ORIGINAL ARTICLE

The Lateral Femoral Cutaneous Nerve
Description of the Sensory Territory and a Novel Ultrasound-Guided Nerve Block Technique

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Background and Objectives: Nerve blockade of the lateral femoral cutaneous (LFC) nerve provides some analgesia after hip surgery. However, knowledge is lacking about the extent of the cutaneous area anesthetized by established LFC nerve block techniques, as well as the success rate of anesthetic coverage of various surgical incisions. Nerve block techniques that rely on ultrasonographic identification of the LFC nerve distal to the inguinal ligament can be technically challenging. Furthermore, the branching of the LFC nerve is variable, and it is unknown if proximal LFC nerve branches are anesthetized using the current techniques. The primary aim of this study was to investigate a novel ultrasound-guided LFC nerve block technique based on injection into the fat-filled flat tunnel (FFFT), which is a duplicature of the fascia lata between the sartorius and the tensor fasciae latae muscle, in order to assess the success rate of anesthetizing the proximal LFC nerve branches and covering of the different surgical incisions used for hip surgery.

Methods: First, a cadaveric study was conducted in order to identify an FFFT injection technique that would provide adequate injectate spread to the proximal LFC nerve branches. Second, a clinical study was conducted in a group of 20 healthy volunteers over 2 consecutive days. On trial day 1, successful complete anesthesia of the LFC nerve was defined by performing a suprainguinal fascia iliaca block bilaterally in each subject. On trial day 2, a triple-blind randomized controlled trial compared the effect of the novel ultrasound-guided LFC nerve block technique for bupivacaine versus placebo. The primary end point was the success rate of anesthesia of the proximal cutaneous area innervated by the LFC nerve for the FFFT injection with bupivacaine versus placebo.

Results: Adequate spread of injectate to the proximal LFC nerve branches in cadavers was obtained by injecting 10 mL with dynamic needle-tip tracking in the FFFT. Application of this technique in the randomized controlled trial provided anesthesia of the lateral thigh with a success rate of 95% (95% confidence interval, 73.9%–99.8%) for the active side and 0% for placebo ($P < 0.001$). The proximal branches were anesthetized with a success rate of 68% (95% confidence interval, 43.4%–87.4%) on the active side. The proximal extent of the anesthetized cutaneous area was on average 7.9 cm distal to the greater trochanter.

Conclusions: This novel LFC nerve block technique is easy and quick and reliably produces anesthesia of the lateral thigh. The greater trochanter is rarely included in the area of anesthesia, which reduces the coverage of each specific surgical incision. The success rate of 68% in anesthetizing the proximal nerve branches must be further evaluated by future research.

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The lateral femoral cutaneous (LFC) nerve innervates the skin of the lateral thigh, and the effect of peripheral LFC nerve blockade on pain after hip surgery has been assessed in several studies.[1–7] These studies are heterogeneous concerning surgical approach and combination of nerve blocks. However, across these differences, an analgesic effect of the LFC nerve block has been reported in patients after hip surgery.

The success of the LFC nerve block in reducing postoperative pain relies on adequate anesthesia of the area of the surgical incision. On this matter, specific issues should be given attention. First, most surgical incisions for hip surgery involve the proximal part of the lateral thigh, hence the importance of anesthetizing the proximal LFC nerve branches. Moreover, the location of the surgical incision differs among the various hip surgery techniques, and each approach should be evaluated separately in relation to the area of cutaneous anesthesia. Finally, anatomical variations of the LFC nerve and its branching are frequent (Fig. 1). These variations make details of the regional anesthetic technique important because all techniques may not necessarily anesthetize all LFC nerve branches and may therefore anesthetize different skin areas. Studies that present and investigate specific techniques of the LFC nerve block are few and do not provide detailed information on the area anesthetized by the applied techniques.[11–15] Similarly, in-depth details of the applied surgical techniques are mostly absent from the few studies focusing on mapping the anesthetized skin area after LFC nerve blockade.[16–18]

Previously published ultrasound-guided nerve block techniques are targeting the LFC nerve, or one of its branches, deep to the inguinal ligament or anterior to the sartorius muscle. Anesthetizing the LFC nerve deep to the inguinal ligament holds the risk of concomitant femoral nerve block, whereas targeting the nerve anterior to the sartorius muscle is associated with the risk of variable success rates and technical challenges such as poor visualization of all the branches of the target nerve.[11,13]

Distal to the anterior superior iliac spine (ASIS), the LFC nerve is consistently found in a fat-filled flat tunnel (FFFT)[19] formed by a double layer of the fascia lata between the sartorius and the tensor fasciae latae muscle.[20–22] Ultrasonography easily identifies the FFFT and the LFC nerve therein, and the FFFT may serve as a target of injection to anesthetize the LFC nerve.

The aim of this study was to assess the anesthetic effect of a novel ultrasound-guided LFC nerve block technique in the FFFT in a randomized controlled trial (RCT). Prior to the randomized
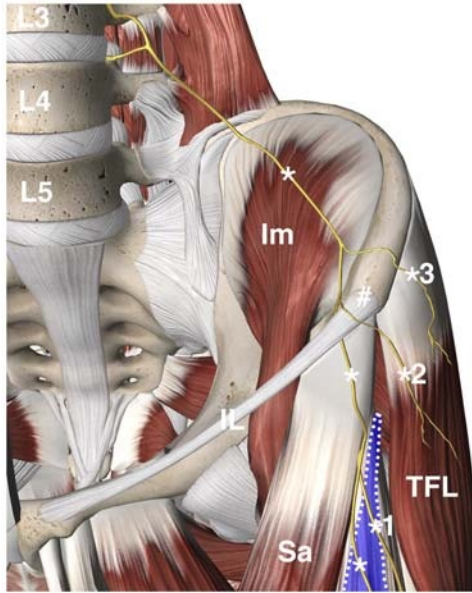
FIGURE 1. The common course of the LFC nerve (*) as it runs deep to the iliac fascia on the ventral surface of the iliac muscle (Im) and descends toward the ASIS (#). It originates as an independent nerve from the L2–3 spinal segments. The nerve passes deep to the inguinal ligament (IL) medial to the ASIS and crosses the superficial surface of the sartorius muscle (Sa). The nerve gives off 1 to 2 branches (*1) to the proximal lateral thigh as it enters into the FFFT (blue area) between the sartorius muscle and the tensor fasciae latae muscle (TFL) muscle.[8] Important variations of the common course of the nerve include an LFC nerve branch (22%–28%) entering the proximal thigh by crossing the ASIS (*2) or less frequently a more posterior LFC branch (11%–18%) crossing the iliac crest posterior to the ASIS (*3).[9,10] The figure is a modified excerpt from Essential Anatomy 5, with permission from 3D4Medical (www.3d4medical.com).

trial, an initial explorative dissection study was conducted in order to identify an efficient technique of injection into the FFFT that would include also the proximal branches of the LFC nerve. In addition, bilateral suprainguinal fascia iliaca compartment (SI-FIC) blocks were carried out in all volunteers and served as a reference of complete LFC nerve blockade.[23]

Our objective was to compare the success rate of anesthesia of the proximal LFC nerve branches and coverage of the surgical incisions for hip surgery of active LFC nerve block in the FFFT to placebo in a triple-blind RCT.

