour 3	95 ± 25	93 ± 32	2.80 (−23.5 to 29.1)	0.25 (−18.4 to 18.9)	0.001	0.48	0.001	0.52
Hour 4	92 ± 34	87 ± 31	4.12 (−25.1 to 33.3)	1.39 (−17.2 to 20.0)	<0.001	0.41	0.001	0.59
Hour 5	95 ± 38	90 ± 29	4.35 (−26.5 to 35.2)	3.71 (−14.9 to 22.3)	<0.001	0.28	0.004[d]	—[d]
Hour 6	88 ± 34	93 ± 31	−5.78 (−35.5 to 23.9)	0.86 (−17.8 to 19.5)	<0.001	0.44	0.001	0.56
Hour 7	85 ± 35	92 ± 29	−6.20 (−35.2 to 22.8)	1.24 (−17.4 to 19.9)	<0.001	0.42	0.001	0.58
Hour 8 (primary)	88 ± 31	94 ± 32	−6.05 (−34.5 to 22.4)	−0.09 (−12.4 to 12.2)	0.001	0.51	0.001	0.49
Hour 9	86 ± 30	90 ± 32	−4.02 (−32.4 to 24.3)	−0.07 (−18.7 to 18.6)	0.001	0.50	0.001	0.50
Hour 10	89 ± 36	88 ± 32	0.93 (−29.5 to 31.4)	2.28 (−16.3 to 20.9)	<0.001	0.36	0.002[d]	—[d]
Hour 11	89 ± 36	87 ± 30	2.16 (−27.5 to 31.8)	0.42 (−18.2 to 19.0)	0.001	0.47	0.001	0.53
Hour 12	87 ± 35	84 ± 29	2.29 (−26.7 to 31.3)	0.86 (−17.8 to 19.5)	<0.001	0.45	0.001	0.55
Hour 13	84 ± 32	89 ± 31	−5.07 (−33.7 to 23.5)	−0.80 (−19.4 to 17.8)	0.001	0.55	<0.001	0.45
Hour 14	85 ± 30	88 ± 29	−3.00 (−29.9 to 23.9)	−2.13 (−20.8 to 16.5)	0.002[d]	—[d]	<0.001	0.37
Hour 22	114 ± 35	119 ± 39	−4.63 (−38.4 to 29.1)	−0.92 (−19.6 to 17.7)	0.001	0.56	<0.001	0.44
Overall				0.49 (−9.38 to 10.4)	<0.001	0.46	<0.001	0.54

The effects of bolus method were consistent over time (group-by-time interaction, $P = 0.76$).

CI = confidence interval; MVIC = maximum voluntary isometric contraction; NI = noninferiority; SUP = superiority.

[a]We tested on both directions. For a particular direction, the noninferiority and superiority testing were conducted at 0.025 (0.05/2, Bonferroni correction). Thus, 95% 2-sided CI was estimated for the assessment at hour 8 and overall assessment. The significance criterion was further adjusted for multiple comparisons to maintain the hypothesis-wise type I error at 0.025 (0.025 in the hypothesized direction); thus, at each assessment time, the significance criterion was 0.0017 (i.e., 0.025/15, Bonferroni correction) and 99.7% CI was estimated.

[b]Effects were estimated using Student *t* test (unadjusted) with repeated measures by the use of an autoregressive correlation structure, with adjustment for the MVIC at baseline, dominant side, and the within-subject correlation.

[c]Effects were estimated using a mixed-effects model with repeated measures by the use of an autoregressive correlation structure, with adjustment for the MVIC at baseline, dominant side, and the within-subject correlation.

[d]Superiority was not assessed because noninferiority was not claimed.

