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ORIGINAL ARTICLE

Characteristics of unilateral spinal anesthesia at different speeds of intrathecal injection

Yılmaz Apaydın · Gulcan Erk · Ozlem Sacan · Civan Tiryaki · Vildan Taspinar

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Abstract
Purpose Unilateral spinal anesthesia is performed to provide restriction of sympathetic and motor block. The purpose of this study is to compare the effect of different speeds of intrathecal injection on unilateral spinal anesthesia.
Methods The patient cohort comprised 66 patients who were placed in the lateral position with the side to be operated on dependent. After dural puncture, the needle aperture was turned towards the dependent side, and hyperbaric 0.5% bupivacaine was injected at a rate of 1 ml/min in Group Slow patients (Group S, $n = 33$) or 0.5 ml/min in Group Extra Slow patients (Group ES, $n = 33$). The lateral position was maintained for 15 min. Skin temperature, loss of pinprick sensation, and degree of motor block were recorded.
Results There were significant differences in the characteristics of the non-operative side between the groups when on the block. Sensorial block was unilateral in 25 (75.8%) patients in Group S and in 29 patients in Group ES (87.9%) 15 min post-injection. At the end of the operation (approximately 50 min after spinal anesthesia), strictly unilateral anesthesia was present in 31 patients in Group ES (93.9%) and in 22 patients in Group S (66.6%) ($p < 0.05$). Unilateral sensory and motor block were observed in both groups, and the incidence of strict unilateral block was significantly higher in group ES patients.
Conclusions The result of the study show that the extra-slow injection of hyperbaric bupivacaine provided strictly unilateral sensorial and sympathetic block in 93.9 and 87.9% of the patients, respectively, and that a slow injection of low doses of hyperbaric 0.5% bupivacaine 1 ml was sufficient to provide unilateral spinal anesthesia.

Keywords Anesthetics · Subarachnoid · Anaesthetics · Local · Bupivacaine

Y. Apaydın · G. Erk · O. Sacan (✉) · C. Tiryaki · V. Taspinar
Department of Anesthesiology and Reanimation,
Ankara Numune Training and Research Hospital,
06100 Samanpazari, Ankara, Turkey
e-mail: ozlemsacan@hotmail.com

Introduction

There are many factors affecting the distribution of local anesthetics through the intrathecal space, including patients' characteristics (age, height, weight, gender, and intra-abdominal pressure), technique of injection (site of injection, direction of injection, turbulence, and barbotage), and features of the cerebrospinal fluid (CSF) and anesthetic solutions [1]. Baricity, density, dose, and volume of injected local anesthetics are major determinants of their spread in the cerebrospinal fluid [2]. It has been claimed that differences in the amount of turbulence created by varying the speed of injection through needles of the same size were not great enough to produce clinically meaningful changes in the spread of the anesthetic solutions used**.** Despite this claim, high injection rates produce turbulent patterns of flow and thus lead to an unexpected spread of anesthesia. Although the speed of injection has been investigated extensively, the results of such studies are conflicting [3, 4]. Globally, the evidence does suggest that faster injections produce a greater spread with plain solution but that the effect is less marked with hyperbaric solutions, with some suggestions that a slower injection actually produces a greater spread [5, 6].

Hyperbaric bupivacaine is often used as a drug of choice in spinal anesthesia [7]. Nair et al. [8] recently reported that hyperbaric bupivacaine caused significantly prolonged recovery with high doses (e.g., 10 or 15 mg) in knee arthroscopy. In the supine position, a lower dose (5 mg) had a higher incidence of failure (25%), while in the unilateral position, doses of bupivacaine as low as 4–5 mg were able to produce enough anesthesia with no or very low incidence of failure [8].

Although Enk [9] pointed out the significance of the 'low-dose, low-volume, and low-flow' technique for achieving unilateral block, little information is available in the literature on a direct comparison of the use of different speeds of injection to produce unilateral spinal block in the lower extremity. To obtain more information on this indication, we designed this prospective, randomized study to compare the effect of different speeds of intrathecal injection on unilateral spinal anesthesia.

Materials and methods

The Hospital Ethical Committee approved the study, and written informed consent was obtained from all participating patients. In total, 66 American Society of Anesthesiologists (ASA) physical status I–II patients, aged 18–65 years, who were scheduled for knee arthroscopy with tourniquet under spinal anesthesia were enrolled in the study. Patients receiving regular analgesic therapy and those with marked scoliosis, diabetes, or peripheral neuropathy, having had prior disc surgery, were excluded.

