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Research article

Fascia iliaca compartment block mitigates the fluctuations in heart rate variability and reduces pain with opioid consumption in elderly individuals with hip fractures: A randomized controlled trial

Xiaoqi Dai [a,1], Dongxue Xing [b,1], Juan Luo [a,1], Yi Yang [a], Jiayuan Zhai [a], Tianwei Tang [a], Wanchao Yang [a,*]

[a] Department of Anesthesiology, The Second Affiliated Hospital of Harbin Medical University, Harbin, 150086, China
[b] Department of Anesthesiology, Linyi People's Hospital, Linyi, 276034, China

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ABSTRACT

Background: Hip fractures, commonly known as the "terminal fracture of life," frequently necessitate prompt surgical intervention and are accompanied by significant perioperative pain.
Objective: This investigation was performed to assess the impact of fascia iliaca compartment block (FICB) on heart rate variability during the perioperative period in elderly individuals with hip fractures.
Design: Single-center, randomized, controlled clinical trial.
Setting: The study was conducted from September 2021 to February 2023 at one tertiary care hospital in China.
Participants: Patients aged ≥60 years who underwent general anesthesia for hip fracture surgery were screened for enrollment. Eighty patients were initially assessed for eligibility, 70 underwent randomization, and 62 were included in the final analysis.
Methods: Preoperatively, the patients were randomly allocated to either receive (Group F) or not receive (Group C) ultrasound-guided suprainguinal FICB. The primary endpoint was heart rate variability indicators at the corresponding time points. The secondary endpoints included the mean arterial pressure and heart rate measured at different time points [upon admission to the operating room (T1), during positioning (T2), at the time of skin incision (T3), 30 min after the start of surgery (T4), and 6 h postoperatively (T5)] and visual analogue scale (VAS) score, dose of oral pain medication over 24 h, and satisfaction scores were valued.
Results: Compared with Group C, Group F had a significantly reduced low-frequency band, high-frequency band, and low-/high-frequency band ratio at T3, T4, and T5 ($P < 0.05$). Group F also had a lower heart rate at T2, T3, T4, and T5 ($P < 0.05$). Moreover, Group F had lower flurbiprofen dosages at 24 h postoperatively ($P < 0.05$) and lower resting VAS scores at 6 and 24 h post-operatively ($P < 0.05$).
Conclusion: Utilization of ultrasound-guided FICB has the potential to yield efficacious analgesic effects, mitigate the pronounced fluctuations in heart rate induced by surgical stimulation, and maintain autonomic function stability to a certain degree.

* Corresponding author.
E-mail address: Dachao_1980@126.com (W. Yang).
[1] Co-first authors: Xiaoqi Dai, Dongxue Xing, and Juan Luo contributed equally to this work.

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What is already known

- ultrasound-guided fascia iliaca compartment block (FICB) can effectively alleviate postoperative pain in individuals with hip fractures.
- FICB significantly extend the duration of regional analgesia without adversely affecting perioperative anticoagulation therapy.
- FICB has been extensively studied with the advent of using ultrasound for visualization, but limited research has focused on its effects on autonomic nerves.

What this paper adds

- using FICB alongside general anesthesia in patients with hip fracture effectively manages pain, stabilizes the significant fluctuations in heart rate induced by surgery and partially stabilizes the functioning of the autonomic nervous system during the perioperative period.
- this approach has been found to yield favorable postoperative analgesic outcomes, thereby promoting patient recovery.

1. Background

Hip fracture is a prevalent condition among elderly patients and often results from trauma. The two main types of hip fractures are intertrochanteric fractures and femoral neck fractures, which account for a substantial proportion (23.79%) of fractures in individuals aged >65 years [1]. Surgical intervention is necessary for approximately 98% of patients with hip fracture, and early surgical treatment (within 48 h of admission) not only alleviates pain but also significantly enhances postoperative quality of life and long-term survival [2,3]. Failure to perform timely surgical treatment for hip fractures has been associated with adverse outcomes [4].

