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Original Article

Application of ultrasound-guided catheter blockade with continuous neuroelectrostimulation for analgesia after total knee arthroplasty

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Abstract: The present study aimed to investigate the effects of ultrasound-guided neuroelectrostimulating continuous catheter blockade (U-NCCB) for analgesia after total knee arthroplasty (TKA). The study included 90 patients who were classified into grades I-III according to the American Society of Anesthesiologists (ASA) system and subjected to unilateral TKA; the patients were randomly assigned to groups I-III-control, ultrasound-guided conventional catheter, and U-NCCB groups, respectively (n = 30, each). The visual analogue scale (VAS) scores, adverse events, and overall patient satisfaction with analgesic therapy were recorded at different postoperative time points. Patients in groups II and III exhibited significantly lower resting and passive VAS scores at all postoperative time points than those in group I ($P < 0.05$). Group III exhibited significantly lower VAS scores at 4, 8, and 12 h postoperation than group II ($P < 0.05$). The overall satisfaction rates of groups II (75%) and III (95%) were significantly higher compared to that of group I (10%; $P < 0.01$), and the overall satisfaction rate of group III was significantly higher compared to that of group II ($P < 0.05$). Application of an electrostimulating catheter under the dual guidance of a nerve stimulator and ultrasound can effectively improve post-TKA analgesia and patient satisfaction.

Keywords: Ultrasound, neuroelectrostimulation, total knee arthroplasty, postoperative analgesia

Introduction

With increasing age, the elderly tend to exhibit an increased incidence of knee lesions such as osteoarthritis, rheumatoid arthritis, and traumatic arthritis, which result in pain, limited mobility, and decreased quality of life [1]. Total knee arthroplasty (TKA) is the primary means for the treatment of end-stage knee diseases in elderly patients as well as the reconstruction of knee function. This procedure has been reported as demonstrating good long-term effects [2]. However, TKA can potentially cause substantial postoperative trauma, and postoperative intravenous administration of analgesic drugs is ineffective for pain relief. In addition, intraoperative application of a tourniquet can result in hypoxia-ischemia in the lower limb on the surgical side as well as postoperative pain; it can also indirectly induce the release of inflammatory cytokines, thus inducing inflammatory responses [3]. Since TKA can induce systemic inflammatory responses, improvement in analgesia and the timely reduction of inflammatory responses are important for the reduction of postoperative complications and improvement of prognosis [4]. Although early postoperative functional training can maximize the prosthetic joint function, approximately 60% of the patients who undergo such training experience severe pain, while 30% experience moderate pain [5], which significantly reduces the effects of rehabilitation. Conventional epidural analgesia can provide effective post-TKA pain relief. However, post-TKA anticoagulation therapy results in an increased risk of hematoma during epidural analgesia. Therefore, epidural analgesia is not used as a routine method for post-TKA analgesia. The knee is richly innervated by several nerves, including the femoral, obturator, saphenous, lateral femoral cutaneous, and sciatic nerves. Studies have shown that continuous femoral nerve blockade results in analgesic effects comparable to or greater than those of epidural blockade [6]. Some studies have also reported that the application of

ultrasound-guided peripheral nerve blockade and catheterization for analgesia after orthopedic surgery is convenient, reliable, and safe and can induce sufficient analgesia to demonstrate its benefits and promote patient satisfaction [7]. Administration of ultrasound-guided anesthesia via a femoral nerve catheter is a new technique. Ultrasound imaging allows clear visualization of the nerves, tissues, and puncturing needles, thus facilitating catheter placement around the femoral nerve, ensuring that the local anesthetic encases the femoral nerve. Ultrasound-guided peripheral nerve blockade and catheterization results in significantly improved blockading than blind probing and nerve stimulator-guided puncturing. A peripheral nerve blockade positioned by an ultrasound-guided nerve stimulator has advantages such as accurate positioning, strong blockading effect, and relatively few complications. It has, therefore, become a commonly applied method for analgesia in lower limb surgery [8, 9]. Continuous femoral nerve blockade can accomplish complete post-TKA analgesia. It is also associated with fewer physiological disturbances to the body than the other analgesic methods, which is conducive for early postoperative rehabilitation after lower limb surgery in elderly patients, particularly those with severe systemic disorders [10, 11]. Although ultrasound-guided continuous femoral nerve blockade is widely used for post-TKA rehabilitative analgesia, inaccurate tip positioning during its application is still reported, with a difference in inaccuracy of 35% in comparison with conventional catheterization methods [12], leading to poor postoperative analgesia. Postoperative pain induces fear related to postoperative exercises in patients. Consequently, patients express unwillingness to perform functional exercises, which seriously affects the outcome of postoperative rehabilitation. Postoperative pain also has serious adverse effects on patients undergoing knee-joint arthroplasty. Therefore, it is necessary to develop an accurate and convenient postoperative analgesic method for continuous analgesia, in order to provide continuous physical and psychological comfort to patients. The catheter tip of a continuous peripheral nerve stimulator, equipped with an electrode, can be used to monitor the accuracy of peripheral nerve catheter placement. In this study, we used ultrasound-guided neurostimulating positioning technology to perform femoral-neuro-electrostimulating catheterization for continuous femoral nerve blockade in order to observe its efficacy in post-TKA analgesia.