The hypothesis was that the success rate of proximal anesthesia of the lateral thigh after the LFC nerve block in the FFFT was significantly higher with bupivacaine compared with placebo.

METHODS

Study 1: Dissection Study of Spread of Injectate

Ten cadavers (7 female, 3 male), donated to the Division of Clinical and Functional Anatomy of the Medical University of Innsbruck for scientific and educational purposes,[24,25] were dissected to evaluate the spread of dye following 2 different techniques of injection. All cadavers were preserved using an arterial injection of an ethanol-glycerol solution and immersion in phenolic acid in water for 1 to 3 months.[26,27]

Injections were carried out under real-time ultrasound guidance, using an Esaote ultrasound system with a high-frequency 13–4 MHz linear array probe (AL2442 probe, Esaote MyLab Seven US System;

Esaote, Genoa, Italy). The LFC nerve was identified in the FFFT in the transverse cross-sectional view approximately 10 cm distal to the ASIS, between the sartorius and the tensor fasciae latae muscles. The LFC nerve was traced proximally with ultrasonography to its point of entry into the FFFT after crossing the anterior surface of the sartorius muscle.

A 70-mm, 22-gauge, short-bevel needle (Stimuplex D Plus; B.Braun, Melsungen, Germany) was inserted out-of plane into the FFFT (Fig. 2), positioning the needle tip next to the nerve (Fig. 3). After randomization (right or left side), methylene blue 2% was injected bilaterally using 2 different techniques of injection: On 1 side, 5 mL was injected into the FFFT, keeping the needle tip immobile. On the contralateral side, 10 mL was injected intermittently into the FFFT and simultaneously advancing the needle tip inside the FFFT toward the ASIS, while tracking the needle tip dynamically with ultrasonography in real time (ie, dynamic needle-tip tracking).

If the FFFT was multicompartmentalized, the subdivision containing the LFC nerve branch that could be traced most proximally was chosen as the point of injection.

After completion of each injection, the investigator who performed the injection, left the dissection room, and another investigator (B.M.), who was blinded to the randomization and not present during the injections, carried out the dissection and documented the spread of dye.

Dissections were performed bilaterally in all 10 specimens. In order to decrease the risk of artifactual spread of dye, each dissection was performed immediately after injection.

Accordingly, 2 initial incisions, the first starting 2 fingerbreadths cranioposterior to the ASIS and extending horizontally 10 cm medially, and a second sagittal incision of approximately 20 cm over the proximal-lateral aspect of thigh went through the skin and subcutaneous tissue overlying the muscles. Subsequently, the triangular tissue flap was raised and reflected medially to expose the inguinal region and the fascia lata of the proximal thigh. The latter was split along the inguinal ligament, as well as distally over the tensor fasciae latae muscle. This exposed the sartorius and tensor fasciae latae muscles as well as the FFFT between
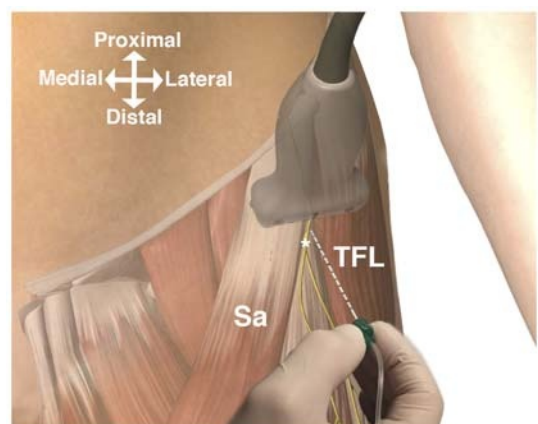
FIGURE 2. Scanning in the transverse plane provides the easiest recognizable ultrasonographic image of the FFFT and the LFC nerve. The out-of-plane needle insertion provides the shortest needle trajectory and is warranted for dynamic ultrasonographic needle-tip tracking in order to facilitate proximal spread during injection. Sa indicates sartorius muscle; TFL, tensor fasciae latae muscle; asterisk (*), LFC nerve. The figure is a modified excerpt from Essential Anatomy 5, with permission from 3D4Medical (www.3d4medical.com).

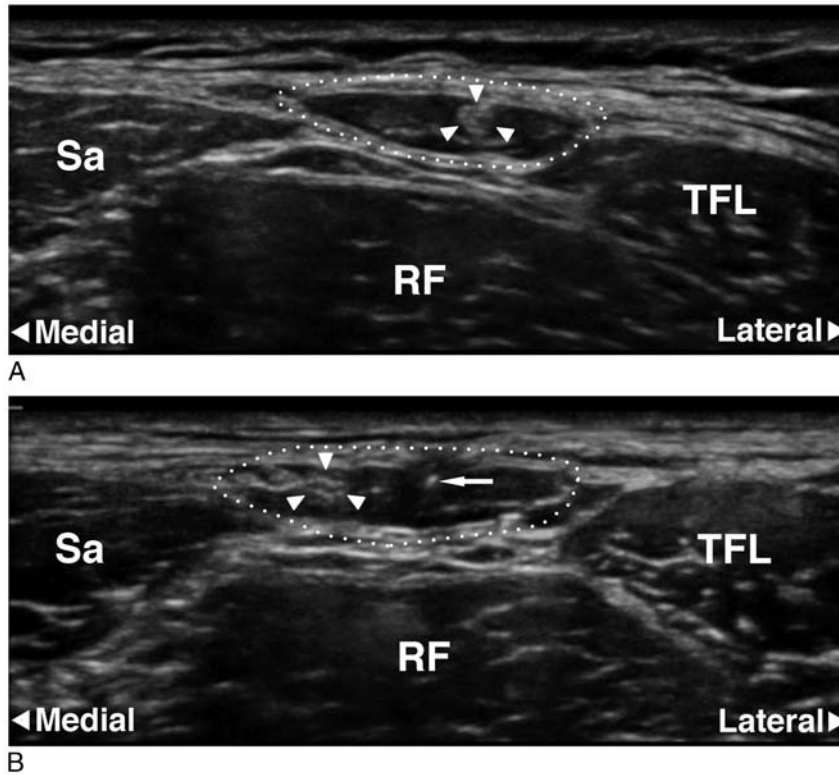**FIGURE 3.** A and B, Ultrasonographic images of the FFFT. A, Transverse scan 10 cm distal to the ASIS. The dotted line indicates the circumference of the FFFT. The hyperechoic LFC nerve (arrowheads) is surrounded by the anechoic (ie, black) fat inside the FFFT. B, Transverse scan 5 cm distal to the ASIS. The needle tip (arrow) is visualized in cross section. The LFC nerve (arrowheads) has just entered into the FFFT after crossing the anterior surface of the sartorius muscle (Sa). RF indicates rectus femoris muscle; TFL, tensor fasciae latae muscle.

them. Finally, all branches of the LFC nerve in the exposed area were identified and followed.

