J Anesth (2014) 28:549–553
DOI 10.1007/s00540-013-1773-7

ORIGINAL ARTICLE

Differential axillary nerve block for hand or forearm soft-tissue surgery

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Received: 10 January 2013 / Accepted: 10 December 2013 / Published online: 28 December 2013

Abstract
Purpose This study determined the effective concentration of ropivacaine required to produce the type of differential block known as sensory block with mobilization, for adequate analgesia after forearm or hand soft tissue surgery by axillary brachial plexus block.
Methods Forty-four patients were enrolled, and ultrasound-guided axillary nerve block with nerve stimulation was achieved using 16 mL of ropivacaine in total. Postoperative analgesia and sensory/motor function, side effects, the use of rescue analgesics, and the patient satisfaction score were evaluated 24 h after surgery. The effective concentration of nerve block was calculated by probit analysis.
Results Eighteen patients achieved differential block and were sufficiently satisfied with the block, which was significantly better than the patient satisfaction obtained with incomplete differential block. The maximum effective concentration of 6 mL of ropivacaine needed for differential block was calculated as 0.1285 %, which meant that 71 % of the patients experienced both sensory block and maintenance of motor function.
Conclusion This analysis showed that 16 ml of 0.1285 % ropivacaine is suitable for achieving differential block in ultrasound-guided axillary nerve block for hand and forearm surgery.

Keywords Axillary nerve block · Orthopedic surgery · Postoperative analgesia

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Introduction

Recently, peripheral nerve block has become a popular technique in extremity surgery, not only because it produces sufficient intraoperative analgesia but also because it alleviates postoperative pain. The administration of a large volume or high concentration of local anesthetic solution increases the success rate of peripheral nerve block and leads to complete sensory and motor nerve block. However, high-dose local anesthetics can cause local anesthetic related systemic toxicity and postoperative patient dissatisfaction due to excessive paralysis [1]. This is also frustrating for orthopedic surgeons because paralysis delays the assessment of nerve function after surgery, especially after soft-tissue surgery, which may damage peripheral nerve function.

Ultrasound guidance for regional anesthesia permits the direct visualization of the nerve structure, the needle pathway, and the spread of local anesthetic in real time, facilitating fine nerve block. The appropriate concentration and volume of ropivacaine for blocking the axillary brachial plexus in upper extremity surgery have been investigated in recent studies [2, 3]. The utilization of ultrasound-guided axillary brachial plexus block allows the dose of local anesthetics to be reduced [4, 5]. It also permits differential block; i.e., differential blockade of the sensory and motor nerves. The type of differential block

known as "sensory block with mobilization" involves blocking the sensory nerve to inhibit painful sensation while partially or completely maintaining motor function. Although differential block at the brachial plexus can increase patient postoperative satisfaction, as it allows upper extremity function to be maintained [6, 7], there are few direct clinical data sets in this regard.

The aim of this study was to determine the effective concentration of ropivacaine required to produce differential block. The differential block required was adequate sensory block with preservation of motor function and sufficient postoperative analgesia, as achieved through ultrasound-guided axillary brachial plexus block, in soft-tissue surgery.

Patients and method

This prospective, single-blind study was performed from December 1, 2010 to June 30, 2011. Ethical approval for the study was provided by the ethics committee of our hospital on October 1, 2010, and written informed consent was obtained from all patients.

Forty-four ASA physical status 1 and 2 inpatients who were scheduled for forearm or hand soft-tissue surgery under axillary brachial plexus block and general anesthesia were enrolled in this study. Patients were excluded if they met any of the following criteria: contraindications for a regional anesthetic technique (e.g., local infection, sepsis, or coagulation abnormality), age <20 or >80 years, weight <40 or >100 kg, allergy to local anesthetic, preexisting neurological deficit, diabetes, or an inability to comprehend pain scales. Sensory and motor function were estimated by independent anesthesiologists. General anesthesia was induced by 2–3 mg/kg propofol and maintained by 60 % nitrous oxide and 1–2 % sevoflurane in oxygen. Airway management was established by applying a laryngeal mask airway. Under general anesthesia, axillary nerve block was then performed under real-time ultrasound guidance with nerve stimulation. The skin around the axillary region on the operated side was prepared under strictly aseptic conditions with iodinated alcohol, and the linear array ultrasound probe (4–13 MHz, 8L-RS transducer; GE Healthcare, Norwalk, CT, USA) was aseptically covered. A short axial view of the target nerves (median nerve, radial nerve, ulnar nerve, and musculocutaneous nerve) was visualized by ultrasound imaging (Vivid-I®; GE Healthcare) to confirm the locations of vessels around the nerves in color Doppler mode. A 50-mm 22-G insulated needle (Stimuplex®; B-Braun/McGaw Medical, Bethlehem, PA, USA) was gently introduced by an in-plane approach toward the edge of each nerve. The needle was connected to a constant-voltage nerve stimulator (Stimuplex DIG®; B-Braun/McGaw Medical) that was set at 2 Hz with a pulse width of 100 μs and a current of 0.8 mA. The needle position was considered acceptable if an evoked motor response such as twitch muscle contraction in the affected region was elicited between 0.5 and 0.8 mA. After careful aspiration to exclude intravascular injection, 4 mL of ropivacaine at concentrations ranging between 0.0833 and 0.25 % were injected for each nerve. The spread of the solution around each nerve was confirmed. The same needle manipulation and injection were performed for every target nerve, so a total of 16 mL of ropivacaine were injected. Sensory block, motor function, and intensity of pain were evaluated immediately after emergence from general anesthesia.

