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ORIGINAL ARTICLE

Potential advantages of an additional forearm rubber tourniquet in intravenous regional anesthesia: a randomized clinical trial

Li Song · Chaoran Wu · Jin Liu · Yunxia Zuo · Ernest Volinn · Jiaxiang Yao

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Abstract
Objective Although the usefulness of an additional forearm tourniquet to conventional intravenous regional anesthesia (IVRA) has been reported, the forearm cuff may disturb the surgical field to some degree, especially in wrist surgery. In the present study, we assessed the clinical efficacy of a temporary additional forearm rubber tourniquet to the conventional upper arm tourniquet on the quality of IVRA.
Methods The study included 32 ASA physical status I and II adult patients undergoing elective hand surgery who were randomly allocated to either an additional forearm tourniquet group (Group F) or to a conventional upper arm tourniquet group (Group C). Upper arm tourniquet IVRA was established using 40 mL of 0.5 % lidocaine in Group C. Hypothetically enhanced forearm tourniquet IVRA was established using 10 mL of 0.5 % lidocaine with an additional forearm rubber tourniquet and then administering 30 mL of 0.25 % lidocaine after removing the forearm tourniquet in Group F. The sensory and motor block onset and recovery times, onset time of tourniquet pain, intraoperative fentanyl consumption, and incidence of local anesthetic toxicity were recorded. The numerical rating score (NRS) of perioperative and postoperative pain and quality of anesthesia were also assessed.
Results Although the total dose of lidocaine in Group F was less and the sensory and motor block onset times were significantly shorter in Group F than those in Group C ($P < 0.05$), there was no difference regarding sensory and motor block recovery times, onset time of tourniquet pain, intraoperative fentanyl consumption, NRS of perioperative and postoperative pain, and the quality of anesthesia in the two groups ($P > 0.05$). Compared with Group C, the incidence of local anesthetic toxicity (i.e., dizziness, 43.8 vs 6.2 %, $P = 0.02$) was significantly decreased in Group F.
Conclusions The combination of the additional forearm and upper arm tourniquets with a smaller amount of local anesthetic achieved more rapid onset of sensory and motor block, a similar quality of anesthesia and a lower incidence of local anesthetic toxicity compared with the conventional technique.

Keywords Intravenous regional anesthesia · Additional forearm tourniquet

J. Liu and Y. Zuo contributed equally to this work.

IRB Contact Information: Registration number: ChiCTR-TRC-12002001, Chinese Clinical Trial Register (ChiCTR), No. 37, Guo Xue Xiang, Chengdu, Sichuan, China 610041, Tel: +86-28-8542-2081, Fax: +86-28-8542-2253, Email: chictr@hotmail.com.

L. Song · C. Wu · J. Liu (✉) · Y. Zuo
Department of Anesthesiology, Translational Medical Neuroscience Center, West China Hospital, Sichuan University, No. 37, Guo Xue Xiang, Chengdu 610041, Sichuan, China
e-mail: scujinliu@gmail.com

L. Song
e-mail: huaxisongli@hotmail.com

E. Volinn
Pain Research Center, Department of Anesthesiology, University of Utah, Salt Lake City, UT 84108, USA

J. Yao
Department of Anesthesiology, The 1st Affiliated Hospital of Kunming Medical University, Kunming 650032, Yunnan, China

Introduction

Intravenous regional anesthesia (IVRA) is an optional anesthetic technique for short surgical procedures of the hands

or feet [1]. It is a safe and effective method for providing anesthesia as well as a bloodless field during surgery. The conventional technique uses an upper arm double-cuff tourniquet [1]. Recently, modified IVRA techniques, including an additional or temporary forearm tourniquet, have been studied in an attempt to accelerate the onset speed of IVRA, decrease the dose of local anesthetic to nontoxic levels, and to improve the quality of anesthesia [2, 3]. In theory, the forearm tourniquet confines the local anesthetic in a smaller venous bed, and concentrates the local anesthetic in the hand and wrist, which hypothetically induces an accelerated onset of IVRA [3]. However, a forearm cuff may be problematic because of the possibility that its placement may obstruct the surgical field to some degree, especially in procedures proximal to the wrist [4, 5]. Consequently, we used a temporary forearm rubber tourniquet as an adjunctive in order to increase the concentration of local anesthetic and accelerate the onset of IVRA. The rubber tourniquet was then removed immediately, and we reduced the concentration of local anesthetic to prevent upper arm tourniquet pain during IVRA. The potential advantages of such a modified forearm tourniquet are to accelerate the onset of IVRA, decrease the dose of local anesthetic, and to provide an unobstructed surgical field.