Methods

Subjects

A total of 90 patients (age range, 52-85 years; body weight, 51-78 kg), classified on the basis of physical status as grades I-III according to the American Society of Anesthesiologists (ASA) system, who underwent unilateral TKA between January 2013 and January 2015 at our hospital were included in this study. The exclusion criteria were as follows: infection at the puncture site, neurological diseases, incorrect understanding of the pain visual analogue scale (VAS), severe psychological problems or history of mental illness, significant cardiovascular diseases, hepatonephric dysfunction, and history of gastric ulcer, coagulation disorders, and allergies to local anesthetics or opioids. The patients were randomly divided into groups I-III (n-30, each), corresponding to the control, ultrasound-guided conventional catheter, and ultrasound-guided neuroelectrostimulating continuous catheter blockade (U-NCCB) groups, respectively. This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of Ningxia People's Hospital. Written informed consent was obtained from all participants.

Anesthetic methods and postoperative analgesia

All of the procedures, data recording, and postoperative follow-up examinations were performed by the same group of anesthesiologists. Upon entering the operating room, patients were subjected to intravenous bypass for the measurement of mean arterial pressure, heart and respiration rates, blood oxygen saturation (SpO_2) level, and intraoperative urine output. All patients were administered lumbar epidural joint anesthesia at the L3-4 or L2-3 intervertebral space, and 2 mL of 0.75% bupivacaine with 3 mL of 0.05 mg fentanyl-isobaric solution was administrated into the subarachnoid space. No epidural catheter was implanted. The anesthetic plane was controlled at the T10-T4 level. Surgery was performed by anterior medial knee incision and a medial patellar approach below a

pneumatic tourniquet, by the same group of senior physicians.

Femoral nerve catheterization

After the administration of subarachnoid blockade anesthesia, patients were placed in the supine position, with the affected limb abducted outwards. A linear probe (frequency, 6-10 MHz; MicroMaxx™ Portable Ultrasound, SonoSite, Bothell, WA, USA) was placed horizontally at the bottom of the inguinal ligament, with its long axis perpendicular to the longitudinal axis of the major thigh, when the cross-sectional ultrasound images of the femoral vein, artery, and nerve, arranged from the inside toward the outside of the iliopubic bow fascia, were clearly displayed. Using the out-of-plane technique, a puncture was placed using a puncturing needle (B/BRAUN Contiplex D 18G, B. Braun Melsungen AG, Melsungen, Germany) until it reached the surface of the femoral nerve, at which point, the head of the needle formed a 45° angle with the skin. In group II, a small amount of saline was injected if no blood appeared when the needle was withdrawn; the diffusion of saline was monitored, and in case of diffusion around the deep femoral nerve of the iliac fascia, 20 mL of a solution comprising 10 mL of 0.75% ropivacaine, 5 mL of 2% lidocaine, 10 mg dexamethasone, and 3 mL normal saline was injected. Conventional continuous catheterization was then performed to a depth of 10-12 cm. Surgery in group III was performed by the same method as that in group II. After administration of the loading dose of local anesthetic, a continuous electrostimulating catheter, connected to a nerve stimulator (Stimuplex HNS 12, B. Braun Melsungen AG, Melsungen, Germany), was implanted if no blood appeared when the needle was withdrawn. If twitching of the quadriceps was still observed at a stimulus threshold of 0.4 mA, the catheter was considered as being positioned correctly; if no twitching of the quadriceps was observed at a stimulus threshold of 0.4 mA, the catheter required repositioning. The patients of all three of the groups were administered postoperative analgesia by means of postoperative electronic analgesic pumps. For Group I, patient-controlled intravenous analgesia (PCIA) was administered with 3 μg/kg sufentanil and 0.04 mg/mL tropisetron hydrochloride (background dosage, 2 mL/h; single-injection dose, 0.5-1 mL; lockout time, 15 min). The analgesic prescription for patients of groups II and III was 120-150 mL of 0.25% ropivacaine (background dosage, 5 mL/h; PCIA, 5 mL/injection; lockout time, 30 min). The patients of all three groups were administered PCA 15 min before the functional exercises. In case of unsatisfactory analgesic effect, 2 mL of 0.1 g tramadol hydrochloride was administered intramuscularly.