Dissection was not extended posterior to the ASIS to identify possible LFC nerve branches crossing the iliac crest at this position.

The end points of the dissection study were success of coloring all branches of the LFC nerve and success of spread proximally and anterior to the sartorius muscle using the 2 different techniques described above. The best injection technique as identified in the dissection study would be applied in the planned randomized controlled comparison of active LFC nerve block versus saline in the clinical study.

Study 2: Clinical Study of the Regional Anesthetic Effect

The study was registered in the EudraCT database (#2016-003213-98, August 17, 2016) and was approved by the Danish Health and Medicines Authority, the Central Denmark Region Committee on Biomedical Research Ethics, and the Danish Data Protection Agency and was monitored by the Good Clinical Practice Unit at Aalborg and Aarhus University Hospitals.

Twenty ASA I and II (American Society of Anesthesiology Physical Status classification) subjects 18 years or older were recruited through a Danish Web site for research volunteers. Subjects who were non-Danish or non-English speakers; had a weight of less than 55 kg, infection, or sensory neurological disorders in the area of the hip; and were pregnant or allergic to local anesthetic were excluded.

The study was conducted as a triple-blind RCT of bupivacaine versus placebo for the LFC nerve block on trial day 2 after prior

bilateral assessment of the area of complete anesthesia of the LFC nerve after the SI-FIC block on trial day 1 (Fig. 4). The study was carried out at the Department of Day Surgery, Aarhus University Hospital, Denmark, during a 2-day session in December 2016. Written informed consent was obtained from all subjects prior to the start of the trial. The volunteers received payment for participation.

The effect of blinded injection with either local anesthetic or placebo in the FFFT was compared with the anesthetized cutaneous area of the suprainguinal fascia iliaca compartment block, which served as a reference for complete anesthesia of the LFC in its intrapelvic trajectory prior to any branching of the LFC nerve.

The investigators who performed the nerve blocks also recorded the data concerning the nerve block procedure. Independent investigators recorded all other end points and performed all other procedures.

Each step in the trial procedure was carried out in separate rooms by individual investigators blinded to the assessments of all other investigators.

Trial Day 1: Bilateral Assessment of Maximum Area of Anesthesia

On the first day, the trial was conducted in 8 (1–8) steps in order to perform bilateral assessment of the maximum area of anesthesia after blockade of the LFC nerve using the SI-FIC block:

(1) Surgical incision lines as well as other reference lines were marked bilaterally on the skin with a UV pen (364 nm; J & Maya, Højbjerg, Denmark) (Figs. 5A, B). An orthopedic surgeon marked the surgical incision lines (J.B.), which are
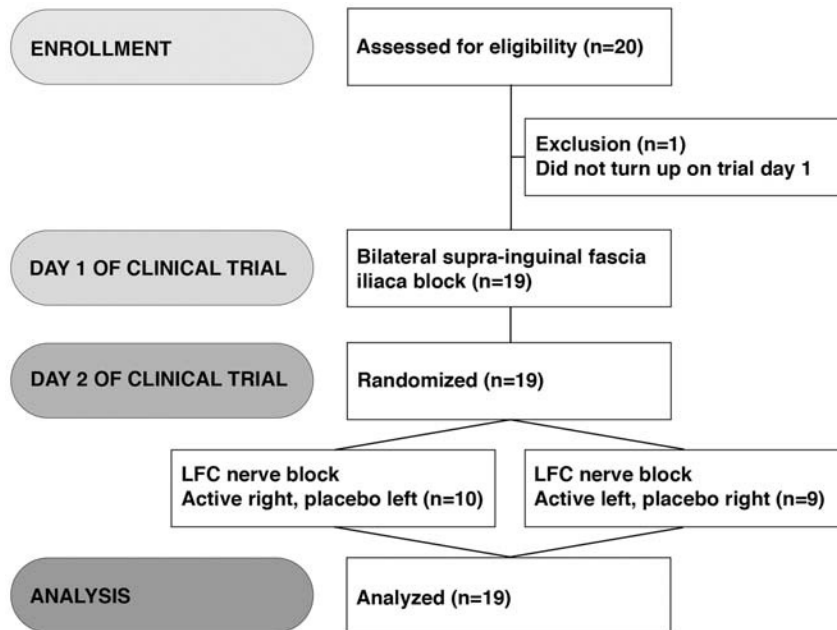
FIGURE 4. Flow diagram of the volunteer trial.

representative of the most commonly used surgical incisional approaches for hip surgery.[28,29]

(2) Prior to nerve blockade, bilateral baseline knee extensor muscle strength was recorded as the average of 3 measurements of maximum voluntary isometric contraction (MVIC), using a handheld dynamometer (Commander Muscle Tester; JTECH Medical, Midvale, Utah).[30]

(3) Bilateral SI-FIC nerve blocks were then performed in order to anesthetize the LFC nerve in its intrapelvic trajectory prior to any LFC nerve branching. Heart rate and oxygen saturation were monitored continuously during the block procedure. An 80-mm, 22-gauge, short-bevel needle (Ultraplex; B.Braun) was inserted in-plane distal to the inguinal ligament guided by ultrasound (15–6 MHz linear transducer, SonoSite X-Porte; FUJIFILM SonoSite, Inc, Bothell, Washington). The fascia iliaca was penetrated, and the fascial plane between the iliac muscle and the fascia iliaca was hydrodissected by the injectate while advancing the needle tip intrapelvically.[23] Twenty milliliters of 1% lidocaine with 1:200,000 epinephrine was injected bilaterally (Lidokain-Adrenalin SAD; Amgros I/S, Copenhagen, Denmark).

(4) One hour after completion of each pair of bilateral SI-FIC nerve blocks, postblock measurements of the knee extensor muscle strength were recorded bilaterally.