Therefore, we designed this study to test the hypothesis that the temporary addition of a forearm rubber tourniquet to the conventional upper arm tourniquet improves the efficacy of IVRA. The primary aims were to assess the sensory and motor block onset and recovery times. The secondary aims were to assess onset time of tourniquet pain, intraoperative fentanyl consumption, and evaluate the intensity of perioperative and postoperative pain, the quality of anesthesia and the incidence of systemic local anesthetic toxicity during IVRA.

Materials and methods

Institutional Review Board approval was provided (Sichuan University, Chengdu, China; http://www.chictr.org/en/proj/search.aspx; Registration number: ChiCTR-TRC-12002001). This prospective, randomized, controlled study included 32 American Society of Anesthesiologist (ASA) physical status I and II patients scheduled for elective hand surgeries (i.e., carpal tunnel, tenolysis, cut tendon repair or neurolysis). Patients with Raynaud's disease, sickle cell anemia, chronic pain, hypertension, use of any analgesics or sedatives ≤24 h before surgery, or allergy to medications of this study were excluded from this study.

After informed consent was obtained from each patient, they were allocated to two groups by means of a computer-generated randomization list. Group C ($n = 16$) received IVRA with an upper arm tourniquet, and Group F ($n = 16$) received IVRA with a forearm tourniquet for venipuncture in combination with an upper arm tourniquet (Fig. 1). The procedure and the use of a numerical rating score (NRS, 0 = no pain and 10 = worst pain imaginable) were explained to the patients. All patients were monitored with standard ASA monitors including ECG, SPO_2 and NIBP. No sedative or analgesic premedications were used. Two intravenous cannulas were placed on each patient—one on the dorsum of the operative hand (20-gauge) and the other on the contralateral hand for crystalloid infusion. For each patient, an automatic pneumatic double tourniquet was positioned around the upper operative arm, which was elevated for approximately 2 min and then exsanguinated with an Esmarch bandage. The proximal tourniquet was inflated to 250 mmHg (or 100 mmHg above the systolic blood pressure) and the Esmarch bandage was then removed. Circulatory isolation of the operative arm was confirmed by the absence of a radial pulse and loss of the pulse oximetry tracing in the ipsilateral index finger. Patients in Group C received IVRA with 40 mL of 0.5 % lidocaine via the ipsilateral cannula over 90 s. Patients in Group F received IVRA (in time order)—(1) application of the additional forearm tourniquet immediately after inflation of the upper arm tourniquet, (2) 10 mL of 0.5 % lidocaine administered via the ipsilateral cannula over 30 s, (3) removal of the additional forearm tourniquet immediately after the first injection of lidocaine, and (4) immediate administration of 30 mL of 0.25 % lidocaine via the same cannula over 60 s after removing the forearm tourniquet. The study design is illustrated in Fig. 2. An anesthesiology resident not involved in this study prepared syringes containing different concentrations of lidocaine, while another

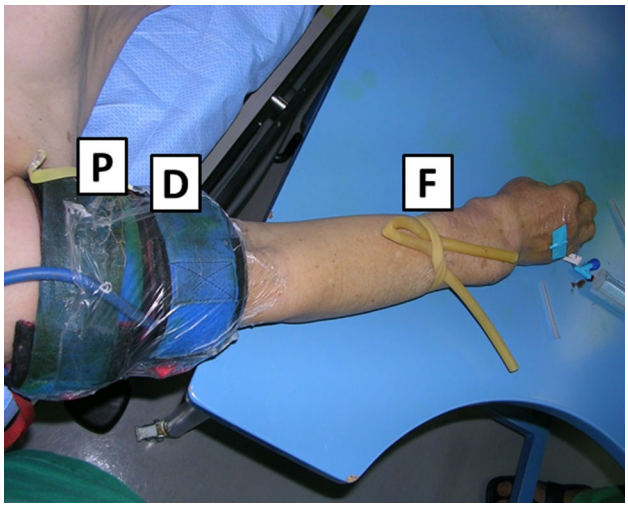

Fig. 1 The procedure for the modified forearm tourniquet. A forearm rubber tourniquet and an upper arm double-cuff tourniquet were applied to the patient. *P* Proximal cuff of double tourniquet, *D* Distal cuff of double tourniquet, *F* Forearm rubber tourniquet