Sensory block was evaluated by the pinprick test at the thenar eminence (median nerve), little finger (ulnar nerve), dorsum of the hand over the metacarpophalangeal joint (radial nerve), and the lateral external side of the forearm (musculocutaneous nerve). Motor function was evaluated by thumb opposition (median nerve), thumb adduction (ulnar nerve), thumb abduction (radial nerve), and flexion of the elbow (musculocutaneous nerve). Immediately after each patient had fully recovered from general anesthesia, we estimated postoperative pain based on a four-grade score (0: no pain, 1: mild pain, 2: moderate pain, and 3: severe pain), sensory block based on the pinprick test (0: anesthesia or complete loss of touch sensation, 1: analgesia or loss of sharp sensation, 2: reduced sensitivity compared with the same territory on the contralateral side at each area, and 3: normal), motor function of each nerve based on the six-grade manual muscle test (MMT, 0: zero, 1: trace, 2: poor, 3: fair, 4: good, and 5: normal), and side effects for 24 h. Effective analgesia, successful sensory block, and maintenance of motor function were defined as pain score $\leq$1, sensory block $\leq$1, and MMT $\geq$ 3, respectively. Differential block was defined as sensory block $\leq$1 and MMT $\geq$ 3 at the end of anesthesia. A rescue nonsteroidal anti-inflammatory drug (NSAID, diclofenac sodium 50 mg, suppository) was prescribed for rescue analgesia after surgery every 8 h, and the frequency of use of the rescue analgesia was recorded. Postoperative satisfaction with the analgesia was reported by the patients 24 h after the end of surgery (0: very poor, 1: poor, 2: adequate, 3: excellent).

For each patient, the concentration of the 16 mL of ropivacaine administered was selected randomly from among the seven different concentrations tested, which were obtained by diluting 0.75 % ropivacaine solution with physiological saline at ratios of 1/3 (0.25 %), 1/4 (0.1875 %), 1/5 (0.15 %), 1/6 (0.125 %), 1/7 (0.1071 %), 1/8 (0.9375 %), and 1/9 (0.0833 %). None of the anesthesiologists were informed of the concentrations used during the study. When four sequential patients receiving a

Table 1 Demographic data for the patients and satisfaction scores

	Total	Incomplete differential block	Complete differential block
Number (male:female)	44 (28:16)	28 (18:10)	16 (9:7)
Age (years)	52 (19)	51 (17)	52 (18)
Body height (cm)	163 (10)	165 (7)	160 (10)
Body weight (kg)	61 (12)	61 (10)	59 (13)
Duration of operation (min)	126 (51)	120 (40)	131 (66)
Duration of anesthesia (min)	187 (61)	180 (50)	196 (71)
Use of rescue NSAIDs[a]	33	19	14
Type of surgery[a]			
Benign tumor excision	10	6	4
Fasciectomy	10	7	3
Tendon release	8	5	3
Cartilage excision	7	4	3
Nerve transposition	9	6	3
Satisfaction score[a] ($p = 0.009^{\#}$)			
0: Very poor	3	3	0
1: Poor	8	8	0
2: Adequate	13	8	6
3: Excellent	19	9	10

[a] Data are presented as the mean (standard deviation) or the number of patients

[#] There was a significant difference in satisfaction score between patients with incomplete and complete differential block

Table 2 Effective concentrations required for analgesia, sensory block, and maintenance of motor function

