Research Article

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Subparaneural injection in popliteal sciatic nerve blocks evaluated by MRI

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Abstract: Intraneural injection of a local anesthetic can damage the nerve, yet it occurs frequently during distal sciatic block with no neurological sequelae. This has led to a controversy about the optimal needle tip placement that results from the particular anatomy of the sciatic nerve with its paraneural sheath.

The study population included patients undergoing lower extremity surgery under popliteal sciatic nerve block. Ultrasound-guidance was used to position the needle tip subparaneurally and to monitor the injection of the local anesthetic. Sonography and magnetic resonance imaging were used to assess the extent of the subparaneural injection.

Twenty-two patients participated. The median sciatic cross-sectional area increased from 57.8 mm2 pre-block to 110.8 mm^2 immediately post-block. An intraneural injection according to the current definition was seen in 21 patients. Two patients had sonographic evidence of an intrafascicular injection, which was confirmed by MRI in one patient (the other patient refused further examinations). No patient reported any neurological symptoms.

A subparaneural injection in the popliteal segment of the distal sciatic nerve is actually rarely intraneural, i.e. intrafascicular. This may explain the discrepancy between the conventional sonographic evidence of an intraneural injection and the lack of neurological sequelae.

Keywords: Popliteal sciatic nerve block; Subparaneural injection; Intraneural injection; Ultrasound-guidance; Magnetic resonance imaging

1 Introduction

An intraneural injection of local anesthetic during peripheral nerve block can cause serious and potentially permanent nerve damage [1]. The measures adopted to prevent this complication include the use of ultrasound and/or nerve stimulation to determine the relative positions of the nerve and the needle tip. Ultrasound has the added advantage in that it allows real-time detection of an intraneural injection.

However, there is a discrepancy between the reported incidence of intraneural injections in distal sciatic nerve block and the incidence of clinical signs of nerve damage associated with this procedure [2,3]. The currently recommended ultrasound criteria for the diagnosis of an intraneural injection into the sciatic nerve (SN) are the presence of a liquid pool "within outer epineurium", an increase in the cross-sectional area of the nerve, and an increased tibial-peroneal spread [4]. Using these criteria, an intraneural injection during popliteal SN block occurs in up to 94%, although in two studies there was no evidence of nerve damage either in postoperative neurophysiological examination or in the clinical follow-up [2,3]. Conversely, the reported overall incidence of persisting postoperative nerve damage after peripheral nerve block is less than 0.1% [5]. This raises the question of whether the SN might be particularly insensitive to local anesthetic damage, or that the diagnostic criteria for intraneural injection might be too unspecific, as the SN occupies a special position among peripheral nerves. In the popliteal

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fossa, the SN divides into the tibial and the common peroneal nerves. In addition, half of the total cross-section inside the epineurium consists of non-neural connective tissue [6]. Much controversy has arisen about defining the outermost sheath (also referred to as outer epineurium, common epineural sheath, paraneural sheath, or circumneural sheath) and the proper injection site [4,7-11]. A "subepineural" injection in the conventional sense of the term [12] of the local anesthetic at the bifurcation of the SN would thus produce all sonographic criteria described above for an intraneural injection [4]. But with regard to the separate tibial and peroneal nerves, which are enveloped "within the common paraneural sheath" [8] referred to as "outer epineurium" [4] at this site, it would actually be an extraneural injection inside this "subparaneural compartment" [9, 10].

The aim of this study was to compare the currently recommended ultrasound criteria for intraneural injection [4] with structural changes in the SN using delayed magnetic resonance imaging (MRI). We performed an ultrasound-guided popliteal SN block in patients undergoing lower limb surgery. The needle tip was preferentially advanced through the above-mentioned outermost paraneural sheath to inject the local anesthetic between the tibial and peroneal nerves. The incidence of intrafascicular fluid in the SN was analyzed using MRI scans. These are more sensitive than computer tomography for detecting interstitial fluid accumulation and should therefore detect intrafascicular fluid more reliably.