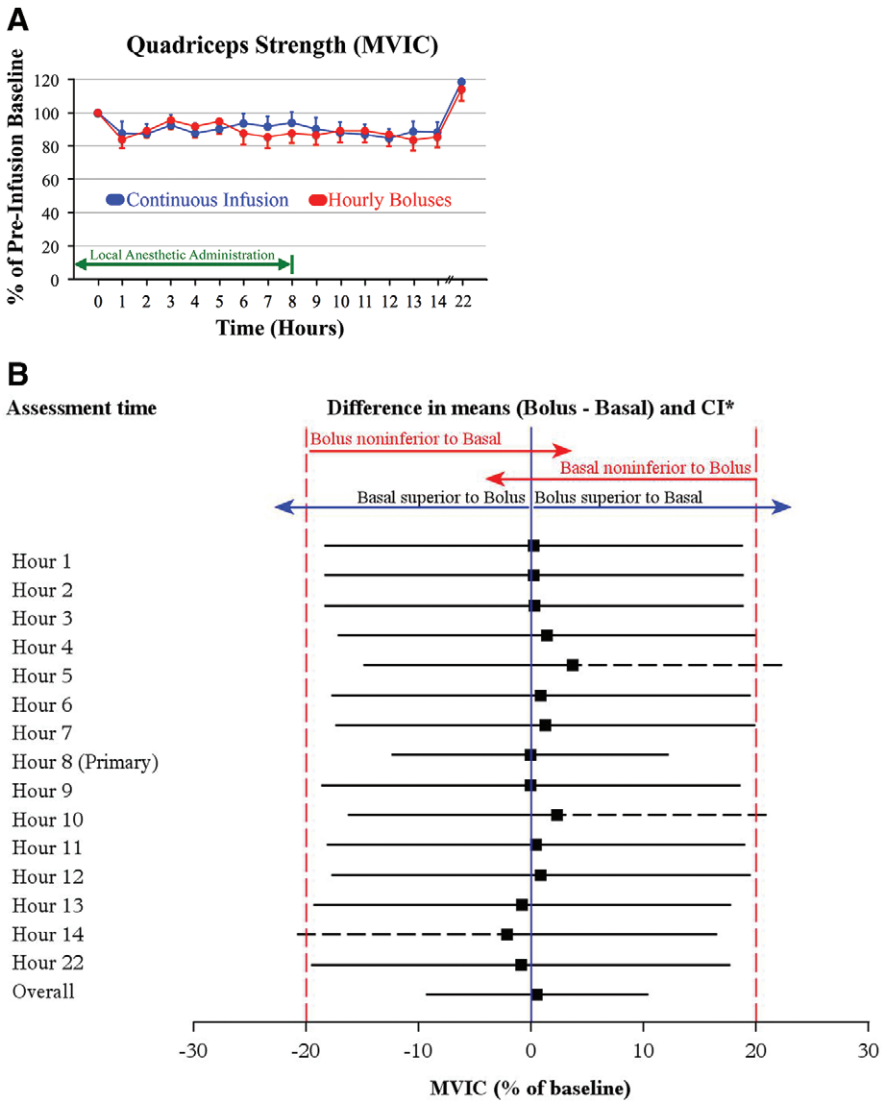

Figure 3. Effects of local anesthetic administration technique (continuous basal infusion versus automatic hourly bolus doses) on quadriceps femoris strength as measured using the maximum voluntary isometric contraction (MVIC). The 2 techniques were equivalent at hour 8 and across all the assessments at ±20% of baseline, except at hours 5, 10, and 14. Panel A, Mean (SE) values are illustrated. Panel B, The difference in means of percent of baseline MVIC was estimated using a mixed-effects model with repeated measures. A 95% 2-sided confidence interval (CI) for the primary analysis at hour 8 and the overall assessment for the secondary analysis and 99.7% CI for the assessments at other times (Bonferroni) were estimated. Bolus was claimed to be noninferior to basal if the lower limit of the 95% CI for the difference in means (bolus – basal) was more than the noninferiority delta of –20% and basal noninferior to bolus if the difference was <20%. If noninferiority was found in a particular direction, superiority was also tested in that direction. Equivalence was claimed if noninferiority was found in both directions, with CI within ±20%.

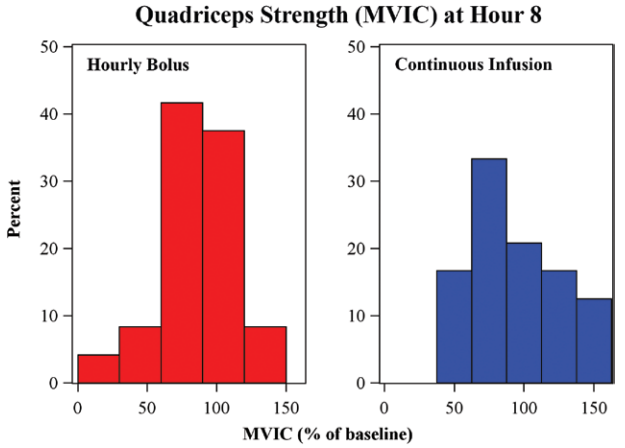

Figure 4. Histograms of the raw data for the maximum voluntary isometric contraction (MVIC) of the quadriceps femoris muscle at hour 8.

perineural local anesthetic infusion. Our results similarly suggest that there is no risk of increasing quadriceps femoris muscle weakness when using a bolus-only method compared with a basal-only administration technique at the volume/rate studied—a reassuring result considering that quadriceps weakness may decrease ambulation and physical therapy ability and increase the risk of falling.[23]

Neuroanatomy

There remains some disagreement about neuroanatomy of the knee, specifically, the relationship of the saphenous nerve to the femoral and medial femoral cutaneous nerves. There is a consensus that the medial femoral cutaneous nerve arises from the anterior division of the femoral nerve. The anterior branch of the medial femoral cutaneous nerve, according to the study by Mochizuki et al.,[9] Standring,[10] and Lee et al.,[11] supplies the anteromedial patella. Conversely, the posterior branch of the medial femoral cutaneous nerve is variously described. According to the study by Lee et al.,[11] the posterior branch of the medial femoral cutaneous nerve supplies the anteromedial thigh skin, as well as the medial leg just below the knee. However, as described by Gray's anatomy (and corroborated by Mochizuki), "the posterior branch... communicates with the saphenous nerve... [and

then] passes down to supply the medial integument of the leg."[10] Baek[4] reports that the medial femoral cutaneous nerve supplies the medial thigh skin as well as the medial aspect of the leg just distal to the knee.