	For effective analgesia (%)	For successful sensory block (%)	For maintenance of motor function (%)	Probability of differential block
EC_{10}	0.054 (−0.114 to 0.084)	0.052 (−0.121 to 0.082)	0.189 (0.163 to 0.276)	Possible
EC_{20}	0.073 (0.048 to 0.096)	0.070 (−0.055 to 0.093)	0.175 (0.153 to 0.242)	Possible
EC_{30}	0.086 (−0.001 to 0.105)	0.083 (−0.008 to 0.103)	0.164 (0.146 to 0.219)	Possible
EC_{40}	0.097 (0.038 to 0.115)	0.094 (0.030 to 0.112)	0.155 (0.139 to 0.199)	Possible
EC_{50}	0.108 (0.070 to 0.128)	0.105 (0.063 to 0.123)	0.147 (0.131 to 0.181)	Possible
EC_{60}	0.119 (0.095 to 0.148)	0.115 (0.090 to 0.142)	0.139 (0.123 to 0.165)	Possible
EC_{70}	0.130 (0.112 to 0.180)	0.126 (0.108 to 0.171)	0.130 (0.111 to 0.150)	Possible
EC_{80}	0.143 (0.124 to 0.224)	0.139 (0.121 to 0.214)	0.120 (0.094 to 0.136)	Impossible
EC_{90}	0.162 (0.138 to 0.289)	0.157 (0.134 to 0.278)	0.106 (0.064 to 0.122)	Impossible
EC_{95}	0.177 (0.148 to 0.344)	0.172 (0.144 to 0.332)	0.094 (0.038 to 0.113)	Impossible

EC effective concentration needed to elicit the required response in the given (as the subscript after "EC") percentage of patients (95 % confidence intervals)

Probability of successful sensory block = 24.258 × concentration − 2.536 ($p = 0.007$)

Probability of maintenance of motor function = −30.925 × concentration + 4.555 ($p = 0.001$)

Probability of effective analgesia = 23.863 × concentration − 2.574 ($p = 0.007$)

particular concentration presented intense blockade (sensory score ≤ 1 and MMT ≤ 2) or severe pain (postoperative pain score ≥ 2), no more patients were allocated to that concentration. Eight patients were allocated to each of the other concentrations. The main outcome variable was the maximum effective concentration (EC_{max}) for differential block, which was calculated as the crossing point of the dose–effect curves for maintenance of motor function and sensory block. The data were analyzed by probit regression analysis to calculate the effective concentration (EC_{10}–EC_{95}) and 95 % confidence intervals. The unpaired *t* test, the Mann–Whitney *U* test, and Fisher's exact test were performed to compare patients who attained complete differential block with those who did not. Demographic data are presented as mean (standard deviation). Statistical analysis was performed using SPSS 18.1.1 (SPSS, Chicago, IL, USA). A value of $p < 0.05$ was considered significant.

Results

Forty-four patients (mean age, duration of operation, and duration of anesthesia: 52 years, 126 min, and 187 min, respectively) were enrolled, and no patient discontinued the protocol because of failed nerve block (defined as completely normal sensation and motor function at the end of anesthesia). A tourniquet was used in each patient from the start of the operation. There was no significant difference in inflation time of the cuff among the groups, and no complication relating to the use of the tourniquet was observed. All patients in the 0.25 and 0.1875 % ropivacaine groups experienced intense motor and sensory blocks; in contrast, all patients in the 0.0833 % ropivacaine group experienced severe pain immediately after the operation. Patient allocation to these groups was stopped after 4 patients had been assigned to each. Differential block succeeded in 18 patients; 1 in the 0.083 %, 2 in the 0.094 %, and 5 in the 0.107, 0.125, and 0.150 % ropivacaine groups, respectively. There was no significant difference in patient characteristics, duration of surgery, duration of anesthesia, and requirement for NSAIDs. However, the satisfaction scores of patients with complete

differential block were significantly higher than those of patients with incomplete differential block (Table 1, $p = 0.009$). The ropivacaine concentrations that led to effective analgesia, sensory block, and maintenance of motor function are shown in Table 2. All four nerves behaved similarly in each patient, and there were no significant differences between the nerves. The EC_{max} of ropivacaine for differential block was calculated theoretically as 0.1285 %, and this concentration would lead to complete differential block in 71 % of patients (EC_{71}), assuming a standard normal distribution. None of the patients developed a hemodynamic problem, respiratory difficulty, neurological complications, or other severe adverse effects.

Discussion

In this study, we successfully demonstrated the possibility of utilizing differential block for hand or forearm soft-tissue surgery. A low concentration of ropivacaine can result in insufficient sensory block despite the maintenance of motor function, whereas a high concentration of ropivacaine can cause sufficient sensory block and analgesia but a loss of motor function. Consequently, the theoretical EC_{max} of ropivacaine for differential block was calculated as 0.1285 % in this study, which was EC_{71} for both sensory block and maintenance of motor function, and in most cases could induce sufficient analgesia. It was theoretically impossible to achieve complete differential block in all patients. We suggest that a prophylactic multimodal analgesic protocol to treat postoperative pain is important for successful postoperative analgesia in patients who receive a differential block before undergoing soft-tissue surgery.