2 Methods

The presented data relating sonographic and MRI evidence of intraneural injection of local anesthetic to clinical nerve damage are part of larger trial comparing neural stimulation-guided versus ultrasound-guided sciatic nerve block. This research as related to human use complies with all relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration, and has the approval of the ethics committee of the University of Goettingen Medical School (No. 4/1/12). It was registered with the clinical trial number DRKS00008767 at the German clinical trial registry DRKS on June 23, 2015.

Patients (18 to 80 years old, ASA I - III) scheduled for surgery of the lower extremity were recruited for the study. They gave written informed consent for the peripheral SN block, the required MRI scans, and the storage and evaluation of their data. Two consultant anesthetists assisted by an anesthesiology intern conducted the study.

All blocks were performed by staff anesthesiologists or senior residents under staff supervision according to German national standards [13]. The puncture site 5- to 10-cm proximal to the popliteal fossa was disinfected and the skin infiltrated with 1% mepivacaine. The regional block needle (21G, 100 mm, SonoPlex Stim cannula, Pajunk®, Geisingen) was advanced under ultrasound guidance (M-Turbo® 12 MHz transducer; FujiFilm SonoSite®) until its tip was 0 to 0.5 cm proximal to the bifurcation of the SN. Ropivacaine 0.375% (maximum 20 ml) and prilocaine 1% (maximum 10 ml) were then injected until fluid could be seen surrounding the entire circumference of the SN. Our aim was to insert the needle through the common paraneural sheath of the SN and to inject the local anesthetic subparaneurally between the tibial and peroneal nerves to obtain an early effect onset, as described by Perlas and colleagues [8]. To avoid mechanical nerve injury resulting from repeated repositioning of the needle, the position was changed only if there was sonographic evidence of an injection between nerve fascicles (*intrafascicular*). A successful injection was defined as either the presence of the local anesthetic in a pool inside the paraneural sheath (*subparaneural*) but not intrafascicular, or/and encircling at least >180° of the circumference of the SN. The sonographic images were stored for later evaluation.

Onset of effect was assessed by the loss of temperature discrimination. This and the sonographic finding of local anesthetic surrounding the nerve were considered sufficient evidence of an adequate effect. The patients were questioned with regard to paresthesias, which were documented if they occurred. General anesthesia with propofol and remifentanil was then induced in patients with operations requiring a thigh tourniquet or the removal of bone graft from the iliac crest.

2.1 Sonography

We assessed the ultrasound images for the traditional four signs of an intraneural injection into the SN (in its entirety including tibial and peroneal nerve) following the slightly modified classification of intraneural injection by Sala-Blanch and co-workers [4]. These are: (1) increase in the cross-section of the SN ≥15% during injection; (2) separation of the paraneural sheath (referred to as "outer epineurium") from the SN by the injectate = *subparaneural* injection; (3) separation of tibial and peroneal nerve by the injectate = *tibial-peroneal nerve separation*. In this case, the local anesthetic would be also classified as *subparaneural* with regard to the SN, but not *intrafascicular*

with regard to the tibial and peroneal nerves; (4) separation of fascicles and/or fascicular bundles by hypoechoic vacuoles in the tibial and/or peroneal nerve = *intrafascicular* injection, indicating a direct involvement of those nerves, which might have a higher incidence of neurological sequelae. The injection was rated as intraneural if one or more of these four signs were detected.

The cross-sectional dimensions of the SN (minimal and maximal diameters, area) were measured at the level of the needle tip (0 to 0.5 cm distal to the bifurcation of the SN in the popliteal fossa) directly before and directly following the injection of the local anesthetic. The circumference of the nerve, including the subparaneural portions of the accumulated local anesthetic pool, was marked, and the area was calculated by the planimetric function of the ultrasound device. We also assessed the extent of the nerve circumference in contact with the injected local anesthetic. Its amount was rated based on stage: *none* (no contact of the injected local anesthetic with the SN), *mild* (local anesthetic in contact with up to half of the circumference of the SN), *moderate* (local anesthetic in contact with more than half but not the entire circumference of the SN), *complete* (local anesthetic in contact with entire circumference of the SN).