(5) Subsequently, the anesthetized area was defined using standardized pinprick (Neuropen; Owen Mumford, Woodstock, United Kingdom). A UV pen was used to mark points (invisible to the naked eye) along the margin of the area that was identified by pinprick.

(6) Another investigator illuminated the areas with UV light bilaterally and drew straight connecting lines with a UV pen between the marked points bilaterally and collected endpoint data.

(7) To assess interobserver variations, definition of the proximal margin of the anesthetized area was repeated with pinprick bilaterally and marked with a UV pen.

(8) The distance between the duplicate registrations was measured on the straight line intersecting the greater trochanter and the lateral edge of the patella (GT-P line) after illuminating the area with UV light.

Trial Day 2: Randomized Controlled Trial Procedure

On the second day, the trial was conducted in 5 (9–13) steps in order to perform a randomized controlled comparison of bupivacaine versus placebo for the LFC nerve block:

(9) Two independent investigators, responsible only for the trial medicine, sealed 20 consecutively numbered envelopes, each with 1 syringe containing 10 mL 0.25% bupivacaine (Marcain; AstraZeneca A/S, Albertslund, Denmark) and 1 syringe containing 10 mL of isotonic saline. Each syringe in every pair was randomly marked either "left" or "right." The investigators kept the randomization list until after the data analysis was completed.

(10) The skin of the lateral thigh was assessed bilaterally with pinprick in each subject to ensure complete cessation of anesthesia from trial day 1. The subjects were then randomized to a number between 1 and 20. This number decided which envelope containing the trial medicine should be used for the following LFC nerve block.

(11) Lateral femoral cutaneous nerve block technique: The LFC nerve block was performed bilaterally with the subject in the supine position. The FFFT injection technique was identical to the most efficient of the 2 ultrasound-guided technique described in METHODS of the dissection study, using 10 mL of injectate and an echogenic nerve block needle (Ultraplex; B.Braun). A linear high-frequency transducer (15–6 MHz linear transducer, SonoSite X-Porte; FUJIFILM SonoSite, Inc) was used to dynamically guide the proximal advancement of the needle tip during injection.

(12) Thirty minutes after completion of the LFC nerve block, the anesthetized area was assessed with pinprick. This procedure was performed as described above except that the marking of the points was done with a normal pen. Two investigators assessed the 2 sides independently in separate rooms. If no area
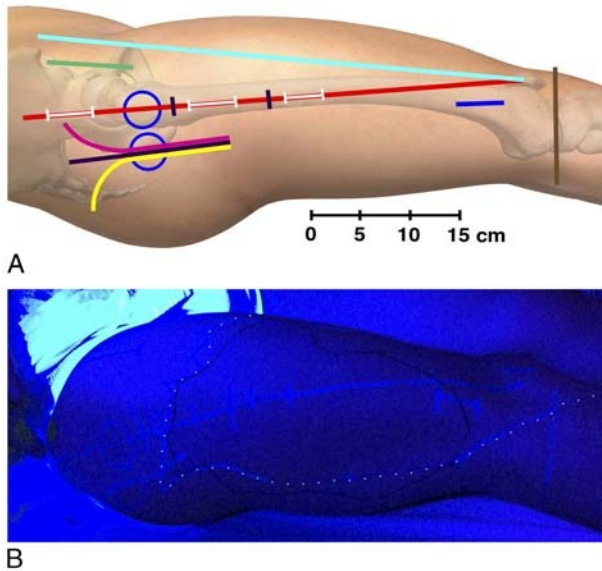
FIGURE 5. A, Graphical depiction of the reference and incision lines marked at the beginning of the trial with a UV marker. The anterior, anterolateral, direct lateral, and posterior approaches are used for hemiarthroplasty and total hip arthroplasty. Sliding hip screw devices, IM nails, and parallel implants (screws and hook-pins) are used for femoral neck and extracapsular proximal femoral fractures. Anterior blue circle, surface projection of the greater trochanter with the subject in the supine position and 20-degree internal rotation; posterior blue circle, surface projection of the greater trochanter with the subject in the lateral position; red line, GT-P line (straight line intersecting the greater trochanter and the lateral edge of the patella); cyan line, ASIS-P line (straight line intersecting the ASIS and the lateral edge of patella); brown line, tibiofemoral joint line; green line, anterior incision; magenta line, anterolateral incision; black line, direct lateral incision; yellow line, posterior incision; proximal white line on the red line, incision for entry point of IM nail; intermediate white line on the red line, incision for proximal locking of an IM nail; distal white line on the red line, incision for distal locking screws of a short IM nail; blue line, incision for distal locking screws of a long IM nail; the red line segment between the 2 black markings, incision for sliding hip screw or parallel implants (parallel screws or hook-pins). The figure is a modified excerpt from Essential Anatomy 5, with permission from 3D4Medical (www.3d4medical.com). B, Photography of the lateral thigh while illuminated with UV light by the last investigator on day 2 of the clinical trial. Incision and reference lines are the same as in A. The solid black line outlines the area anesthetized by the LFC nerve block. The UV marking of the area anesthetized by the SI-FIC nerve block on day 1 is marked with a superimposed white dotted line.

of anesthesia was identified, a sham marking of the skin was carried out in order to blind subsequent investigators.

(13) Following the assessment, the right and left sides were illuminated with UV light (Fig. 5B), each side separately in separate rooms by different investigators, in order to record the anesthesia outcome data.

Primary End Point

The primary end point was successful proximal anesthesia of the lateral thigh after the LFC nerve block of bupivacaine versus placebo LFC nerve block in the FFFT in the RCT. Successful proximal anesthesia of the lateral thigh was defined as anesthesia extending to the proximal border of the area anesthetized with the SI-FIC block performed on trial day 1, which served as the reference for complete anesthesia of the LFC nerve. A maximum deviation of 3 cm was allowed (measurement error) based on previous pilot data. The distance was measured on the axis of the line intersecting the greater trochanter and the lateral edge of the patella (GT-P line).