With advancing age, patients commonly develop a range of organ function impairments that are often accompanied by comorbidities such as coronary heart disease, hypertension, chronic obstructive pulmonary disease, and cerebral infarction. These alterations in physiological functions make anesthesia selection and management much more challenging. Several studies have demonstrated that ultrasound-guided fascia iliaca compartment block (FICB) can effectively alleviate postoperative pain in individuals with hip fractures and significantly extend the duration of regional analgesia without adversely affecting perioperative anticoagulation therapy. Combining ultrasound-guided FICB with general anesthesia not only ensures satisfactory intraoperative comfort for patients and reduces the required amount of intraoperative general anesthetics, but it also offers effective postoperative analgesia and compensates for the limitations of standalone FICB that may not achieve complete surgical blockade [5,6].

This study was performed to examine the impact of FICB on perioperative autonomic function in elderly patients with hip fracture by comparing the analgesic effect of ultrasound-guided FICB performed with 0.33% ropivacaine with or without the block. Although FICB has been extensively studied with the advent of using ultrasound for visualization, limited research has focused on its effects on autonomic nerves. To indirectly assess the functional status of autonomic nervous system activity in this study, heart rate variability (HRV) was utilized as a quantitative, noninvasive, reproducible, and dynamically monitorable index.

2. Methods

2.1. Study design

The protocol of this single-center, single-blind, randomized controlled trial was approved by the Ethics Committee of the Second Affiliated Hospital of Harbin Medical University (number: KY2021-266). All methods were performed in accordance with relevant guidelines and regulations. The study was conducted at the Second Hospital of Harbin Medical University from May 2022 to October 2022. The enrolled patients and their families were informed of the details and consented before the start of this study. The study was registered with the Chinese Clinical Trials Registry (number: ChiCTR2100050752, date: September 4, 2021).

2.2. Participants

We enrolled patients with hip fracture aged ≥60 years with an American Society of Anesthesiologists risk score of I to III and a body mass index of ≤30 kg/m^2. Patients with allergy to local anesthetics, puncture site infection, comorbid psychiatric abnormalities or cognitive impairment, postoperative admission to the intensive care unit, or unwillingness to cooperate in the study were excluded.

2.3. Randomization, intervention, and anesthetic management

A study investigator screened all potential participants the day before the surgery. The patients were divided into two groups (n = 31 each) using the random number table method: those who received general anesthesia (Group C) and those who received general anesthesia combined with FICB (Group F). The patients strictly fasted for 8 h and abstained from water for 4 h before surgery. After entering the operating room, all patients were routinely monitored with the bispectral index, electrocardiography (ECG), blood oxygen saturation (pulse oximetry), and noninvasive arterial blood pressure.

2.3.1. Group C

General anesthesia was induced via intravenous administration of sufentanil (0.3–0.5 mcg/kg), lidocaine (1–2 mg/kg), etomidate (0.3–0.5 mg/kg), and atracurium (0.3–0.6 mg/kg) to facilitate endotracheal intubation. Anesthetic maintenance involved the use of sevoflurane and remifentanil. Sevoflurane was initially administered at a dose of 0.6–0.8 minimum alveolar concentration, with subsequent adjustments based on measurement of the bispectral index (40–60). Remifentanil was administered at a dose of 10 mcg/kg/h, with adjustments made according to the patient's analgesic requirements (systolic blood pressure changes within 20% of baseline values). Postoperatively, flurbiprofen was administered at a dose of 1–2 mg/kg.