After standard volume expansion with 7 ml/kg lactated Ringer's solution, standard monitoring procedures were used, including non-invasive arterial pressure, heart rate, and pulse oximetry. Baseline arterial blood pressure was recorded at the end of the volume expansion, prior to performing the spinal block.

The room temperature was kept constant (23.5 ± 0.5°C) during the study. Thermistors were attached to both feet of the patient, between the base of the first and second toes, and connected to a two-channel temperature monitor (Datex Ohmeda; ADU/5 Anesthesia Delivery Unit, Bromma, Sweden).

All patients were placed in a lateral position with the side to be operated on dependent, whereas the vertebral column was kept as horizontal as possible by tilting the table. Dural puncture was performed with the midline approach at the L3–4 interspace using a 25-gauge Quincke spinal needle. After the free flow of CSF was observed, the needle orifice was turned toward the operative side and hyperbaric 0.5% bupivacaine 1 ml (Marcaine Spinal Heavy, 0.5%; room temperature; AstraZeneca, Wilmington, DE) was injected.

Patients were randomly allocated to two groups according to a computer-generated randomization sequence. Patients in Group Slow (Group S; $n = 33$) were injected with the local anesthetic solution at a speed of 1 ml/min, while those in Group Extra Slow (Group ES; $n = 33$) were injected at a speed of 0.5 ml/min. The lateral decubitis position was maintained for 15 min after local anesthetic injection, then patients were turned onto the supine position.

Heart rate, mean arterial pressure, and peripheral oxygen saturation values were measured in every 5 min for the first 30 min after local anesthetic injection, following which the measurements were continued at 15-min intervals for the remainder of the operation time. Hypotension, defined as a systolic arterial pressure 30% less than baseline values, was treated with an intravenous (iv) infusion of 250 ml lactate Ringer's solution in 5 min. If this was ineffective 5 mg of ephedrine was given. Bradycardia (<60 beat/min) was treated with 0.5 mg of atropine iv. Skin temperature was recorded prior to the dural puncture and 15 min after intrathecal injection.

An independent observer blinded to the injection speed recorded the evaluation of the sensory and motor blocks on both sides. The sensory block was assessed as a complete loss of pinprick sensation, and the motor blockade was evaluated using a modified Bromage scale (0 = no motor block; 1 = hip blocked; 2 = hip and knee blocked; 3 = hip, knee, and ankle blocked). A sympathetic block was defined as an increase in foot temperature of at least 0.5°C from the baseline values at 15 min post-injection. During the first 30 min following the injection, sensory and motor blocks were tested bilaterally at the third minute, and then at 5-min intervals. Subsequent evaluations were made every 10 min until complete regression of the spinal block. Readiness to surgery was defined as a loss of pinprick sensation at L1 on the operative side at the 15th min of lateral decubitis position. Failure of the unilateral motor block was defined as any motor function loss on the non-operative side**.** Failure of the sensorial unilateral block was defined as the loss of pinprick sensation at any level on the non-operative side, and failure of the unilateral sympathetic block was defined as a temperature increase in the foot of the non-operative side of ≥0.5°C at 15 min post-intrathecal injection.

Onset time of sensory and motor blocks, maximal level of sensory and motor blocks, the time to first two segments and complete regression of sensory and motor blocks (walking-up time), and voiding time were recorded. The quality of the spinal anesthesia was assessed according to the need for supplementary iv analgesics and sedatives: adequate spinal anesthesia = no analgesic requirement during the surgery; inadequate spinal anesthesia = need for additional analgesia (0.1 mg iv bolus of fentanyl); failed spinal anesthesia = need for general anesthesia.

The sample size of 33 patients in each group was determined to detect a difference of occurrence of strictly

Table 1 Demographic data of the two groups

Demographic variables	Group S ($n = 33$)	Group ES ($n = 33$)	p
ASA (I/II)	12/21	14/19	0.617
Age (year)	42.1 ± 11.3 (19–59)	40.6 ± 14.0 (18–62)	0.748
Weight (kg)	74.8 ± 6.9	73.6 ± 6.5	0.400
Height (cm)	170 ± 7.9	179 ± 9.9	0.437
Gender (F/M)	14/19	15/18	0.804
Duration of surgery (min)	34.5 ± 9.7	34.8 ± 11.8	0.922

Group S slow injection (1 ml/min), *Group ES* extra-slow injection (0.5 ml/min), *ASA* American Society of Anesthesiologists, *F* female, *M* male
Values are expressed as the mean ± standard deviation (SD), as the median, with the range in parenthesis, or as count (n)

unilateral spinal anesthesia between the groups with a power of 80% ($\beta = 0.2$) The results were analyzed using the Student's t, χ^2, Fisher's exact, Wilcoxon, and Mann–Whitney tests, as appropriate (Minitab ver. 10.5 for Windows 95; Minitab, State College, PA). A p value of <0.05 was regarded as significant. Continuous variables are presented as the mean ± standard deviation (SD) or as the median (range); categorical data are presented as number (%).