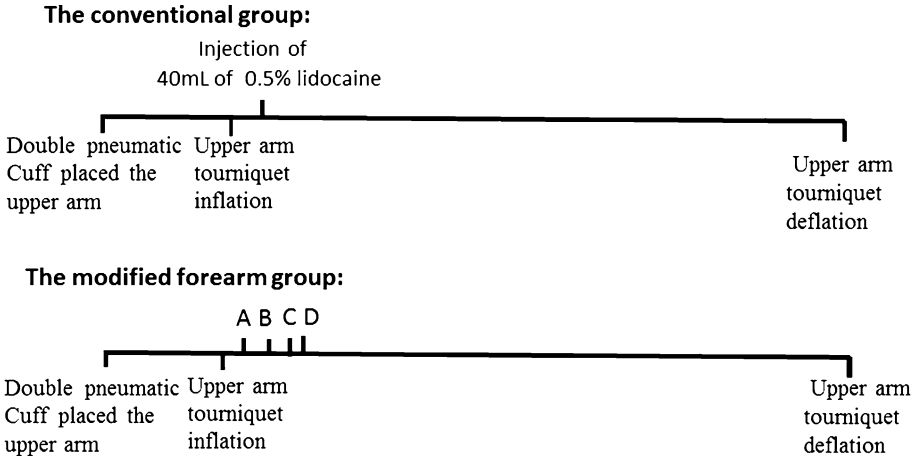

Fig. 2 The scheme shows the experimental design of this study. *A* The additional rubber forearm tourniquet for venipuncture applied immediately after inflation of the upper arm tourniquet. *B* 10 mL of 0.5 % lidocaine was administered via the ipsilateral cannula over 30 s. *C* The additional rubber forearm tourniquet was removed immediately after the first injection of lidocaine. *D* 30 mL of 0.25 % lidocaine was immediately administered via the same cannula over 60 s after removing the forearm rubber tourniquet

anesthesiologist blinded to the study injected the solutions. Following all injections of lidocaine (the second injection in Group F), the sensory block was assessed by a pinprick using a 22-gauge, shot-bevel needle every 15 s. Sites for sensory testing included the thenar eminence (median nerve); the hypothenar eminence (ulnar nerve) and the first web space (radial nerve). The sensory block onset times in three nerves of the hand were noted as the times elapsed from the end of all injection of lidocaine to no response to pinprick in three dermatomes. The motor block was assessed by asking the patients to flex and extend their fingers every 15 s. Sites for motor testing included the thumb (radial nerve), index finger (median nerve), and the digitus minimus manus (ulnar nerve). The motor block onset times in three nerves of the hand were noted as the time elapsed from the end of all injections of lidocaine to no voluntary movement in fingers of the three nerves, respectively [6]. After sensory and motor block was achieved, the distal tourniquet was inflated to 250 mmHg (or 100 mmHg above the systolic blood pressure), and the proximal tourniquet was then released, and surgery started.

The tourniquet pain was assessed using NRS intraoperatively every 5 min after inflation of the distal tourniquet. The onset time of tourniquet pain was recorded as the time from the distal tourniquet inflation to the patient's initial report of tourniquet pain (NRS $\geq$4). Patients reporting tourniquet pain and surgical pain (NRS $\geq$4) were given fentanyl 1 μg/kg i.v., with the dose and time recorded. The tourniquet was not deflated for at least 30 min but was not inflated for >60 min. If the surgery extended beyond one hour, general anesthesia was given, and the patient was excluded from this study. After the surgery, the distal tourniquet was deflated by a cyclic deflation technique over 1–2 min. Recovery of the sensory and motor block was then tested at the same nerve sites every 15 s. Sensory and motor recovery times were noted as the time elapsed from tourniquet deflation to recovery of sensation and motor in three nerve dermatomes, respectively. The surgical time and tourniquet time were also recorded in all the patients.