Monitoring of treatment outcomes

The VAS scores during rest were recorded at 4, 8, 12, 24, and 48 h post-surgery, and the passive VAS score was recorded at 48 h post-surgery (0 points, no pain; 10 points, severe pain).

The total volume of analgesic administered per patient was recorded at 48 h post-surgery. The number of effective pump-presses, dosage of intramuscular injections of tramadol, and incidence of side effects such as dizziness, nausea, vomiting, pruritus, and drowsiness were recorded.

The start time of ambulation, as well as the number of walking events per day, was recorded. Additionally, the overall patient satisfaction with analgesic therapy was recorded at the end of analgesic therapy-each patient was asked to provide a comprehensive assessment of the analgesic effects, adverse reactions, and cost/performance ratio, and based on the responses, patient satisfaction was classified into four categories: very satisfied, satisfied, generally neutral, and dissatisfied.

Patients in groups II and III were monitored for adverse events, including catheter prolapse and leakage. A VAS score ≥ 6 points within 4 h of surgery was considered as indicating catheterization failure, and the patient was switched to venous analgesia.

Side effects such as cardiovascular events, cerebrovascular events, deep vein thrombosis, postoperative cognitive dysfunction, limb numbness and paresthesia, and pulmonary embolism and infection were monitored and recorded for 3 to 5 days after surgery.

Statistical analysis

All statistical analyses were performed using the SPSS v.19.0 software (SPSS Inc., Chicago, IL, USA). The measurement data were represented as the mean values ± standard devia-

Table 1. General information among 3 groups*

Index	Group I	Group II	Group III
Gender (male/female)	13/17	14/16	12/18
Age (years)	56.62±6.28	57.42±4.20	58.62±6.17
Height (cm)	156.4±7.1	154.5±7.7	156.9±7.4
Weight (kg)	56.2±8.3	60.2±8.5	55.2±8.2
ASA classification (I/II/III)	8/13/9	7/15/8	5/15/10
Complication (yes/no)	18/12	13/17	15/15
Anesthetic time (min)	215±25.7	221±28.6	217±23.8
Surgical time (min)	93.65±25.1	95.73±23.7	96.68±27.2
Tourniquet-applying time (min)	66.7±7.6	65.3±8.2	68.5±4.7
Intraoperative anesthetic dosage (ml)	3	3	3

*$P > 0.05$ of each index among 3 groups. ASA, American Society of Anesthesiologists.

Table 2. VAS scores at different time points among the 3 groups (points)

Postoperative time	Group I		Group II		Group III	
	Resting VAS	Passive VAS	Resting VAS	Passive VAS	Resting VAS	Passive VAS
4 h	5.9±1.5#	5.8±1.3#	3.0±0.9※	3.1±1.6※	2.1±0.8	1.8±1.3
8 h	6.7±1.1#	7.0±1.3#	3.4±1.0※	3.6±1.8※	2.2±1.0	1.7±1.1
12 h	7.3±1.2#	7.2±0.7#	3.3±1.1※	3.8±1.1※	1.9±0.9	1.8±1.4
24 h	7.7±0.6#	7.9±1.4#	2.8±1.3	3.2±1.5	2.0±1.3	2.4±1.9
48 h	7.2±1.0#	7.1±1.6#	2.7±1.4	3.0±1.2	2.4±1.6	2.8±1.7

Note: #$P < 0.05$ compared with group II and group III at the same time point; ※$P < 0.05$ compared with group III at the same time point. VAS, visual analogue scale.

Table 3. Postoperative activities and satisfaction of analgesia among 3 groups

Index	Group I	Group II	Group III
Catheterization failure (%)		10 (3/30)	0Δ
Starting time of ambulation (days)	4.48±0.78	2.23±0.62*	1.51±0.32*
Number of daily walking (times)	2.16±0.73	5.68±0.52*	7.61±0.27*
Satisfaction rate (%)	10	76.7*	93.3*

Note: *$P < 0.05$ compared with group I; Δ$P < 0.05$ compared with group II.

tions (SD). Parameters whose variation among the three groups met the criteria for normality and homogeneity of variance were analyzed by single-factor ANOVA; parameters whose values differed significantly among the three groups were analyzed by pairwise comparison using the SNK-q test. Comparison of parameters whose variation among the three groups failed to meet the criteria for normality or homogeneity of variance was performed using the Rank-Sum test, and their pairwise comparison was performed using the Kruskal-Wallis H test. The enumeration data were compared using the χ^2 test. Values of $P < 0.05$ were considered statistically significant.