2.3.2. Group F

With the patient in the supine position, the ultrasound transducer was positioned perpendicularly to the inguinal ligament and directed toward the umbilicus, specifically within the outer and middle thirds of the line connecting the anterior superior iliac spine and the pubic symphysis. The midpoint of the probe was situated above the inguinal ligament. Real-time ultrasound imaging was utilized to identify the internal oblique, sartorius, and iliacus muscles, which were enveloped by the fascia iliaca. This identification technique is commonly referred to as localization of the "bow tie sign" [7]. Following aseptic preparation of the injection site and ultrasound probe, a peripheral plexus stimulation needle was inserted parallel to the ultrasound-guided beam (using the in-plane technique) from a caudad-to-cephalad direction. The needle was directed through the sartorius muscle toward the iliacus muscle until its tip reached the plane between the internal oblique and iliacus muscles. The operator administered 30 mL of 0.33% ropivacaine after ensuring no blood was drawn back, resulting in the observation of a narrow liquid dark zone separating the iliacus muscle from the iliac fascia [8,9]. The effect of the sensory nerve block was evaluated by checking for loss of cold sensation at 5-min intervals for 20 min after the injection. The researchers employed a 3-point scale (2, normal sensation; 1, dull sensation; and 0, sensory deficit) to assess the innervation areas of the femoral and lateral femoral cutaneous nerves, which correspond to the anterior and lateral regions of the femoral trunk. If the innervated region exhibited normal sensation, the block was deemed unsuccessful and excluded from the study. The subsequent procedure mirrored that in Group C. The study employed a single-blind design, wherein the investigator confirmed that the patients met the preoperative inclusion criteria and obtained written informed consent from all patients. The investigator also placed an ambulatory ECG device on the patients and collected data at T1 (i.e., upon arrival in the operating room; see details below). An anesthesiologist administered anesthesia and managed the patients in accordance with the experimental design and requirements. The same investigator who collected the index data at T1 also collected data during the intraoperative and postoperative periods and performed follow-up assessments of the patients. A statistician analyzed the data from both experimental groups.

2.4. Data collection and outcomes

Upon admission to the operating room, the investigator placed a TLC4000 ambulatory ECG device on each patient. The electrode pads and lead wires were connected in accordance with the international standard of 12-lead ECG. Two new No. 5 alkaline batteries were inserted, and the machine was activated, ensuring a continuous monitoring period of at least 18 h. The collected data were then exported for HRV frequency domain and time domain analysis using the accompanying software.

The HRV changes were assessed at various perioperative time points: upon admission to the operating room (T1), during positioning (T2), at the time of skin incision (T3), 30 min after the start of surgery (T4), and 6 h postoperatively (T5). The low-frequency band (LF), high-frequency band (HF), and LF/HF ratio of the HRV were assessed. Additionally, the overall HRV changes were analyzed using the frequency domain indexes LF, HF, LF/HF, and total power, as well as the following time domain indexes: standard deviation of the NN intervals (SDNN), standard deviation of the average NN intervals (SDANN), root mean square of successive differences between normal heartbeats (rMSSD), and percentage of adjacent NN intervals that differ from each other by > 50 ms (pNN50).

The mean arterial pressure and heart rate were observed and recorded at various time points throughout the surgical process from T1 to T5. Additionally, the dosage of intraoperative remifentanil and the time of extubation were documented. Extubation time refers to the duration between the discontinuation of anesthetics and the removal of the endotracheal tube. Furthermore, the B-type natriuretic peptide (BNP), troponin I (TnI), and C-reactive protein (CRP) concentrations were recorded 24 h postoperatively, and tramadol and flurbiprofen usage was documented for 24 h postoperatively. The patients' VAS scores were documented at 6 and 24 h postoperatively. Cognitive function was evaluated preoperatively using the Mini-Mental State Examination, and the presence of postoperative delirium (POD) was assessed from the first to third days postoperatively using the 3D-CAM Delirium Scale. The duration of hospitalization was also recorded. Patient contentment with anesthesia was measured using a scale ranging from 0 to 10, with 0 indicating no satisfaction and 10 indicating high satisfaction.

2.5. Statistical analyses

This study was a randomized controlled trial, and the difference in the patients' HRV was the main outcome index. According to the results of the pretest, the mean $\pm$ standard deviation of 5-min LF for Groups F and C were 97.44 ± 39.86 and 136.44 ± 36.84, respectively. The test efficacy $(1-\beta)$ was set at 0.90 with a significance level of $\alpha = 0.05$ and type II error rate (β) of 0.10. The sample size of each group was determined using PASS 15 software (NCSS, Kaysville, UT, USA), with N1 and N2 both set to 28. To account for an anticipated 20% attrition rate, at least 35 patients per group (at least 70 patients total) were required. SPSS 27.0 statistical software (IBM Corp., Armonk, NY, USA) was used for data processing. The Shapiro–Wilk method was used to test the normality of the measurement data. Normally distributed data are presented as mean $\pm$ standard deviation, and the independent-samples *t*-test was used for comparison between groups. Non-normally distributed data are presented as median (interquartile range), and the Mann–Whitney *U*

test was used for comparison between groups. Differences were considered statistically significant at $P < 0.05$.