Secondary End Points

The study included the following 12 (a-m) secondary outcomes: (*a*) distance from the proximal margin of the anesthetized area to the greater trochanter after the LFC nerve block; (*b*) distance from the proximal margin of the anesthetized area to the greater trochanter after the SI-FIC block; (*c*) distance from the distal margin of the anesthetized area to the tibiofemoral joint line after the LFC nerve block; (*d*) distance from the distal margin of the anesthetized area to the tibiofemoral joint line after the SI-FIC block (the distal extent of the SI-FIC block was not measured beyond the tibiofemoral joint line; in case of anesthesia distal to the joint line, the distance was registered as 0 cm); (*e*) inclusion of each marked surgical incision line in the anesthetized area after the LFC nerve block (total, partial, or absent inclusion); (*f*) success rate of total inclusion of the distal locking incision of the long intramedullary (IM) nail; (*g*) anteromedial and posterolateral extent of the anesthetized area after the LFC nerve block; (*h*) frequency of motor block of the femoral nerve after the LFC nerve block (motor block was defined as at least 25% reduction in MVIC compared with baseline measurements); (*i*) frequency of motor block of the femoral nerve after the SI-FIC block; (*j*) duration of anesthesia after the LFC nerve block; (*k*) quality of ultrasonographic visualization of the LFC nerve inside the FFFT (good, reduced, poor); (*l*) LFC nerve block performance time; (*m*) discomfort during LFC nerve block performance (numeric rating scale [NRS] 0–10 from no discomfort [0] to worst imaginable discomfort [10]).

Data were collected and recorded using the secure, online database system REDCap (6.15.4 Vanderbilt University, Nashville, Tennessee).

Statistical Analysis

Statistics were analyzed using Stata 13.1 (StataCorp LLC, College Station, Texas). Differences between paired categorical variables (success/failure) were analyzed with McNemar test and presented with rate, *P* value, and approximated confidence intervals (CIs). The level of significance was 0.05. Other results are presented as mean with 95% CI and SD, or median and interquartile range as appropriate. Descriptive bilateral variables (distances, procedure duration, discomfort) were analyzed using data from the sides randomized to active treatment on day 2 only.

Our null hypothesis was no difference in success rate for local anesthetic compared with placebo regarding anesthesia of the proximal branches of the LFC nerve using the novel LFC nerve block technique (see Primary End Point).

RESULTS

Dissection Study

The LFC nerve and all its branches were stained in all 10 cadaver sides injected with 10 mL using dynamic needle-tip tracking (100%; 97.5% CI, 69.2%–100% [1-sided]). In 2 of the 10 cadaver sides injected with 5 mL and immobile needle tip, the most proximal of the LFC nerve branches was not stained (Fig. 6). In the other 8 cadaver sides injected with 5 mL, all the branches were stained (80%; 95% CI, 44.4%–97.5%), and the difference of 20% (95% CI, −14.8% to 54.8%) between the 2 techniques was not statistically significant (*P* = 0.5).
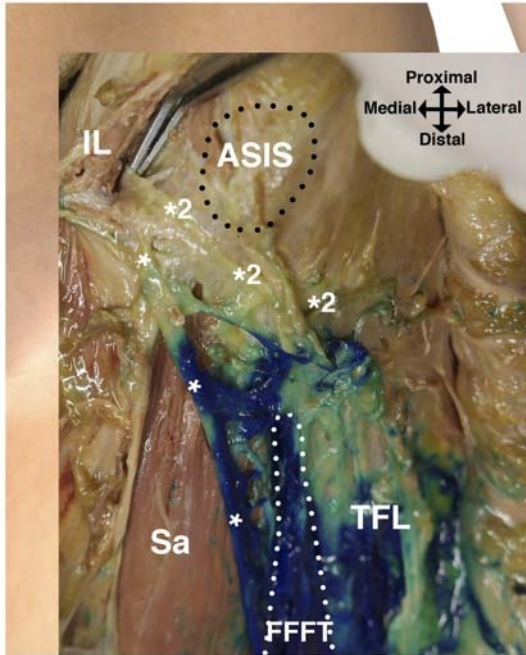
FIGURE 6. Dissection of the left side of a cadaver in the supine position after injection of 5 mL of methylene blue into the FFFT (white dotted line). Most of the dye is confined inside the FFFT with some spread across the surface of the tensor fasciae latae muscle (TFL). Across the surface of the sartorius muscle (Sa), the dye spread only narrowly along the LFC nerve (*) toward the inguinal ligament (IL). In this cadaver, the proximal spread of dye did not extend to the proximal LFC nerve branch (*2) branching off just distal to the IL. The proximal LFC nerve branch crosses just inferior to the ASIS and ramifies to innervate the gluteal skin without entering the FFFT.

The FFFT and the LFC nerve inside the FFFT could be identified ultrasonographically in all cadaver sides. The mean distance from the ASIS to the point of needle insertion was 6.9 cm (95% CI, 5.5–8.2 cm) on the side injected with 5 mL and 5.2 (SD, 1.0) cm (95% CI, 4.5–5.9 cm) on the side injected with 10 mL. The dye spread outside the FFFT, across the anterior surface of the sartorius muscle deep to the fascia lata, in all 10 cases of the cadaver sides injected with 10 mL, 100% (97.5% CI, 69.2%–100% [1-sided]), and in 4 of the 10 cadaver sides injected with 5 mL, 40% (95% CI, 12.2%–73.8%). The difference of 60% (95% CI, 19.6%–100%) was statistically significant (*P* = 0.03).

Clinical Study

Twenty volunteers were enrolled in the study. One volunteer did not show up on the first day of the trial and was excluded. The 19 remaining volunteers (Table 1) all had successful bilateral SI-FIC blocks on day 1. On trial day 2, after the randomized bilateral LFC nerve blockade with bupivacaine versus placebo, cutaneous anesthesia was found on the lateral thigh in 18 of the 19 active sides, 94.7% (95% CI, 73.9%–99.8%), and in 0 of 19 in the placebo sides, 0% (95% CI, 0.0%–17.6%), difference of 94.7% (95% CI, 79.4%–100%; *P* < 0.001).

Primary Outcome

The LFC nerve block successfully produced anesthesia that reached as proximal as the area anesthetized by the reference SI-FIC block in 13 of the 19 active sides, 68.4% (95% CI,

TABLE 1. Characteristics of the Study Group (n = 19)

Age, y	27 (8.9)
Height, cm	175 (9.6)
BMI, kg/m^2	24.5 (1.7)
ASA I:II	19:0
Female:male	8:11

Values are mean (SD) or n.

BMI indicates body mass index (calculated as kilograms divided by the square of height in meters).

43.4%–87.4%), and in 0 of the 19 placebo sides, 0% (95% CI, 0.0%–17.6%). The difference between active and placebo LFC nerve block in the FFFT was 68.4% (95% CI, 42.3%–94.6%), which is statistically significant (*P* < 0.001).

The success rates of the LFC nerve block to include the different incisions in the anesthetized area are presented in Figure 7. Total inclusion of the distal incision line for the long IM nail locking screws demonstrated a success rate of 89.5% (95% CI, 66.9%–98.7%) after the SI-FIC nerve block.