2.2 MRI

The MRI scans were performed with a 3.0-T MRI system (TimTrio, Siemens Healthcare, Erlangen, Germany) and included T1- and T2-weighted sequences with and without fat suppression. The macrocyclic agent gadobutrol (Gadovist, Bayer-Schering Healthcare, Berlin, Germany) was used if the patient had consented and there were no contraindications (see Table 1 for imaging protocol).

The baseline dimensions of the SN were obtained from an MRI scan performed prior to the nerve block. A second scan was performed at least eight hours following the block to detect signs of a persisting accumulation of local anesthetic. If no preoperative MRI scan was available, the contralateral SN was used as reference and internal control [14]. The major and minor axes (A and B, resp.) and the intensity of the SN of both legs were measured at 0 to 0.5 cm proximal to the bifurcation of the SN in the popliteal fossa. The cross-section of the nerve was nearly elliptical before and eight hours after the block, and the area was calculated using the equation for an ellipse: Area = π * A/2 * B/2. Furthermore, we evaluated distribution of hyperintensive fluid with regard of the SN. We estimated the amount of fluid around the SN or its two branches and in the subparaneural compartment according to the aforementioned sonographic criteria (*none*, *mild*, *moderate*, *complete*). We used a contrast agent to detect further damage to the nerve sheath.

On the second postoperative day a study doctor recorded paresthesias or other neurological symptoms and questioned the patients regarding their satisfaction with the anesthetic management graded on a scale of 1 (= very satisfied) to 6 (= very dissatisfied). Furthermore, the patients were asked if they would recommend the anesthetic technique used in the procedure.

2.3 Statistical analysis

The primary outcome was the incidence of intrafascicular fluid in the SN detected by ultrasound and MRI. Secondary outcomes were the increase in cross-sectional area in the sonograph and MRI, as well as neurological symptoms. The data were analysed using the statistics program StatSoft® (Dell Inc., Texas, USA). Continuous data were tested for normal distribution using the Kolmogorov-Smirnov test. Normally distributed data were described using mean and standard deviation, other data using median and range.

Table 1: MRI imaging protocol

	T1 SE FS axial	T2 TSE axial	T2 TSE FS axial	T1 SE FS axial
TR/TE [ms]	682/8.4	4520/84	4520/84	682/8.4
Slice Thickness (mm)	3.5	3.5	3.5	3.5
Spacing	10%	10%	10%	10%
Voxel (mm)	0.5x0.5x3.5	0.6x0.5x3.5	0.6x0.5x3.5	0.5x0.5x3.5
FOV (mm)	200x200	160x160	160x160	200x200
TA (min:sec)	3:10	4:19	4:33	5:53
Fat Saturation	SPAIR		SPAIR	SPAIR
Contrast Agent				gadobutrol

SE = spin echo, TSE = turbo spin echo, FS = Fat Saturation, TR = repetition time, TE = echo time, FOV = field of view, TA = acquisition time, SPAIR = Spectral Attenuated Inversion Recovery

Categorical data are given as absolute numbers. Normally distributed data were compared using the Student's *t*-test, non-parametric data with the Mann-Whitney U-test. Categorical data were compared using Fisher's exact test. A p-value <0.05 was defined as statistically significant.

3 Results

Twenty-three patients were recruited for the study. One patient was excluded because of incomplete data. Biometric data and ASA classification are given in Table 2.

Fourteen of the 22 patients (63.6%) had a general anesthetic in addition to the SN block for the reasons described above (see Methods). Median surgery time was 61 minutes [range 5-235].

Sonography performed during or immediately after performing the block revealed a significant median increase in the cross-sectional area of 41.9 [5.1-234.5] mm² (Table 3). The cross-sectional area of the SN determined by ultrasound was 57.8 [32.7-96.4] mm² pre-block and 110.8 [54.5-292.2] mm² post-block (p < 0.001).

Based on the current definition of intraneural injection into the SN (see Methods), this was present in twenty-one patients (95.5%). Sonographic signs of a subparaneural injection were seen in 72.7% of the patients (Table 4). Fifty percent exhibited an increased tibial-peroneal separation (Figure 1).