3. Results

3.1. Patient characteristics

In total, 80 patients were initially assessed for eligibility in the study. However, 10 patients were subsequently excluded from participation for various reasons (blindness, n = 1; cancellation of scheduled surgeries, n = 4; and cognitive impairment, n = 5). Consequently, only 70 patients remained eligible and were randomly assigned to the study groups. Within Group C, one patient declined to wear an ambulatory ECG device and three patients opted to self-administer oral analgesics. In Group F, one patient refused to wear an ambulatory ECG, one patient did not cooperate with postoperative follow-up, one patient self-administered oral analgesics, and one patient required postoperative admission to the intensive care unit. Finally, 31 patients each were included in Group C and Group F (Fig. 1). Fig. 2 shows an ultrasound-guided image of the "bow tie sign" in FICB. (A and B represent pre-block image; C and D represent post-block image). The demographic and clinical characteristics of the patients are concisely summarized in Table 1. Notably, no statistically significant differences were observed in terms of sex, age, body mass index, years of education, Mini-Mental State Examination score, and surgery time.

3.2. Comparison of 5-min HRV at various perioperative time points between the groups

The 5-min HRV at various perioperative time points in both groups of patients is shown in Table 2. No statistically significant differences in the LF, HF, or LF/HF ratio at T1 were observed between the two groups ($P > 0.05$). The LF and LF/HF ratio were significantly lower in Group F than Group C at T3, T4, and T5, and the HF was significantly lower in Group F than Group C at T5 ($P < 0.05$ for all). Except at T5, no significant difference in mean arterial pressure was observed between the two groups at any time point during the perioperative period ($P > 0.05$). Similarly, no significant difference in heart rate was observed between the two groups at T1 ($P > 0.05$). However, the heart rate was significantly lower in Group F than in Group C at T2, T3, T4, and T5 ($P < 0.05$).

3.3. Comparison of perioperative long-duration HRV between the groups

The perioperative long-duration HRV was compared between the two groups, and the results are presented in Table 3. No statistically significant differences in the frequency domain indicators (total power, LF, HF, and LF/HF) or time domain indicators (SDNN,

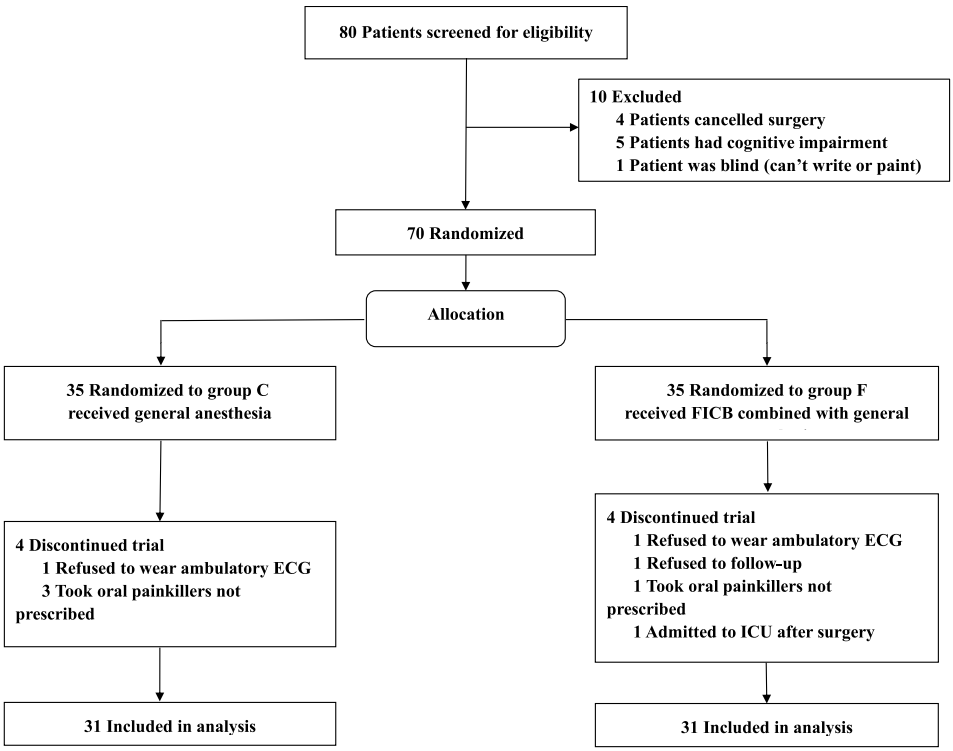

Fig. 1. Patient recruitment, randomization, and follow-up FICB, fascia iliaca compartment block; ECG, electrocardiography; ICU, intensive care unit.