Results

Patient characteristics

There were no statistically significant differences in sex, age, height, weight, ASA classification, complications, anesthetic and surgical times, tourniquet-application time, intraoperative anesthetic dosage, and intra and postoperative vital signs among the three groups ($P > 0.05$, **Table 1**).

VAS scores

Patients of groups II and III exhibited significantly lower resting and passive VAS scores at all postoperative time points than those of group I ($P < 0.05$). Patients of group III exhibited significantly lower VAS scores at 4 and 8 h post-surgery than those of group II ($P < 0.05$, **Table 2**).

Postoperative activity and satisfaction with analgesia

The patients of groups II and III exhibited earlier starting times of ambulation than those of group I, and the numbers of walking events per day of the patients of groups II and III were greater compared to that of the patients of group I; these differences were statistically significant ($P < 0.05$). According to the results of comprehensive satisfaction assessment in terms of analgesic effects, functional recovery, and comfort, the overall satisfaction rate of group II was 76.7%, with 23 patients indicating being very satisfied or satisfied. Among the patients of group III, 28 indicated being very satisfied or satisfied, and the overall satisfac-

Table 4. Comparison of number of postoperative pump-pressing, number of effective pressing and dosage of tramadol among 3 groups

Index	Group I	Group II	Group III
Number of postoperative pump-pressing (times)	11.18±2.99	5.48±2.44$^{\Delta}$	3.32±2.12$^{\Delta}$
Number of effective pressing (times)	3.15±1.91	4.90±1.68$^{\Delta}$	3.30±0.38$^{\Delta}$
Dosage of tramadol (mg)	250±50	50±50$^{\Delta}$	0$^{\Delta}$

Note: $^{\Delta}P < 0.05$ compared with group I.

tion rate was 93.3%, which was significantly higher compared to those of groups I (3/30; 10%; $P < 0.010$) and II ($P < 0.05$). Group II exhibited three cases of catheterization failure (catheterization failure rate of 10%), which was higher compared to that of group III ($P < 0.05$, **Table 3**).

The total number of postoperative pump-presses of group I was greater compared to those of groups II and III, while the numbers of effective pump-presses for groups II and III were greater compared to that of group I. The dosage of intramuscular tramadol injection in group I was higher compared to those in groups II and III (**Table 4**).

Safety evaluation

No instances of serious life-threatening adverse reactions, such as respiratory depression, deep vein thrombosis, and pulmonary embolism, were observed within 1-3 days postsurgery. In group II, 4 patients complained of discomfort at the puncture site, while difficulty in catheterization was experienced in the case of 2 patients. No instances of local infection, catheter dislocation, hematoma, secondary motion, or sensory disorders in the nerve-dominant regions were observed among the patients of groups II and III. Furthermore, one of the patients of group II experienced dizziness. The rate of drowsiness in group I was 60% (18/30), the rate of dizziness, nausea, and vomiting was 33% (10/30), and the rate of pruritus was 17% (5/30). These symptoms were treated symptomatically, and they resolved upon the stoppage of PCIA.

Follow-up examination

In group I, one of the patients exhibited deep vein thrombosis and another experienced postoperative cognitive dysfunction. However, none of the patients of groups II or III exhibited adverse cardiovascular or cerebrovascular events, deep vein thrombosis, postoperative cognitive dysfunction, limb numbness or paresthesia, or pulmonary embolism or infection.

Discussion

Knee arthroplasty stimulates structures such as the synovial tissues, fat pads, and nerve endings inside the joint cavity, causing severe postoperative pain that can persist for 48-72 h after surgery [13]. Post-TKA pain is mostly moderate to severe and can be categorized as nociceptive, neuropathic, and mental/psychological types of pain [14, 15]. Inadequate postoperative analgesia results in a direct decrease in the degree of patient satisfaction, thus affecting postoperative recovery. Lately, intraoperative local anesthesia and nerve blockade analgesia have been used in orthopedic surgery, where they have been reported as being effective. In comparison with general anesthesia, local anesthesia and nerve blockade exhibit fewer incidences of postoperative complications, require shorter durations of hospitalization, and reduce postoperative neuroendocrine stress responses and central nervous system sensitivity to intraoperative pain [16]. Administration of whole-process postoperative analgesia in order to overcome postoperative pain and promote early rehabilitation exercises has gained importance, especially among the elderly patients, who are relatively more sensitive to pain and appear to have a critical requirement of postoperative analgesia. Early post-TKA functional exercises can promote functional recovery of the knee, which is an important part of successful surgery. Surgery-induced soft-tissue trauma and inflammation are the main causal factors of pain after TKA. Most patients are reluctant to perform functional exercises at the early postoperative stages because of pain at the incision site, which indicates that effective postoperative analgesia can prompt patients to participate in early rehabilitation exercises. In comparison with opioids and intraspinal analgesia, nerve blockade anal-