The proximal border of the anesthetized area was distal to the greater trochanter on average after the LFC nerve block as well as the reference SI-FIC nerve block. The mean distances from the proximal margin of the greater trochanter to the proximal margin of the area anesthetized by the LFC nerve block (Fig. 8) and the SI-FIC block were 7.9 (SD, 8.0) cm (95% CI, 3.9–11.9 cm) and 6.8 (SD, 5.3) cm (95% CI, 4.2–9.3 cm), respectively.

The distal border of the anesthetized area after the LFC nerve block was on average 7.6 (SD, 6.6) cm (95% CI, 4.3–10.9 cm) proximal to the tibiofemoral joint line (Fig. 8).

The SI-FIC block produced an area of cutaneous anesthesia of the lateral thigh that extended distal to the tibiofemoral joint line in the majority of subjects, crossing the crus obliquely distal to the patella to continue medially corresponding to the territory of innervation of the saphenous nerve. As the distance to the joint line was registered as 0 cm per protocol if the anesthesia extended distal to the joint line, the mean distance from the area anesthetized by the SI-FIC block to the tibiofemoral joint line was 0.7 (SD, 1.3) cm (95% CI, 0.1–1.3 cm).

Anteromedially, the anesthetized area after the LFC nerve block crossed the anterior line connecting the ASIS to the lateral edge of the patella (ASIS-P line) in 77.8% (95% CI, 52.4%–93.6%), with a mean
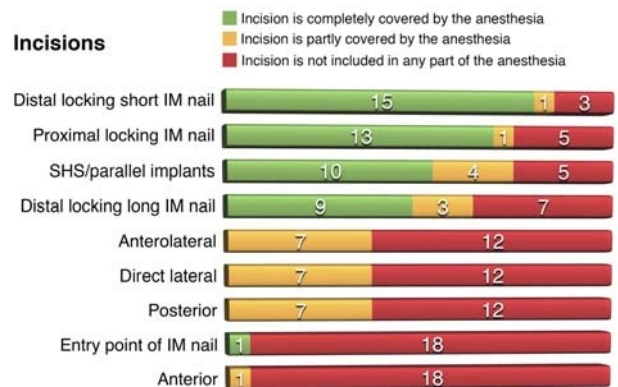

FIGURE 7. Success of the anesthetized area to cover specific incisions after the FFFT nerve block. For each of the incisions, the corresponding bar shows the actual number of successes, partial successes, or failures.
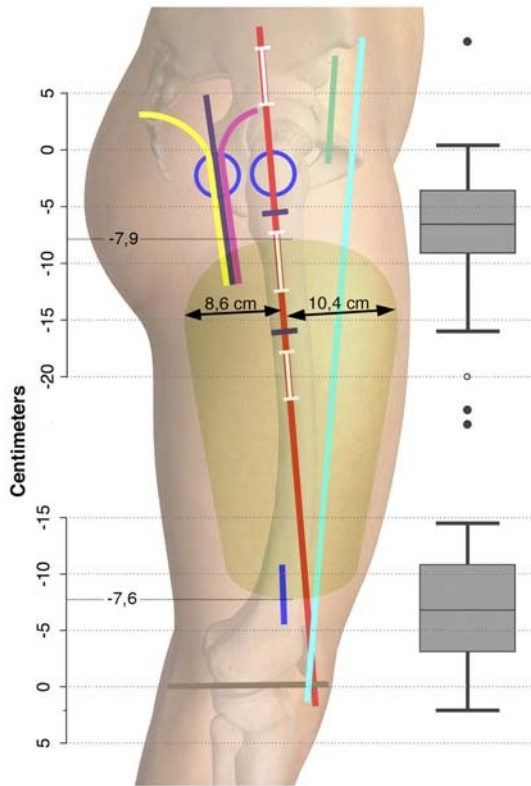
FIGURE 8. The green area summarizes the average extent of the anesthetized area after an FFFT nerve block. The mean distances defining the proximal-distal extent of the anesthetized area are as follows: −7.9 cm below the greater trochanter and −7.6 cm above to the tibiofemoral joint line, respectively. The anteromedial-posterolateral extension (double-headed arrows) was 10.4 cm to the GT-P line from the anteromedial margin and 8.6 cm from the posterolateral margin. The box plots display the median, range, and interquartile range of the distal and proximal distances from the anesthetized area to the greater trochanter and the tibiofemoral joint line, respectively. Four outliers are shown as 1 hollow circle belonging to the distal box plot and the 3 solid circles belonging to the proximal box plot. Lines and incisions are explained in Fig. 4A. The figure is a modified excerpt from Essential Anatomy 5, with permission from 3D4Medical (www.3d4medical.com).

distance to the line of 2.9 (SD, 3.6) cm (95% CI, −1.6 to 4.7 cm). Positive values mean that the medial border of the anesthetized area is medial to the ASIS-P line. The maximum anteromedial extent of the anesthetized area, measured from the GT-P line and perpendicular to this line, was on average 10.4 (SD, 3.4) cm (95% CI, 8.7–12.1 cm), and the average maximum posterolateral extent was 8.6 (SD, 2.4) cm (95% CI, 7.4–9.8 cm) (Fig. 8).

The LFC nerve block was successful in avoiding motor block of the femoral nerve in 18 of the 19 subjects, 94.7% (95% CI, 74.0%–99.9%). In the 1 remaining subject, the reduction in MVIC was 33%. As a comparison, a motor block was avoided in only 2 of the 19 subjects, 10.5% (95% CI, 1.3%–33.1%), after receiving the SI-FIC nerve block. The difference between the SI-FIC and the LFC nerve block was 84.2%, which is statistically significant ($P < 0.001$).

The quality of the ultrasonographic visualization of the LFC nerve inside the FFFT was graded as good bilaterally in 16 of the 19 subjects. In 3 subjects, it was good on one side and reduced on the other. The ultrasonographic visualization was not graded as poor in any of the subjects.

The duration of the LFC nerve block procedure was on average 3.4 (SD, 1.6) minutes (95% CI, 2.6–4.2 minutes) from the beginning of the scan to the end of injection.

Discomfort during the LFC nerve block procedure was scored using the NRS from 0 to 10. Median NRS was 3 (interquartile range, 2–3).

Mean duration of anesthesia after the LFC nerve block, based on self-reporting, was 27.0 hours (95% CI, 20.4–33.6 hours; range, 10.2–63.7 hours).

The distance between the duplicate measurements of the proximal margin of the anesthetized reference area on trial day 1 showed a mean of 1.2 (SD, 4.5) cm (95% CI, −1.0 to 3.3 cm; fifth percentile, −7.5 cm).

DISCUSSION

Dissection Study

Prior to the present volunteer trial, we conducted a dissection study to assess and compare the feasibility of novel LFC nerve block techniques using injection into the FFFT.