Varying volumes of subparaneural local anesthetic were seen in 16 of the 22 patients (Table 4), whereas there was sonographic evidence of intrafascicular local anesthetic in two patients. The postinjection fluid distribution around the SN was moderate in 18 (81.8%) and complete in 3 (13.6%) patients (Table 4).

MRI was performed at 681±160 minutes after the block in 20 patients, of whom 11 were with gadobutrol contrast. Fluid distribution around the SN was still moderate in ten and complete in three patients at the time of imaging (Table 5). Figure 2 shows the MRI of one of the two patients with sonographic evidence of an intrafascicular injection (the other refused the MRI) (Figure 2). There were no signs of structural damage to the SN in the other patients (Figure 3).

The cross-sectional area of the SN in the MRI was 99.9 [43.2-267.7] mm² pre-block and 115 [48.4-367.6] mm² post-block (p = 0.94). If no pre-block MRI was available, the post-block MRI area of the contralateral SN was used as

Table 2: Patient characteristics and process times (*mean ± SD)

	Patients n=22
Height (cm)*	176 (9.0)
Weight (kg) *	81.5 (13.0)
Age (yrs) *	38.2 (15.1)
Sex (male/female), n	11 / 11
ASA I, n	16
ASA II, n	5
ASA III, n	1

ASA = American Society of Anesthesiologists, SD = standard deviation

Table 3: Ultrasound dimensions of the SN (median [range])

		Patients n=22
Major nerve diameter (mm)		
	Pre-block	12.7 [8.9 - 16.1]
	Post-block	16.2 [10.1 - 29.0]
	Difference	4.2 [-1.8 to +20.2]
Minor nerve diameter (mm)		
	Pre-block	6.0 [3.8 - 9.2]
	Post-block	9.4 [3.8 - 14.3]
	Difference	3.4 [0 - 12.2]
Cross-sectional area (mm²)		
	Pre-block	57.8 [32.7 - 96.4]
	Post-block	110.8 [54.5 - 292.2] p<0.0001
	Difference	41.9 [5.1 - 234.5]

SN = sciatic nerve

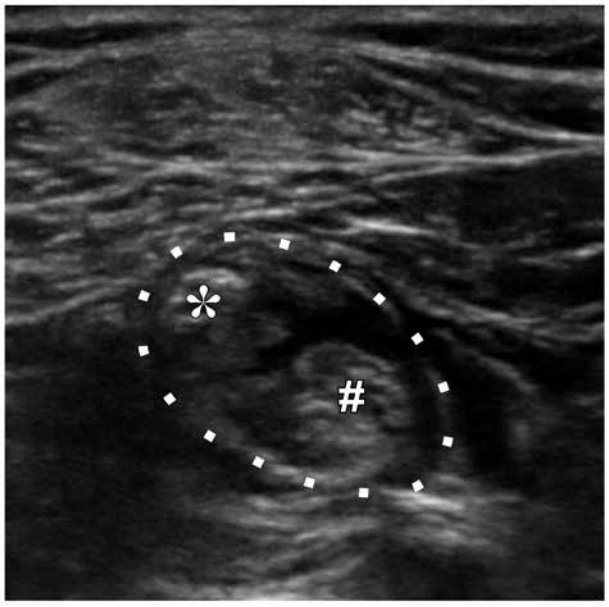

Figure 1: Post-block sonogram of the sciatic nerve.

Sonogram of the SN just proximal to its bifurcation after subparaneural injection of local anesthetic. The dotted line marks the paraneural sheath enveloping the tibial (*) and the common peroneal (#) nerves, which are separated by the injected local anesthetic.