gesia was reported as exhibiting minimal physiological effects on patients and fewer complications. Since nerve blockade analgesia involves the blockage of only one limb, it circumvents the hemodynamic changes caused by an excessively wide blocking range. The results of the present study indicate that continuous femoral nerve blockade exhibits better postoperative analgesic effects than intravenous analgesia, and the former method could significantly reduce the incidence of opioid-related adverse reactions. In the present study, analgesia by U-NCCB exhibited exact analgesic effects, fewer side effects, and greater patient comfort than intravenous analgesia. It is, therefore, more conducive for postoperative functional exercises and increased patient and surgeon satisfaction, which is consistent with the findings of a previous study [17].

Lately, continuous femoral nerve blockade has become the primary means of postoperative analgesia and rehabilitation after TKA. The effects of femoral nerve blockade depend on the position of the catheter tip relative to the femoral nerve, and the position of catheterization directly influences the analgesic effects of femoral nerve blockade [6]. Continuous femoral nerve blockade can improve postoperative analgesic effects following TKA. However, an inaccuracy of 20-50% in tip-positioning is still observed with continuous femoral nerve blockade, which is greater compared to that observed with conventional catheterization. Barrington et al. [18] suggested that the electrode at the tip of a continuous peripheral neurostimulating catheter might be responsible for the greater accuracy of catheterization in comparison with that of a conventional catheter. In the present study, positioning was performed using an ultrasound-guided neuroelectrostimulating technique, which improved the accuracy of positioning of the stimulating catheter, thus significantly improving the postoperative analgesic efficacy. Group III exhibited significantly lower VAS scores at 4 and 8 h post-surgery than group I, and this result might be related to the proximity of the catheter tip to the femoral nerve in the patients of group III. The VAS scores at 12 h post-surgery exhibited no statistically significant differences among the three groups, which is most likely related to the infiltration of local anesthetic upon long-term infusion. Our results revealed that the rate of catheterization failure of group III was significantly lower compared to that of group I, indicating that U-NCCB can result in a significant improvement in the accuracy, success rate, and patient satisfaction with regard to femoral nerve blockade analgesia. Kim performed single femoral nerve blockade in combination with continuous epidural analgesia after TKA and reported that this method exhibited better analgesic effects than intravenous analgesia. However, the author reported that, with time, the muscle strength decreased because of pain or surgical reasons (i.e., the tourniquet), which, in turn, resulted in a decrease in the strength of the quadriceps at 24 h post-surgery [19]. Jaeger et al. [20] maintained femoral nerve blockade in combination with epidural analgesia for 24 h after surgery and reported the achievement of satisfactory postoperative analgesia as well as a decrease in the strength of the quadriceps at 24 h post-surgery. The results of the present study showed that, except at 72 h post-surgery, the patients of groups II and III exhibited earlier starting times of ambulation at all postoperative time points than the patients of group I. In addition, the numbers of walking events per day in groups II and III were greater compared to that in group I, which indicated that the strength of the quadriceps among the patients of groups II and III were better compared to that among the patients of group I. Therefore, it may be concluded that U-NCCB not only ensures effective analgesia, but also reduces the impact of postoperative pain on the strength of quadriceps. This could enable patients to undertake early rehabilitation exercises for the improvement of lower limb function, thus effectively reducing the rate of incidence of associated complications. In addition, U-NCCB was safer than conventional analgesia, as evidenced by the lower incidence of postoperative complications. Therefore, the former method can result in an improvement in the rate of patient recovery and reduction in the duration of hospitalization.

In summary, U-NCCB can improve the positioning accuracy of catheterization, increase the effects of analgesia after TKA, and promote patient rehabilitation and satisfaction during hospitalization. Therefore, it can be used as the analgesic method of choice for peripheral nerve blockade.

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Disclosure of conflict of interest

None.

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