At completion of the surgery, the quality of anesthesia was graded by the anesthesiologist who was blinded to the technique according to the following numeric scale—Grade 4 = excellent (no complaint of pain from the patient), Grade 3 = good (minor complaint; fentanyl not required), Grade 2 = moderate (fentanyl required), and Grade 1 = failure (patient given general anesthesia) [7]. The quality of anesthesia was also graded by the surgeon according to the following numeric scale—Grade 3 = good, Grade 2 = moderate, and Grade 1 = poor [7].

Patients were monitored for symptoms (dizziness, visual disturbances, perioral tingling and tinnitus) and signs (hypotension, cardiac arrhythmias, seizures) of local anesthetic toxicity throughout the surgical procedure and for 24 h after the surgery (first 2 h in postanesthesia care unit and following 22 h in the orthopedic ward). Postoperative pain was assessed at 30 min, 60 min and 24 h after the surgery using NRS.

Statistical analysis

In a study by Asik et al. [8], a sample size of 16 patients in each group was determined to be sufficient to demonstrate a 35 % difference in sensory block time with $\alpha = 0.05$ and power of 0.8. All data were analyzed with SPSS11.5 software (SPSS Inc., Chicago, IL, USA). Demographic data, hemodynamic data, fentanyl consumption, and times (surgical times, sensory and motor block onset and recovery times, onset times of tourniquet pain and total tourniquet times) were compared between the two groups using unpaired Student's *t* test. The NRS and the quality of anesthesia (assessed by anesthesiologists and surgeons) were compared using Mann–Whitney *U* test. The incidence of local anesthetic toxicity was compared using Fisher's exact test. $P < 0.05$ was considered statistically significant.

Table 1 Demographic characteristics of the patients

	Group C ($n = 16$)	Group F ($n = 16$)	P
Age (years)	32.6 ± 10.9	31.3 ± 10.6	0.74
Gender (F/M) (*n*)	12⁄4	13⁄3	
Weight (kg)	60.2 ± 6.9	61.1 ± 6.8	0.72
Height (cm)	168.7 ± 10.9	169.2 ± 11.5	0.61
Type of surgery			
Carpal tunnel (*n*)	6	7	
Tenolysis (*n*)	5	4	
Cut tendon repair (*n*)	4	3	
Neurolysis (*n*)	1	2	
Surgical times (min)	35.2 ± 2.8	34.1 ± 3.4	0.91
Tourniquet times (min)	47.5 ± 5.2	46.1 ± 4.7	0.29

Age, weight, height, surgical times and tourniquet times are represented as mean ± SD

M male, *F* female

Results

All patients completed the study successfully. The demographic data and features of their surgery and anesthesia are shown in Table 1. Both groups were similar with regard to age, gender, weight, height, type of surgery, surgical time, and tourniquet time. There was no statistical difference in HR, SPO_2, or NIBP at any time during the study between the two groups (data not presented).

Sensory and motor block onset and recovery times are showed in Table 2. Sensory and motor block onset times of ulnar, median and radial nerve in Group F were significantly shorter than those in Group C ($P < 0.001$; $P < 0.05$). Moreover, in both Group F and Group C, sensory and motor block onset times of radial nerve were shorter than those of ulnar and median nerves ($P < 0.05$) (Table 2). However, sensory and motor block recovery times were

Table 2 Evaluation of the efficacy, complication, perioperative and postoperative NRS scores of two groups