Table 4: Spread of local anesthetic around the SN assessed by sonography during injection

	Patients n=22
Amount of SN circumference, n	
(0) none	0
(1) mild (< 50%)	1
(2) moderate (50 - 99%)	18
(3) complete (100%)	3
Patients with intraneural fluid, n	16
Subparaneural, n	
(0) none	6
(1) mild	5
(2) moderate	2
(3) complete	9
Tibial-peroneal nerve separation, n	11
Intrafascicular injection, n	2

SN = sciatic nerve

Table 5: Extent of fluid accumulation around the circumference of the SN shown by MRI on the evening after surgery.

	Patients
T2 SPAIR (n = 20)	n
(0) none	1
(1) mild (< 50%)	5
(2) moderate (50 - 99%)	10
(3) complete (100%)	3
T1 SPAIR CA (n = 11)	n
(0) none	9
(1) mild (< 50%)	0
(2) moderate (50 - 99%)	0
(3) complete (100%)	2
Intrafascicular fluid accumulation	n
T2 SPAIR (n = 20)	1
T1 SPAIR CA (n = 11)	1

CA, contrast agent, SN = sciatic nerve, SPAIR = Spectral Attenuated Inversion Recovery

the reference. There was no difference between pre- and post-block (Table 6). There was also no difference in the MRI intensity of the SN between pre- and post-block (222 [120-604] vs. 230 [107-743]; p = 0.29).

No patient reported the occurrence of paresthesias while the block was being performed or of any other neurological symptoms at a later time. All would recommend the SN block as anesthetic technique and rated overall high satisfaction with this anesthetic technique (1.4±0.59).

4 Discussion

In this study we assessed the incidence of an intraneural injection during ultrasound-guided popliteal SN blocks according to the currently used criteria [4]. We classified injections that would be rated as intraneural according to these criteria as either intrafascicular or subparaneural. The latter classification represents an injection of local anesthetic through the common paraneural sheath envel-

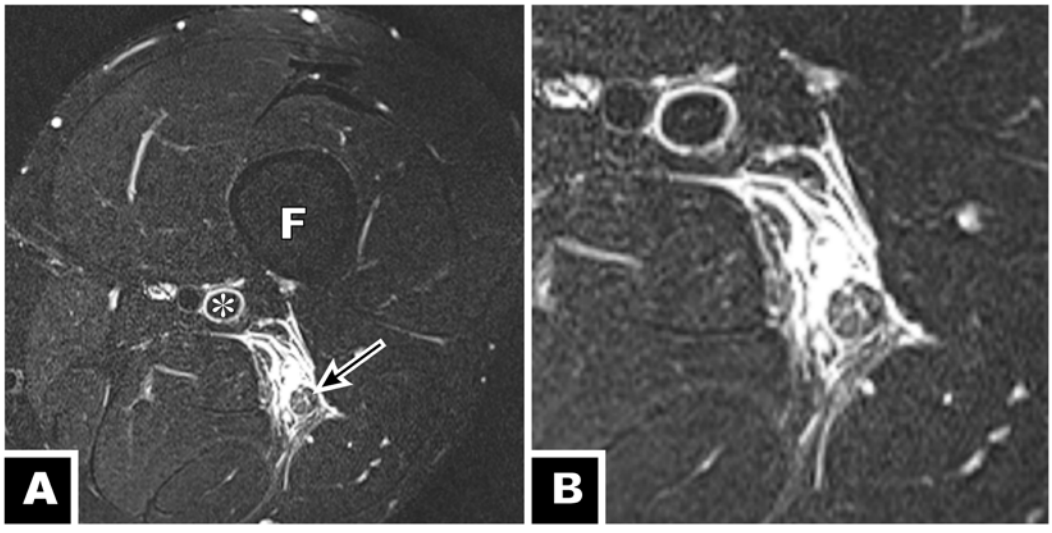

Figure 2: Post-block MRI-scan showing intrafascicular fluid accumulation inside the sciatic nerve

A: MRI-scan (T2, TSE, SPAIR, axial plane) with signs of intrafascicular fluid accumulation just proximal to the bifurcation of the SN (indicated by arrow) of a patient with sonographic evidence of intrafascicular injection (* popliteal artery; F, femur). Note the persisting amount of hyperintensive fluid around the SN.