Results

Sixty-six patients ($n = 33$ in each group) successfully completed the study. Inadequate and failed spinal blocks were not observed. There were no significant differences in the demographic data between the patients in the two groups (Table 1). There was a significant difference between the groups in terms of the maximal level of sensory block between the operated and non-operated side; however, no statistical differences in the maximal level of sensorial block on the operative side was observed between the groups. The maximum sensory level on the operated side was T12 (T10–T12) in Group ES and T10 (T8–T12) in Group S at 30 post-intrathecal injection ($p = 0.181$). On the non-operative side, the maximal level of sensory block was higher in Group S patients at 5, 10, 15, 20, 30, 40, and 50 min post-intrathecal injection ($p < 0.05$); in Group S and Group ES, the sensory block occurred in ten patients at L2 (L1–L3) and four patients at L2 (L2–L3), respectively, at 30 min post-intrathecal injection ($p = 0.001$) (Fig. 1). In Group S, a strictly unilateral sensory block (no sensory block detectable at all on the non-operative side) was observed in 25 (75.8%) and 22 (66.7%) patients at 15 min post-intrathecal injection and at the end of the operation, respectively. In Group ES, a strictly unilateral sensory block was observed in 29 patients (87.9%) at 15 min post-intrathecal injection and, interestingly, in 93.9% of the patients at the end of operation ($n = 31$) ($p < 0.05$).

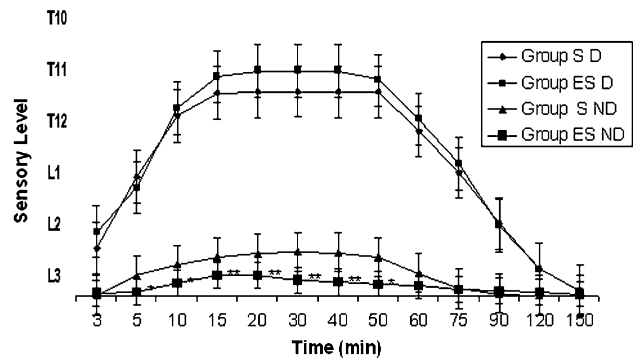

Fig. 1 Evaluation of median upper limit of sensory block on the operative and non-operative side at times post-injection of spinal anesthesia at an injection speed of 1 ml/min (Group S) or 0.5 ml/min (Group ES). *GroupS D* Group Slow, dependent side, *Group ES D* Group Extra Slow, dependent side, *Group S ND* Group Slow, non-dependent side, *Group ES ND* Group Extra Slow, non-dependent side. *$p < 0.05$ vs. Group S ND, **$p < 0.01$ vs. Group S ND

Motor blockade of the operated lower extremity was not different between the groups at any times, while the non-operated lower extremity was blocked in significantly more patients in Group S than in Group ES at 5, 10, 15, 20, 30, 40, and 50 min post-intrathecal injection ($p < 0.05$) (Fig. 2).

Mean blood pressure and heart rate at 120 min post-intrathecal injection decreased significantly from the baseline values in Group S ($p = 0.001$), but intra-group and inter-group analysis did not show any difference at any time in the means of blood pressure and heart rate between groups.

The onset time of the sensorial and motor block in the operative side of Group S and Group ES patients were 4.0 ± 1.2 and 5.8 ± 2.3 min, and 3.7 ± 1.0 and 5.5 ± 2.1 min post-intrathecal injection, respectively, and these values were not different between the groups (Table 2).