	Group C ($n = 16$)	Group F ($n = 16$)	P
Ulnar nerve			
Sensory block onset time (min)	5.7 ± 1.0	3.3 ± 1.2	<0.001
Sensory block recovery time (min)	5.2 ± 1.1	5.1 ± 1.3	0.69
Motor block onset time (min)	11.3 ± 4.3	7.8 ± 4.2	0.03
Motor block recovery time (min)	5.0 ± 1.4	5.1 ± 1.2	0.49
Median nerve			
Sensory block onset time (min)	5.9 ± 1.0	3.3 ± 1.2	<0.001
Sensory block recovery time (min)	5.8 ± 1.6	5.5 ± 1.0	0.47
Motor block onset time (min)	10.4 ± 2.6	7.3 ± 1.0	0.03
Motor block recovery time (min)	5.2 ± 1.0	5.3 ± 1.0	0.78
Radial nerve			
Sensory block onset time (min)	4.6 ± 0.9*	1.7 ± 0.7*	<0.001
Sensory block recovery time (min)	5.1 ± 1.3	5.2 ± 1.1	0.54
Motor block onset time (min)	9.2 ± 1.1†	5.3 ± 1.3†	<0.001
Motor block recovery time (min)	5.0 ± 1.4	5.2 ± 1.3	0.43
Onset time of tourniquet pain (min)	24.3 ± 4.9	24.9 ± 6.5	0.77
Intraoperative fentanyl consumption (μg)	67.4 ± 12	68.2 ± 11	0.12
Anesthesia quality scores			
Quality of anesthesia (anesthesiologist)	4 (2–4)	4 (2–4)	0.56
Quality of anesthesia (surgeon)	3 (2–3)	3 (2–3)	0.62
Local anesthetic toxicity			
Dizziness	7 (43.8 %)	1 (6.2 %)	0.02
NRS scores			
Start of surgery	1 (0–2)	1 (0–2)	0.77
End of surgery	2 (1–3)	2 (1–3)	0.86
Postsurgery 30 min	2 (2–3)	2 (1–3)	0.47
60 min	3 (2–4)	3 (2–4)	0.75
24 h	3 (2–4)	3 (2–4)	0.89

Sensory block onset and recovery time, motor block onset and recovery time, onset time of tourniquet, intraoperative fentanyl consumption are represented as mean ± SD. Anesthesia quality scores and NRS scores are represented as median (interquartile range). Complication is represented as number (%)

NRS numerical rating score

* $P < 0.001$, compared with sensory block onset time of ulnar and median nerves; † $P = 0.01$, compared with motor block onset time of ulnar and median nerves

not only significantly different between the two groups but also among the ulnar, median and radial nerves ($P > 0.05$) (Table 2).

Onset time of tourniquet pain as well as the perioperative and postoperative NRS were similar for the two groups ($P > 0.05$) (Table 2). Intra-operatively, no medication other than fentanyl for analgesia was given to patients. Four patients in Group C and three patients in Group F were given fentanyl for supplemental analgesia; however, cumulative fentanyl consumption did not significantly differ between the two groups ($P > 0.05$) (Table 2).

The quality scores of anesthesia graded by anesthesiologists were excellent or good (grade 4/3) in 12 patients in Group C and in 13 patients in Group F, and thus did not significantly differ between the two groups ($P > 0.05$) (Table 2). Additionally, the quality scores of anesthesia graded by surgeons did not significantly differ between the two groups either ($P > 0.05$) (Table 2).

The incidence of dizziness was significantly reduced in Group F compared with Group C (6.2 vs 43.8 %, $P = 0.02$) (Table 2). No other symptoms (visual disturbances, perioral tingling and tinnitus) or signs (hypotension, cardiac arrhythmias, seizures) of local anesthetic toxicity were observed in either group.

Discussion

This study explored the potential advantages of a temporary additional forearm tourniquet to the conventional IVRA. The combination of forearm and upper arm tourniquets with a smaller amount of local anesthetic achieved more rapid onset of sensory and motor block, similar quality of anesthesia and lower incidence of local anesthetic toxicity compared with the conventional technique.

A forearm tourniquet as an adjunct to IVRA resulted in a faster onset of anesthesia, compared with the conventional upper tourniquet [2, 3, 9, 10]. A plausible biological mechanism for this effect is that confinement of the local anesthetic in a smaller venous bed might increase the pressure and promote retrograde flow to the site(s) of action which would increase the speed of onset of block and allow a smaller dose of local anesthetic to be used [3]. However, a forearm cuff may obstruct the surgical field to some degree, especially in procedures proximal to the wrist [4, 5]. Therefore, unlike previous studies [2, 9–11], we used a temporary rubber tourniquet for venipuncture in IVRA, which allowed the surgical field to remain unobstructed. Our results were consistent with previous findings in other studies on forearm tourniquet IVRA [2, 3, 9, 10]. The sensory and motor block onset times were more rapid in the temporary additional forearm tourniquet IVRA compared with the conventional upper arm tourniquet IVRA. Additionally, the sensory and motor testing of ulnar, median and radial nerves was also assessed in our study. Of note was that sensory and motor block onset times of the radial nerve were shorter than those of ulnar and median nerves in both modified and conventional IVRA. The mechanism for this might be related to venous vascularity leading to an increase in local anesthetic in the vicinity of the radial nerve [12]. This interesting result suggested that the dose of local anesthetic might be further reduced during minor surgical procedures of the radial hands. Furthermore, surgeons whose patients were included in the study were also satisfied with the temporary forearm rubber tourniquet; presumably because it was removed before the start of the surgery (otherwise the surgical field would have been unobstructed).