The consistent location of the LFC nerve within the FFFT had already been established.[20–22] However, it was unknown if proximal branches crossing the sartorius muscle distal to the ASIS traverse the FFFT to reach the gluteal area or bypass the FFFT by superficial or proximal trajectories. In case of all nerve branches passing through the FFFT, a minimal volume injected into the FFFT could be speculated to suffice. In case of nerve branches bypassing the FFFT, concomitant spread of injectate outside the FFFT would be required for complete anesthesia of the LFC nerve. Hence, 2 different techniques were compared in the dissection study in order to obtain an intra-FFFT spread versus an extra-FFFT spread: a low volume (5 mL) injected with a static needle-tip position versus a larger volume (10 mL) injected with dynamic needle-tip tracking. The injection of 10 mL of dye with simultaneous proximal advancement of the needle caused the dye to spread proximally throughout the FFFT and outside the FFFT, deep to the fascia lata on the anterior surface of the sartorius muscle. An interesting finding was that the dye spread tightly along the nerves beyond the overall spread of the dye (Fig. 6), typically reaching the inguinal ligament in the cadaver sides injected with 10 mL.

Injection into the FFFT facilitated spread in the correct layer deep to the fascia lata when dye was observed outside the FFFT. Spread of dye outside the FFFT and along the LFC nerve was of consequence, because proximal LFC nerve branches did not always enter the FFFT (Fig. 6) and were colored only by spread outside the FFFT in some sides. The 2 proximal nerves unstained by the two 5-mL injections traversed the area just distal to the ASIS without entering the FFFT.

Because of the more extensive spread with the 10-mL technique with complete coloring of the proximal LFC nerve branches, we selected this technique for the clinical study, although a statistically significant difference of success in coloring all nerve branches could not be demonstrated within this sample of 20 cadaver sides.

Certain limitations to the dissection study should be mentioned. The dissection study was exploratory and not powered to show a statistically significant difference in success rate of coloring all nerve branches between the 2 FFFT injection techniques. Furthermore, the spread of injectate found by dissection in soft embalmed cadavers may not accurately reflect the spread of local anesthetic in the living person.

It can be speculated that the observed nonsignificant difference in distance between the ASIS and the point of needle insertion might have affected the results. In the case of the 2 injections that failed to color the proximal LFC nerve branches,

both failures were caused by 5-mL injections not spreading outside the FFFT. Probably the successful spread outside the FFFT is primarily due to the volume of the injectate. Thus, it is unlikely that a needle insertion point of the 5-mL injections a few centimeters more proximal would have changed the results.

Finally, we explored only the spread of 5 and 10 mL of injectate. Despite the high success rate of coloring all nerve branches in the soft embalmed cadavers, it can be speculated that a larger volume (eg, 15 mL) would be needed to achieve an equivalent spread in living patients. Consequently, assessment of the optimal technique and volume of an LFC nerve block in the FFFT requires further research.

Clinical Trial

The clinical study of 19 human volunteers demonstrated that 10 mL of local anesthetic injected into the FFFT while advancing the needle proximally with dynamic needle-tip tracking is successful in anesthetizing the LFC nerve with an approximate success rate of 95%. The reason why 1 block failed to anesthetize the LFC nerve despite good ultrasonographic visualization of the FFFT and the nerve therein can only be speculative. The needle was inserted at the level of the anterior LFC nerve as it entered the FFFT, followed by proximal dynamic advancement of the needle tip in the FFFT while performing intermittent injections. This technique is meant to ensure an initial spread around the anterior LFC nerve main trunk, as well as a final proximal needle-tip position that ensures spread to the proximal LFC nerve branches. It is possible in the case of the single failure that injection was initiated too proximal in the FFFT to reach the anterior LFC nerve main trunk.

The nerve block procedure was uncomplicated in terms of easy ultrasonographic identification of the FFFT and LFC nerve, short procedure time, and low procedural discomfort. Concomitant femoral motor block defined by more than a 25% reduction in MVIC was avoided in all but 1 subject. The MVIC reduction of 33% in this subject, however, did not result in any subjective reduction in muscle strength, and the subject was able to walk at all times.

The duration of anesthesia was 27 hours on average, which is longer than expected with bupivacaine.[31] Data on duration of LCF nerve blockade are not available from other studies. It should be noted that the duration was self-reported by each subject as the time until the return of normal sensation in the anesthetized area after they had returned home.

The anesthetized area after the LFC nerve blockade extended distal to the tibiofemoral joint line in only 1 subject, and the mean distance was 7.6 cm proximal from the anesthetized area to the joint line. After the reference SI-FIC block, the anesthetized area of the lateral thigh extended distal to the tibiofemoral joint line in 13 of the 19 subjects. In the remaining 6 subjects, the anesthetized area of the lateral thigh abutted the joint line without extending beyond it. The difference in distal extent between the SI-FIC and the LFC nerve block was expected because of blockade of the anterior cutaneous branches of the femoral nerve with the SI-FIC block. The distal extension of the anesthetized area is clinically relevant for anesthesia of the surgical incision for the distal locking screws applied for the long IM nail, which is why the success of the SI-FIC block to cover this specific incision was included as a specific secondary end point. Complete coverage of this particular surgical incision line was raised from a success rate of 50% for the LFC nerve block to 89.5% for the SI-FIC block. To the best of our knowledge, a selective nerve block of the anterior cutaneous branches of the femoral nerve has never been published.

The proximal border of the anesthetized area reached the proximal margin of the greater trochanter in only 2 of 19 subjects

after the LFC nerve block, as well as after the reference SI-FIC block. On average, the proximal border of the anesthetized area after both nerve block techniques was several centimeters distal to the proximal margin of the greater trochanter. This result strongly indicates that blockade of the LFC nerve, regardless of nerve block technique, cannot be expected to have any analgesic effect proximal to the greater trochanter. This is consistent with the findings by Davies et al,[17] who found only very limited anesthesia of the surgical incisions used for hip arthroplasty after a nerve block of the LFC nerve.

The surgical incision lines that we have included in this trial represent the incision lines most commonly used for hip surgery.[28,29] The assessment of anesthesia of each surgical incision line suggests that the LFC nerve block does not anesthetize the surgical incision of the anterior approach or the surgical incision for the entry point of the IM nail. Furthermore, the anterolateral, the direct lateral, and the posterolateral incision lines were only partially included in the anesthetized area, suggesting that the LFC nerve block is required but not sufficient to anesthetize the area intersected by these surgical incisional approaches. Finally, the incision lines representing the sliding hip screw and parallel implants (parallel screws or hook pins), together with the proximal IM nail locking and the short IM nail distal locking screws, were all completely included in the anesthetized area in more than 50% of the subjects. For these incision lines, the LFC nerve block is the most relevant nerve block.