The utilization of an ultrasound-guided nerve block technique facilitates accurate peripheral nerve block, and achieving accurate nerve block permits the accurate estimation of onset time, duration, and the optimal concentration or volume of local anesthetic. Recent studies have shown that onset times of axillary brachial plexus block associated with the use of 150–200 mg of ropivacaine were 10–20 min for sensory block and 15–35 min for motor block or sufficient surgical analgesia, and such levels of ropivacaine led to sensory block for 9–11 h [2, 3]. It has been reported that the duration of the sensory block induced by high-dose ropivacaine (636 min) did not significantly differ from the duration of the motor block it induced (642 min), and that these durations were not suitable for day-stay upper-limb surgery [8]. Indeed, the durations of the sensory and motor blocks obtained using ropivacaine did not differ significantly at several ropivacaine concentrations [6]. A higher dose of ropivacaine is expected to produce a more potent blockade [9]. The results of a dose–concentration study of the treatment of postoperative upper extremity pain and of the degree of motor block indicated that increasing ropivacaine concentration led to a weaker grip, which could compromise patient satisfaction [10]. In the present study, EC_{max} for ropivacaine was 20.56 mg. This is obviously less than the usual dose employed for brachial plexus block, because we performed axillary nerve block to treat postoperative pain, not to achieve intraoperative analgesia. Although we performed nerve block under general anesthesia, and did not observe a strict onset or duration of the nerve block, the blocking effects of ropivacaine were maintained during the operation, and its potency continued beyond the end of surgery, as seen in previous studies [2, 3, 8]. We believe that the effects of the differential block continued for several hours after surgery, and led to better postoperative patient satisfaction, and that the use of a more dilute block containing the same dose of ropivacaine has the potential to achieve differential block with better analgesia [10].

Prolonged or excess motor block is not appropriate for patients undergoing soft-tissue surgery with a short operation time or day surgery, because motor block sometimes causes self-caring disability and delays discharge [11]. Soft-tissue surgery is performed around the hand or forearm using delicate surgical techniques, and care is taken by orthopedic surgeons to prevent neural damage. Even when there is no obvious nerve damage as a result of the operation, surgical release around a nerve or fasciectomy presents a risk of neurological complication. In addition, postoperative inflammation or swelling may lead to neural compression, and this worsens the neuronal damage. Nerve function should be confirmed soon after hand or forearm surgery. Thus, maintaining adequate motor function makes it feasible to perform a postoperative manual muscle test. Patients are also afraid of severe postoperative pain, which is sometimes a factor in patient discharge from the hospital following day surgery. Differential block does not provide intense analgesia. Multimodal analgesia through medication, neural blockade, and topical analgesia have recently been recommended as routes to better analgesia with reduced side effects [12, 13]. NSAIDs effectively treat postoperative pain by suppressing inflammation, and peripheral nerve block is able to inhibit painful nerve conduction. Although differential block cannot inhibit every nerve input, the present study showed that postoperative pain and satisfaction scores were acceptable in most patients. NSIADs were used almost freely, and no patients experienced postoperative nausea or vomiting. Slight motor block just after surgery was acceptable to both patients and orthopedic surgeons. Thus, a combination treatment with NSAIDs and differential block will provide adequate analgesia that is satisfactory to both patients and surgeons.

An important limitation of this study is the difficulty of the pharmacological determination of the ropivacaine concentration needed for differential block. We calculated the EC_{10-95} values for effective analgesia, sensory block, and motor function separately by probit analysis. Although a low concentration of ropivacaine enables mobilization of an upper extremity to be maintained, it does not lead to sufficient postoperative analgesia or sensory block. In contrast, although a high concentration of ropivacaine can achieve postoperative analgesia and sensory block, mobilization is hindered. This is why differential nerve block produces a bell-shaped dose–response curve, and the EC value for no pain with mobilization could not be calculated directly. A second limitation of this study was that we did not observe the time courses of sensory block and motor block. To reduce patient discomfort, general anesthesia was induced before confirming the onset of axillary block, so the duration of differential block could not be determined in this study.

In conclusion, the EC_{max} when using 16 ml of ropivacaine to obtain differential block was 0.1285 %. Despite the resulting weak nerve block, the use of differential block in combination with NSAIDs led to sufficient analgesia and adequate motor function for both patients and orthopedic surgeons. Further studies are needed to compare various local anesthetics in the context of achieving adequate differential block.

Acknowledgments This research received no specific grant from any funding agency in the public, commercial, and not-for-profit sectors.

Conflict of interest All named authors hereby declare that they have no conflicts of interest to disclose.

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