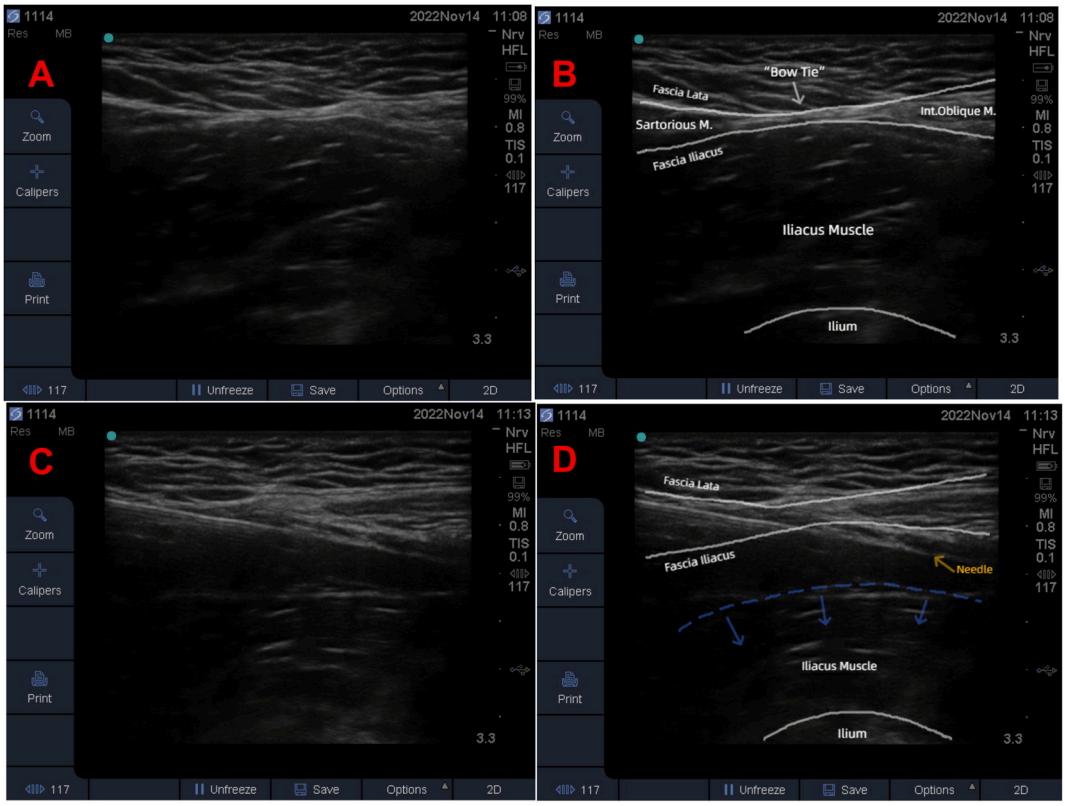

Fig. 2. Ultrasound images of "bow tie sign" A and B represent pre-block image; C and D represent post-block image.

Table 1
Patients' demographic and clinical characteristics.

	Group C (n = 31)	Group F (n = 31)	*P* value
Male	13 (41.9)	14 (45.2)	0.798
Female	18 (58.1)	17 (54.8)	
Age (years)	76.23 ± 5.95	74.42 ± 4.81	0.194
BMI (kg/m^2)	23.40[22.20–25.40]	24.10[22.10–24.80]	0.966
Education (years)	6 [6–8]	6 [5–8]	0.903
MMSE	28[27–29]	28[27–29]	0.665
Surgery time (h)	1.44 ± 0.16	1.45 ± 0.23	0.764

Note: Data are expressed as n (%), mean ± standard deviation, or median (interquartile range).
BMI, body mass index; MMSE, Mini-Mental State Examination.

SDANN, rMSSD, and pNN50) in relation to the perioperative long-duration HRV were observed between the two groups (P > 0.05).