B: Enlarged detail view of the SN showing multiple hyperintensive fluid accumulations located intrafascicularly (compare Figure 3B). The entire circumference of the SN is still surrounded by hyperintensive fluid .

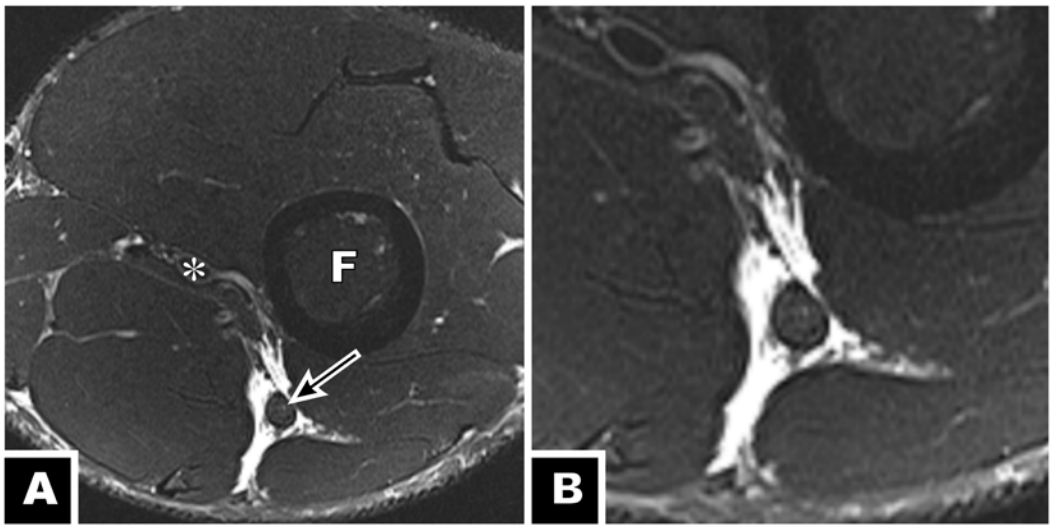

Figure 3: Post-block MRI-scan showing no signs of intrafascicular fluid accumulation inside the sciatic nerve

A: MRI-scan (T2, TSE, SPAIR, axial plane) without no sign of intrafascicular fluid accumulation just proximal to bifurcation of the SN (indicated by arrow) but with hyperintensive fluid accumulation around the nerve (* popliteal artery; F, femur).
B: Enlarged detail view of the same SN showing the distribution of hyperintensive fluid around the entire SN but lacking intrafascicular fluid accumulation (compare Figure 2B).

Table 6: MRI dimensions of SN (median [range])

		Patients n=20
Major nerve diameter (mm)		
	Pre-block	7.0 [4.6 - 12.0]
	Post-block	7.5 [5.7 - 13.0]
		p=0.51
	Difference	0.2 [-2.3 to +1.0]
Minor nerve diameter (mm)		
	Pre-block	4.4 [2.5 - 7.1]
	Post-block	4.7 [2.7 - 9.0]
		p=0.72
	Difference	0.2 [-2.0 to +1.0]
Cross-sectional area (mm^2)		
	Pre-block	99.8 [43.2 - 267.7]
	Post-block	115.4 [48.4 - 367.6]
		p=0.94
	Difference	5.0 [-112.2 - +43.4]

oping the SN and into the space between the tibial and peroneal nerves.

Usually, an intraneural injection of the local anesthetic is a dreaded complication of peripheral nerve block because it can inflict the nerve with mechanical, vascular, and chemical damage [1]. The current recommendation is to avoid such injections, including subepineural [4]. However, the sciatic nerve seems to occupy a special position among the peripheral nerves. First of all, it contains a large amount of connective tissue and might therefore be less vulnerable to damage [6]. Second, its distal portion comprises two separate nerves, tibial and peroneal, each with its own epineurium but still surrounded by a common paraneural sheath just proximal to its bifurcation [7]. The results of several studies have shown that a subparaneural injection into the popliteal section of the SN, i.e. into the space between the tibial and peroneal nerves, does not carry an increased risk of nerve damage because it is not subepineural [2,3,8,9,12,15]. Perlas and co-workers [8] stress the point that the optimal location for local anesthetic deposition is close to the SN through its common paraneural sheath to ensure consistent success and rapid onset.