Increases in temperature on the operative side were reported in all patients; however, on the non-operative side, there was no temperature increase in 55 patients (83.3%). The sympathetic block was unilateral (lack of temperature increase on non-operative side) in 26 patients in Group S (78.8%) and in 29 patients in Group ES (87.9%) at 15 min post-intrathecal injection ($p > 0.05$). The time to first two segment and complete regression of sensorial block on the operative side was not different between the groups. The time to complete regression of the sensorial block on the operative side was 127 (85–180) min in Group S and 136 (100–170) min in Group ES ($p = 0.184$), while complete regression on the non-operative side time was 57 (45–69) and 70 (42–95) min, respectively ($p = 1$). One-degree motor block regression times and complete motor block regression times were similar between the groups (Table 2).

In no case was urinary retention reported, and time to voiding was 261 ± 84 min in Group S and 262 ± 85 min in Group ES ($p = 0.804$). No serious perioperative complications were reported in any of the 66 patients.

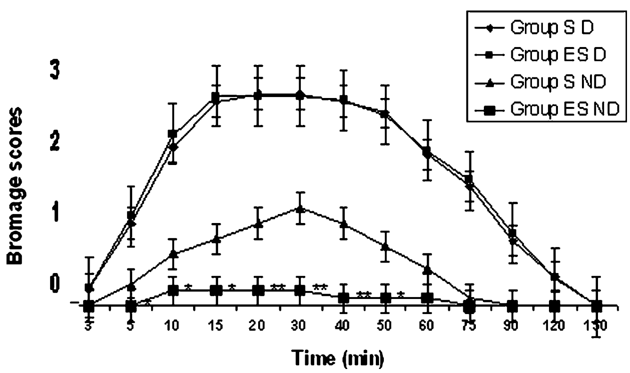

Fig. 2 Evaluation of motor block degree on operative and non-operative side at times post-injection of spinal anesthesia at an injection speed of 1 ml/min (Group S) or 0.5 ml/min (Group ES). *$p < 0.05$ vs. Group S ND, **$p < 0.01$ vs. Group S ND. Groups are as defined in caption to Fig. 1

Postoperative follow–up revealed no neurological complications or post-dural puncture headache.

Discussion

In the study reported here, we used a low dose of 5 mg of 0.5% hyperbaric bupivacaine at different injection speeds and achieved successful spinal anesthesia for knee arthroscopy surgery in 100% of the patients. Our results also show that the relatively slower speed of injection (0.5 ml/min) allowed a more marked restricted block of sensory and motor nerve roots on the operative side than the faster speed of injection (1 ml/min). The distribution of local anesthetic is affected by the four major factors: a lateral position, a slow speed of intrathecal injection, baricity, and extreme reduction of the dose. Following the initial findings on these factors reported by Greene [6], various controlled studies have failed to demonstrate the importance of the speed of injection on performing unilateral spinal anesthesia.

The reduction of anesthetic dose is crucial to restricting the spinal block to one side. A strict correlation between the dose of anesthetic used and lateralization of sensory block has been demonstrated [8, 10]. An extreme reduction of the speed of injection can increase the restriction of spinal anesthesia because of the inability of a small dose of local anesthetic to spread into a sufficient number of nerve roots on the ipsilateral side. Injection through a side-injection needle results in streaming and directional flow in the direction of the needle side, whereas the use of a slow injection speed provides a laminar flow, which minimizes the mixing of hyperbaric bupivacaine with the CSF and improves the unilateral distribution of the spinal anesthesia [11]. Given the baricity effects of the local anesthetics, unilaterality can be maintained if the patient remains in a

Table 2 Onset time of sensory level and motor block on the operative and non-operative side, time to first two segment and complete regression of sensorial level, and motor block in the two groups

Variables	Group S ($n = 33$)	Group ES ($n = 33$)	p values
Onset time of sensorial block on operative side (min)	3 (3–5)	4 (3–5)	0.281
Onset time of motor block on operative side (min)	5 (3–8)	5 (3–7)	0.285
Onset time of sensorial block on non-operative side (min)	5 (3–8)	5 (4–7)	0.280
Onset time of motor block on non-operative side (min)	12 (7–20)	10 (7–15)	0.382
Time to first two segment regression of sensorial block on operative side (min)	65 (50–95)	63 (45–75)	0.995
Time to complete regression of sensorial block on operative side (min)	127 (85–80)	136 (100–70)	0.184
Time to complete regression of sensorial block on non-operative side (min)	70 (42–95)	57 (45–69)	0.493
Time to 1° motor block regression on operative side (min)	60 (50–75)	60 (50–75)	1.000
Time to complete regression of motor block on operative side (min)	120 (90–50)	120 (90–150)	1.000
Time to void	261.0 ± 84	262.3 ± 84.9	0.804