3.4. Comparison of secondary indicators between the groups

Comparison of the secondary indicators between the two patient groups is shown in Table 4. The intraoperative remifentanil dosage was significantly lower in Group F than in Group C (P < 0.05). Additionally, the postoperative extubating time was significantly shorter in Group F than in Group C (P < 0.05). There was no statistically significant difference in the tramadol dosage at 24 h postoperatively between the two groups (P > 0.05). However, the flurbiprofen dosage at 24 h postoperatively was significantly lower in Group F than in Group C (P < 0.05). Additionally, the resting visual analogue scale scores at 6 and 24 h postoperatively were significantly lower in Group F than in Group C (P < 0.05). There were no significant differences in the BNP, TnI, and CRP concentrations at 24 h postoperatively between the two groups (P > 0.05). Additionally, the TnI concentration at 24 h postoperatively was <0.017 μg/L in both groups. There was no statistically significant difference in the occurrence of POD between the two groups (P > 0.05). Similarly, no significant difference was found in the number of postoperative hospital days between the two groups (P > 0.05). However, the patients in Group F expressed significantly higher satisfaction with anesthesia (P < 0.05).

Table 2
Comparison of 5-min HRV, MAP, and HR at various perioperative time points between the two groups.

Group	Indicators	T1	T2	T3	T4	T5
Group C (n = 31)	LF (ms^2/HZ)	176.83 ± 47.57	118.78 ± 28.17	128.4[112.0–152.4]	146.5[129.9–165.1]	148.23 ± 43.44
	HF (ms^2/HZ)	99.09 ± 29.64	93.50 ± 20.49	87.3[77.1–101.1]	97.1[83.3–116.7]	106.08 ± 32.67
	LF/HF	1.81 ± 0.20	1.28 ± 0.16	1.43[1.37–1.57]	1.48[1.41–1.58]	1.42[1.29–1.59]
	MAP (mmHg)	109.10 ± 14.21	87.61 ± 12.56	90.0[83.0–93.0]	85.0[80.0–88.0]	109.0[97.0–113.0]
	HR (times/min)	84.0[78.0–88.0]	73.61 ± 10.40	68.0[65.0–74.0]	70.0[64.0–77.0]	84.45 ± 6.66
Group F (n = 31)	LF (ms^2/HZ)	182.60 ± 57.19	113.42 ± 44.30	93.4[76.20–123.9][c]	105.0[79.4–125.4][c]	70.84 ± 24.53[c]
	HF (ms^2/HZ)	103.17 ± 28.20	87.84 ± 34.41	71.3[58.6–94.9][c]	80.6[61.0–86.8][c]	56.25 ± 19.90[c]
	LF/HF	1.76 ± 0.17	1.30 ± 0.20	1.26[1.19–1.35][c]	1.30[1.22–1.42][c]	1.28[1.21–1.35][c]
	MAP (mmHg)	113.84 ± 13.34	89.87 ± 9.86	86.0[84.0–90.0]	84.0[80.0–87.0]	102.0[99.0–106.0][c]
	HR (times/min)	80.0[74.0–86.0]	63.71 ± 6.32[c]	62.0[60.0–65.0][c]	62.0[59.0–63.0][c]	74.29 ± 4.48[c]

Note: Data are presented as mean ± standard deviation or median (interquartile range).
HRV, heart rate variability; MAP, mean arterial pressure; HR, heart rate; LF, low-frequency band; HF, high-frequency band; LF/HF, low-/high-frequency band ratio.
[c]$P < 0.05$ compared with Group C.

Table 3
Comparison of long-duration HRV in perioperative period between the two groups.

Indicators	Group C (n = 31)	Group F (n = 31)	*P* value
TP (ms^2/HZ)	3911.50 ± 1777.77	3545.29 ± 1241.62	0.298
LF (ms^2/HZ)	163.7[106.7–215.2]	137.8[101.0–192.5]	0.297
HF (ms^2/HZ)	132.7[97.4–174.2]	129.3[78.3–156.7]	0.218
LF/HF	1.12 ± 0.23	1.21 ± 0.21	0.099
SDNN	87.1[70.9–107.0]	81.2[70.1–116.1]	0.888
SDANN	106.4[75.6–144.9]	117.2[87.2–136.4]	0.598
rMSSD	37.45 ± 16.91	34.85 ± 16.10	0.670
pNN50	5.94 ± 9.77	5.10 ± 9.06	0.809