According to previous studies, forearm tourniquet IVRA allowed the dose of lidocaine to be decreased by up to 50 % [2, 3, 10, 11]. In a study by Ye et al. [13], 7 mL of 0.5 % lidocaine for the rubber forearm tourniquet IVRA also achieved successful anesthesia. To further explore the optimal dose of lidocaine in this modified IVRA, we conducted a preliminary test; the data obtained showed that 10 mL of 0.5 % lidocaine achieved a complete anesthetic effect but incomplete tourniquet analgesia. Therefore, for modified forearm IVRA in our study we used 10 mL of 0.5 % lidocaine for surgical anesthesia and 30 mL of 0.25 % lidocaine for relieving tourniquet pain. The lidocaine dose (200 vs 125 mg) was higher in Group C compared to Group F, which demonstrated that a smaller dose of local anesthetic was required for temporary additional forearm tourniquet IVRA.

The onset time of tourniquet pain was similar in both the modified and conventional IVRA groups in this study. In other words, 30 mL of 0.25 % lidocaine achieved a similar analgesic effect to tourniquet tolerance as 40 mL of 0.5 % lidocaine during IVRA. This result indicated that a lower concentration of local anesthetic might act on the sensory nerve terminals and a higher concentration of local anesthetic might act on both nerve trunks and sensory nerve terminals. The metabolic changes that occurred in an exsanguinated extremity during tourniquet ischemia were reflected in hypoxia, hypercapnia, acidosis and lactacidemia [12]. These changes, which stimulated the sensory nerve terminals, were probably major components in tourniquet pain during IVRA [12]. Accordingly, we may use a lower concentration of local anesthetic to prevent tourniquet pain during IVRA; however, in order to optimize the concentration and volume of local anesthetic for tourniquet tolerance, an ensuing study design with different dose ranges would be required.

Local anesthetic toxicity was the most important complication limiting the use of IVRA [14]. Therefore, it is desirable to use a minimal amount of local anesthetic. In this current study, the use of the additional forearm tourniquet compared to a conventional upper arm tourniquet allowed

the dose of local anesthetic to be decreased to approximately half of what was required with the upper arm tourniquet, thereby providing an enhanced safety margin for patients. The most frequent complication we observed was dizziness, which might have been induced by systemic absorption of local anesthetics and after tourniquet deflation in IVRA. The lower incidence of dizziness in the additional forearm group was principally because the dose of local anesthetic was significantly decreased. Otherwise, with the additional forearm tourniquet, more rapid movement of local anesthetic out of the vascular system conceivably provides a potential benefit in the event of unintended tourniquet release, because local anesthetic becomes sequestered in the tissues earlier, therefore reducing the peak plasma concentration of local anesthetic [3]. Fortunately, the dizziness of patients was resolved readily after administering supplemental oxygen.

There are two limitations in this study. Firstly, masking of the two groups was incomplete (including different injection numbers in the two groups and no mask on the patient). Secondly, the patient population size was relatively small, and patients came from a single hospital. Additionally, the study lacked another modified group in which the same amount of lidocaine was used as the conventional group. In further studies, the masking should be more complete, and the procedures described in this study should be performed in different patient populations.

In conclusion, a temporary additional forearm rubber tourniquet in combination with the upper arm tourniquet significantly provided clinical benefits by accelerating the onset of sensory and motor block, reducing the dose of local anesthetics, and decreasing the incidence of systemic local anesthetic toxicity. Notably in view of these advantages, tourniquet tolerance, postoperative pain, and quality of anesthesia were similar to conventional IVRA. Further studies in other patient populations are warranted to ensure that our findings on advantages and adverse events are replicable.

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