Values are expressed the mean ± SD, or as the median, with the range in parenthesis lateral position for surgery; however, eventual turning of the patient into a supine position results in partial redistribution to bilateral anesthesia [12]. Casati et al. [5] reported that turning of the patients into the supine position results in a decrease in the unilateral sensorial block from 73 to 56%. We did not observe any change in the number of strictly unilateral sensorial blocks in the 0.5 ml/min injection speed group. In a previous study with 8 mg hyperbaric bupivacaine 0.5%, unilateral sensory and motor blocks of up to 55 and 78%, respectively, were reported [13]. In our study, a more restricted spinal anesthesia was achieved, with unilateral sensory and motor blocks in up to 93.9 and 90.9% of patients when the 0.5 ml/min injection rate was used. The rate of unilateral spinal block observed in our study was also higher than that reported in other controlled studies in which the maintenance of lateral position was the same as our study [4, 5, 14]. The lower dose of local anesthetic with the lower speed of intrathecal injection may explain the observed differences.

The time for regression of sensory level by two segments on the operative side and the time for regression of motor block by 1° in our results are a bit shorter than those in previous reports [5, 11]. These findings may be due to the lower dose of bupivacaine.

The unilateral distribution of spinal anesthesia is advantageous in surgical procedures involving one leg because the hemodynamic effects of spinal anesthesia are reduced [1–3, 15].

The slower and more restricted spinal block produced a more stable cardiovascular profile because of the restricted sympathetic denervation during the unilateral spinal anesthesia [15, 16]. Sympathetic denervation can be determined by measuring skin temperature [17, 18]. In our study, assessment of the injection rate-dependent spread of sympathetic denervation was determined by comparing temperature changes in the feet. While all of the patients had an increase in the feet temperature on the operative side, only 11 (16%) patients exhibited a >0.5°C increase in foot temperature on the non-operative side(3 patients in Group S, 7 in Group ES). The rate of unilateral sympathetic block (83.3%) was greater than that described in a previous study (69%) in which a comparable injection flow (1 ml/min) was used [19]; however, the volume and doses of hyperbaric bupivacaine were higher in that study than in ours. Therefore, the difference in the rate of unilateral sympathetic block may have been affected by the dose and volume.

Even though in previous studies hypotension has been reported in 5–7% of cases by optimization of unilaterality and decreased extent of sympathetic block [12, 15], we did not have any case of hypotension requiring even the rapid iv infusion of lactate Ringer's solution. These findings may be due to both the small dose and the extra-slow injection of local anesthetic restricting the spread of sympathetic block. Because the level of sympathetic denervation determines the magnitude of cardiovascular responses to spinal anesthesia, it might be anticipated that the higher rate of unilateral sympathetic block, the lower would be the change in cardio-circulatory parameters. In the presence of a partial sympathetic blockade, a reflex increase in sympathetic activity occurs in sympathetically intact areas [20]. Although a more marked unilateral distribution of sympathetic block was observed in Group ES patients, there were no differences in hemodynamic effects between the groups in our study. Sufficiently powered studies should be performed to evaluate the hemodynamic impact of unilateral spinal anesthesia, especially in ASA physical status III and IV patients, who would probably have a greater hemodynamic benefit from a restricted spinal block.

The simultaneous use of a lateral decubitus position during the entire procedure, a directional needle, a slow injection rate of anesthetic (over 60 s), and the low dose of hyperbaric anesthetic restricted the anesthetic block to a limited field. Although extremely low speeds of intrathecal injection, as reported by Casati et al. [5], should not be advocated when attempting unilateral spinal anesthesia as there are no clinical advantages, we suggest that the extreme reduction of the injection rate is one of the major critical factors. A slow directional injection produces a much higher concentration of hyperbaric solutions in the directional side, whereas a fast injection produces a lower concentration of solutions because of turbulence, resulting in more mixing and dilution in the spinal cord model [21]. Contrary to our results, previous studies using hyperbaric bupivacaine, even at different injection rates, have not shown a difference in anesthetic profile [4, 5]. One likely explanation is that the speed of injection in those studies was not slow enough to produce a unilateral spread of anesthesia. Our study showed a strict correlation between the speed of injection and lateralization of sensory, sympathetic, and motor block.

We conclude that when a small dose of 0.5% hyperbaric bupivacaine is injected extra slowly into patients who are placed in the lateral position for 15 min after spinal injection, a more marked restricted block of motor and sensory nerve roots on the operative side can be achieved.

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