Note: Data are expressed as mean ± standard deviation or median (interquartile range).
TP, total power; LF, low-frequency band; HF, high-frequency band; LF/HF, low-/high-frequency band ratio; SDNN, standard deviation of the NN intervals; SDANN, standard deviation of the average NN intervals; rMSSD, root mean square of successive differences between normal heartbeats; pNN50, percentage of adjacent NN intervals that differ from each other by >50 ms

Table 4
Comparison of secondary indicators between the two groups of patients.

Indicators	Group C (n = 31)	Group F (n = 31)	*P* value
Remifentanil (mcg/kg/h)	9.26[8.50–10.30]	5.34[4.55–6.21]	<0.001
Extubation time (min)	14.0[12.0–16.0]	9.0[8.0–10.0]	<0.001
Tramadol (mg)	0[0–100.0]	0[0–100.0]	0.797
Flurbiprofen ester (mg)	200.0[150.0–200.0]	125.0[100.00–150.0]	<0.001
VAS at 6 h after surgery	3.0[3.0–4.0]	2.0[2.0–3.0]	<0.001
VAS at 24 h after surgery	4.0[4.0–5.0]	3.0[3.0–4.0]	<0.001
BNP after surgery (pg/ml)	485.5[311.0–680.0]	384.0[246.5–470.0]	0.074
CRP after surgery (mg/L)	60.61 ± 26.11	45.33[25.78–70.20]	0.080
Postoperative delirium	7 (22.5%)	5 (16.1%)	0.520
Postoperative hospital days	5.0[4.0–6.0]	5.0[5.0–6.0]	0.202
Satisfaction with anesthesia	6.0[6.0–7.0]	8.0[7.0–9.0]	<0.001

Note: Data are expressed as median (interquartile range), mean ± standard deviation, or n (%).
VAS, visual analogue scale; BNP, B-type natriuretic peptide; CRP, C-reactive protein.

3.5. Complications of nerve block

No complications associated with the nerve block, including puncture needle misplacement, bleeding at the puncture site, local hematoma formation, and toxic reactions to the local anesthetic, were observed in Group F. Furthermore, no instances of nerve injury were identified during the subsequent postoperative follow-up assessments.

4. Discussion

In tandem with the growth of the aging demographic in China, there has been a corresponding rise in the occurrence of hip fractures among the elderly. Although surgical intervention enhances the well-being of older individuals, the notable fluctuations in HRV and hemodynamics resulting from diverse stimuli during the perioperative period have captured the attention of anesthesiologists. The

present study showed that using FICB alongside general anesthesia in patients with hip fracture not only effectively manages pain but also stabilizes the significant fluctuations in heart rate induced by surgery and partially stabilizes the functioning of the autonomic nervous system during the perioperative period. Additionally, this approach exhibits exceptional postoperative analgesic efficacy, thereby promoting favorable patient recovery in the postoperative period. Fifty years ago, measurement of HRV was incorporated into the clinical setting to capture the fluctuations in fetal ECG on a beat-to-beat basis [10]. HRV serves as a quantitative, noninvasive, reproducible, and dynamic monitoring tool that enables indirect assessment of autonomic nervous system activity [11]. Determination of HRV relies on ECG analysis, yielding a time series wherein the durations of normal QRS wave groups are measured in milliseconds as continuous values [12]. Frequency domain analysis further discerns three primary spectral parameters: very low frequency, low frequency, and high frequency. The total power represents the variance of all QRS intervals [12,13]. In the characterization of autonomic nervous system activity, the LF component is commonly regarded as a combined effect of the sympathetic and vagal nervous systems, with the sympathetic nervous system activity being predominant. The HF component is associated with the respiratory rhythm and primarily reflects the tone of the vagal nervous system. The LF/HF ratio serves as an indicator of the dynamic equilibrium between the sympathetic and vagal nervous systems. Total power represents the overall autonomic activity and encompasses the sum of HRV over a specified period [14]. In the time domain analysis, SDNN primarily captures variations in overall HRV activity, while rMSSD and pNN50 are considered to reflect the activity of the vagus nerve [15,16].