The primary end point of the present volunteer trial was success rate of cutaneous anesthesia of the area innervated by the most proximal branches of the LFC nerve in the randomized comparison of bupivacaine versus placebo for the LFC nerve block. The maximum proximal extent of this area was defined prior to the RCT by the area anesthetized with the reference SI-FIC block. According to this definition, the LFC nerve block technique failed to anesthetize the proximal branches of the LFC nerve in 32% (Fig. 9). Thus, a success rate of 68% was recorded. This result was statistically significant when compared with placebo. A priori, a success rate of 100% was not anticipated because of well-documented anatomical variations of the branching and distribution patterns of the LFC nerve. In 22% to 28% of cadaver sides in previous dissection studies, an LFC nerve branch is reaching the proximal aspect of the thigh by crossing the ASIS,
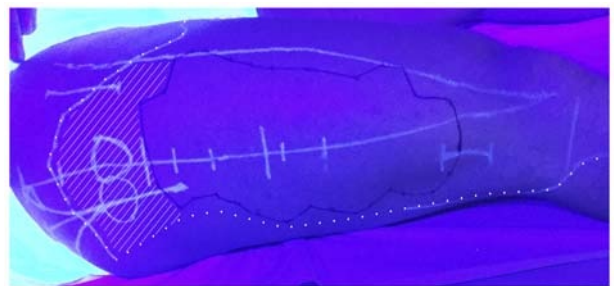

FIGURE 9. Photography of the lateral thigh while illuminated with UV light on day 2 of the clinical trial. The shaded area represents an example of a failure to anesthetize the proximal branches of the LFC nerve. There is approximately 10 cm between the proximal border of the area anesthetized by the SI-FIC block (superimposed white dotted line) and the proximal border of the area anesthetized by the LFC nerve block (solid black line). In this image, the proximal margin of the SI-FIC block is atypical as it extends beyond the average. In the majority of subjects, the proximal border of the anesthetized area was distal to the greater trochanter.

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and in 11% to 18%, an LFC nerve branch reaches the proximal thigh by crossing the iliac crest posterior to the ASIS.[9,10] The results of our dissection study support that the LFC nerve branches crossing the ASIS can be anesthetized with an injection into the FFFT. However, branches crossing the iliac crest posterior to the ASIS cannot be reached by this nerve block technique. To the best of our knowledge, a nerve block technique that anesthetizes these branches has not yet been published other than presumably the fascia iliaca compartment technique, anesthetizing the LFC nerve in its intrapelvic trajectory prior to any branching. Consequently, a failure rate of 10% to 20% for the LFC nerve block based on injection into the FFFT was expected a priori. In other words, we could not expect more than 80% success rate of inclusion of the most proximal branches of the LFC nerve with the FFFT technique. The discrepancy between the expected and observed success rates (80% and 68.4%, respectively) is due to either suboptimal proximal spread of local anesthetic with the FFFT technique, suboptimal performance of the FFFT technique, too short observation time after block performance, or measurement error.

We allowed a measurement error of 3 cm per protocol in the comparison of proximal margin of the anesthetized area between the 2 techniques based on pilot data. However, our repeated estimates of the proximal margin of the anesthetized area with the SI-FIC nerve block technique demonstrated that this error was too narrow to allow the intended type 1 measurement error of 5%. If the correct fifth percentile of the duplicate measurements (−7.5 cm) were used as the allowed deviation for our primary end point, the success rate would be 79% (15/19; 95% CI, 54%–94%) instead of the 68%.

Some other limitations to the volunteer trial should be mentioned: In the volunteer trial, the distance from the needle insertion point to the ASIS was not measured. If spread outside the FFFT is obtained, which is positively correlated to the volume of injectate according to the dissection study, then the level of needle insertion presumably affects the proximal extent of this spread. However, a significant difference in the mean distance between active and placebo sides would be unlikely because of the randomized and blinded design.

Moreover, the volunteer trial was conducted in a group of subjects who differed concerning age, weight, and comorbidities compared with the typical hip surgery patients. Even though individual patterns of innervation are not believed to change through life and should therefore not affect the primary end point, other end points may show to be different in a group of patients, for example, performance time and quality of ultrasonographic visualization.

Finally, we used the SI-FIC block as a criterion standard of anesthesia of all branches of the LFC nerve. The proximal border of the anesthetized area after the LFC nerve block was compared with this criterion standard. If the SI-FIC block does not reliably anesthetize all LFC nerve branches, the success rate of the LFC nerve block of anesthetizing the proximal LFC nerve branches would be overestimated. Our validation of the technique is based on a previous dissection study of the SI-FIC block technique. In that study, coloring of the LFC nerve in its intrapelvic trajectory was assessed to be reliable in all cadaver sides.[23] This finding was further supported by a more recent study of clinical anesthesia of the lateral thigh.[32] Anesthesia was found in all subjects in a case series of patients receiving a suprainguinal fascia iliaca block. The 100% bilateral success rate of lateral anesthesia after the SI-FIC block performed in the current study additionally adds to the validation of the SI-FIC block to reliably anesthetize the LFC nerve.

Blockade of the nerves innervating the skin area proximal to the area innervated by the LFC nerve could serve as an alternative method of assessing the success rate of anesthetizing the proximal LFC nerve branches in future research trials. Continuity of the area anesthetized by the 2 nerve blocks would allow estimation of the frequency of anesthesia of the proximal LFC nerve branches. In addition, anesthesia of the area proximal to the area innervated by the LFC nerve is a clinically relevant issue in order to anesthetize the skin intersected by most surgical incisions as demonstrated by the present study.

CONCLUSIONS

The present study demonstrates that cadaveric injection of 10 mL of dye in the FFFT with dynamic needle-tip tracking toward the ASIS under ultrasound guidance produces spread of dye to the proximal branches of the LFC nerve.

Applying this novel LFC nerve block technique in the randomized volunteer trial demonstrated that this new nerve block technique was safe and easy to perform with a success rate of anesthetizing the LFC nerve of 95%. The area of clinical anesthesia was distal to the proximal border of the greater trochanter in the majority of the subjects. The surgical incisions extending proximal to the greater trochanter were typically not completely covered by the LFC nerve block. The most proximal LFC nerve branches were anesthetized with a success rate of 68% when the SI-FIC block was used as a reference of the entire LFC nerve territory of innervation. Further research is needed to obtain complete cutaneous anesthesia of the areas intersected by the different hip surgery approaches.

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