All of these authors agree that the saphenous nerve is a distinct entity from the medial femoral cutaneous nerve. Most authors also agree that the posterior branch of the medial femoral cutaneous nerve communicates with the saphenous nerve at some point along its course. Others, however, state that the saphenous nerve arises directly from the posterior division of the median femoral cutaneous nerve rather than from the posterior division of the femoral nerve itself. According to the study by Oh et al.,[6] "The medial femoral cutaneous (MFC) nerve originates from the femoral nerve 4 cm distal to the inguinal ligament. It then crosses the femoral artery at the apex of the femoral triangle and divides into anterior and posterior branches. The anterior branch innervates the anterior medial thigh, and the posterior branch innervates the medial aspect of the leg just below the knee as the saphenous nerve." These apparent disagreements may be related to the variability in neuroanatomy among individuals[9] and multiple reported areas of communication between the 2 nerves along their courses. Our results from the current investigation stand regardless of who is correct, because our study was designed to assess clinical—rather than theoretical—effects. We located the electrodes to measure cutaneous analgesia/anesthesia on the medial aspect of the knee, which all authors agree is innervated by the medial femoral cutaneous nerve.

Study Limitations

The most significant limitation of our study is that cutaneous electrical current was used as a surrogate for postoperative pain in the volunteer subjects.[14–17] We were able to exclude a confounding variable—postoperative pain—by including only healthy volunteers, allowing us to isolate the effects of the administration method on cutaneous sensation and muscle strength; however, whether postoperative pain and cutaneous sensation are well correlated remains unknown, complicating extrapolation to clinical practice. Regardless, this clinical trial found no evidence to support the hypothesis that local anesthetic administration technique (basal versus bolus) influences cutaneous block effects to nearly any degree.

In addition, our results involving 0.2% ropivacaine and adductor canal catheters may not be applicable with other types of catheters (e.g., sciatic),[24] other insertion techniques,[5,25] other local anesthetics,[26] or different ropivacaine concentrations.[27] Most importantly, a larger volume of local anesthetic in each bolus might improve cephalad spread and analgesia in the distribution of the medial femoral cutaneous nerve. Of course, this might also lead to additional femoral nerve involvement and increased quadriceps weakening.

In summary, we found no evidence to support the hypothesis that changing the local anesthetic administration technique (continuous basal versus hourly bolus) when using an adductor canal perineural catheter at 8 mL/h decreases cutaneous sensation in the distribution of the medial femoral cutaneous nerve. Therefore, it is highly unlikely that 1 method will result in improved cutaneous analgesia after knee surgery, at least by a mechanism involving this sensory nerve. In addition, it does not appear that using either administration technique will further weaken quadriceps strength and thus, presumably, the risk of falling. Further research is needed to investigate larger volumes of local anesthetic bolus doses in a clinical postsurgery patient population.

DISCLOSURES

Name: Amanda M. Monahan, MD.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Amanda M. Monahan approved the final manuscript.
Name: Jacklynn F. Sztain, MD.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Jacklynn F. Sztain approved the final manuscript.
Name: Bahareh Khatibi, MD.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Bahareh Khatibi approved the final manuscript.
Name: Timothy J. Furnish, MD.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Timothy J. Furnish approved the final manuscript.
Name: Pia Jæger, MD, PhD.
Contribution: This author helped interpret the analysis and write the manuscript.
Attestation: Pia Jæger approved the final manuscript.
Name: Daniel I. Sessler, MD.
Contribution: This author helped interpret the analysis and write the manuscript.
Attestation: Daniel I. Sessler approved the final manuscript.
Name: Edward J. Mascha, PhD.
Contribution: This author provided the data analysis and helped write the manuscript.
Attestation: Edward J. Mascha approved the final manuscript.
Name: Jing You, MS.
Contribution: This author provided the data analysis and helped write the manuscript.
Attestation: Jing You approved the final manuscript.
Name: Cindy H. Wen, BS.
Contribution: This author helped conduct the study, write the manuscript, and has seen the original study data.
Attestation: Cindy H. Wen approved the final manuscript.
Name: Ken A. Nakanote, BA.
Contribution: This author helped write the manuscript.
Attestation: Ken A. Nakanote approved the final manuscript.
Name: Brian M. Ilfeld, MD, MS.
Contribution: This author designed the original study, secured appropriate funding, has seen the original study data, reviewed the analysis of the data, approved the final manuscript, and is the author responsible for archiving the study files.
Attestation: Brian M. Ilfeld approved the final manuscript.
This manuscript was handled by: Terese T. Horlocker, MD.

ACKNOWLEDGMENTS

The authors thank for the invaluable assistance of the University California San Diego Clinical and Translational Research Institute (San Diego, CA) and the Investigational Drug Service (San Diego, CA) without which this study would not have been possible.

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