Because even small amounts of local anesthetic can trigger inflammation as well as mechanical damage to the nerve [16] we performed MRI scans after the blocks to detect persisting intrafascicular fluid or signs of damage to the nerve tissue at the injection site. Sala-Blanch and co-workers [3] were the first to demonstrate the surprisingly high incidence of intraneural injections during popliteal SN blocks by analyzing sonographic and computer tomographic images recorded shortly after the nerve block. Our sonography scans performed during the block confirmed these observations. We waited until after the block had resolved before performing the MRI scans, which allowed us to detect signs of local nerve damage, e.g. intrafascicular fluid, intensity increase, edema, structural damage arising after the injection, and to assess any persisting neurological symptoms.

We determined the cross-sectional area of the SN by planimetry of the sonographic image. All other studies [2,3,8,17,18] have relied on an approximation using the

equation for the area of an ellipse, a shape that does not accurately match the neural cross-section. There was a nearly 50% increase in the cross-sectional area of the SN in the sonographic images. This is consistent with the results of Sala-Blanch and co-workers [4]. Neither the cross-sectional area nor the intensity in MRI scans differed between pre- and post-block, which was expected given the time lapse between the two images. However, we were still able to detect a moderate amount of fluid around SN in more than 60% of the patients.

Although we deliberately sought to perform an "intraneural", i.e. a subparaneural, injection, there were only two instances in which the needle tip was seen to actually be in an intrafascicular position. This was resolved by altering the needle position. Intrafascicular fluid accumulation was seen in the MRI in one of these two patients. Unfortunately, the second patient had not consented to the MRI, so that there is no data. However, neither patient had any signs or symptoms of nerve damage, which corresponds to the reports of Sala-Blanch and co-workers [3]. Furthermore, there were no signs of nerve inflammation or intrafascicular fluid in the MRI scans of the patients with a subparaneural fluid seen in the corresponding ultrasound images. These findings corroborate the sensitivity of ultrasound-guidance in recognizing intrafascicular nerve block injections.

Although we deliberately performed "intraneural" injections, none of the patients complained of paresthesias. Sala-Blanch et al. [2] also had a high incidence of intraneural injections, and although 14% of his patients complained of paresthesias, none of them had neurological symptoms. We believe that the paresthesias experienced by his patients could result from his use of nerve stimulation to locate the nerve, whereas we only used sonography for this purpose. Furthermore, according to the results of Cappelleri and colleagues [18] paresthesias seems to be a poor marker for intrafascicular injections in SN blocks in any case. This study did also not detect any difference in postoperative electrophysiological signs of subclinical axonal damage regardless of whether the injection was subparaneural or intrafascicular [18].

Our study had several limitations. In addition to the relatively small sample size, there was no neurological or neurophysiological follow-up examination. Therefore, we cannot conclude with the necessary degree of confidence that the subparaneural injection as described is a safe technique. However, Sala-Blanch and colleagues [3] did perform postoperative neurophysiological tests on their patients, and there were no pathological results despite the high rate of intraneural injections. Another possible source of error was that there was no preoperative MRI for some patients, and we were forced to make the comparison with the contralateral sciatic nerve. A difference between the two nerves may have affected our measurements. Furthermore, the duration of surgery and with it the tourniquet time varied widely depending of the operation, and this might affect structural nerve damage.

The findings of our study emphasize the conclusion that a subparaneural, i.e. under the paraneural sheath (or outer epineurium), injection at the popliteal segment of the SN is not actually intraneural, i.e. intrafascicular in the strict sense. Furthermore, these results also show that ultrasound-guided needle positioning is a safe procedure. Notwithstanding this, we recommend avoiding intrafascicular injections, because structural effects inside the nerves can still be detected after the block has resolved – in contrast to subparaneural injection –, and this may contribute to the multifactorial causation of nerve damage.

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