In the present study, LF and LF/HF decreased in Group F during the skin incision phase, 30 min after commencement of surgery, and 6 h postoperatively. The reduction in LF implied a suppression of sympathetic activity, whereas the decrease in LF/HF indicated an improved capacity to regulate the equilibrium between the sympathetic and vagal nervous systems, thereby facilitating a more seamless surgical procedure. This implies that FICB effectively mitigates the stress response, diminishes the pain-induced functional disparity between the parasympathetic and sympathetic nervous systems, and stabilizes the autonomic nervous system function. Additionally, Latson and colleagues have suggested that different anesthetic induction agents may affect HRV differently [17]. In this study, although, we were unable to demonstrate any major difference in the HRV spectral response to anesthetic induction agents and inhalation agents which were consistent between the two groups, we did, indeed, observe a slowing of heart rate between T2 and T5 among these patients. The results of this study are qualitatively identical to Galletly's observations during inhalation anesthesia [18]. The heart rate was significantly higher in Group C than in Group F both intraoperatively and postoperatively, suggesting that FICB effectively facilitated surgical anesthesia and postoperative pain relief. No substantial disparity was found in the long-term HRV index between the two groups. This observation may be attributed to two potential factors. First, we conducted continuous collection and analysis of long-duration ECG during anesthesia and after surgery to acquire the findings. Second, conducting a separate postoperative long-duration ECG collection and HRV analysis in future follow-up studies may yield more robust outcomes. Notably, despite certain trends in certain indicators, no statistically significant differences were observed, potentially because of the relatively limited sample size. Patients' physiological functions decline as they age, and the presence of severe pain during the initial postoperative phase elicits a robust stress response within the body. This response subsequently heightens the perioperative risk, hinders patients' recovery, and augments the likelihood of encountering diverse postoperative complications [19]. The physiological aging process in elderly individuals is accompanied by progressive degenerative changes in their autonomic nervous system. Consequently, there is a decline in the ability of the cardiovascular system to respond to stress and adaptively regulate itself. Additionally, the autonomic capacity to regulate the cardiac rhythm diminishes, and the delicate balance between sympathetic and vagal regulation of the heart rate becomes easily disrupted. These factors significantly contribute to the occurrence of adverse cardiac emergencies, including abnormal cardiac function and myocardial infarction, during the perioperative period [20]. Hence, we compared the BNP and TnI concentrations at 24 h postoperatively in both groups. However, no notable disparities were observed. Although Group F exhibited lower BNP concentrations than Group C, this may have been attributed to the lower heart rate, diminished myocardial oxygen consumption, and equilibrium between oxygen supply and demand among patients in Group F. Nevertheless, the lack of statistical significance can be attributed to the limited sample size.

Many patients with hip fractures receive intravenous analgesia in the postoperative period, which is susceptible to insufficiencies compared with nerve block analgesia. Such insufficiencies in postoperative analgesia can elicit a robust stress response within the body, resulting in heightened periods of bed rest, impeding early postoperative recuperation, and augmenting the likelihood of infection. CRP serves as a highly responsive marker of infection within the body; its elevation is directly correlated with the severity of bacterial infection [21]. In this study, the CRP concentration on the first postoperative day was not significantly different between Groups C and F. The comparison between the preoperative and postoperative CRP concentrations was hindered by the unavailability of preoperative CRP data for certain patients.

We also evaluated the patients' preoperative cognitive function and the incidence of POD in this study. Previous research has indicated that approximately 30% of patients develop POD, and it is often triggered by severe pain and the administration of multiple analgesics. Theoretically, FICB holds the potential to substantially diminish the need for perioperative opioids, consequently mitigating the likelihood of POD in elderly individuals with hip fractures [22]. In this study, we excluded patients with preoperative cognitive dysfunction. We then compared the incidence of POD between the two groups. However, no significant differences were found. A separate study demonstrated that the addition of FICB to combined spinal–epidural anesthesia effectively decreased the occurrence of POD in elderly patients undergoing hip surgery [23]. Another study showed that the utilization of continuous preoperative FICB with ultrasound guidance in elderly patients with hip fractures not only successfully alleviated preoperative pain but also reduced the occurrence and duration of POD [24]. In the present study, the intraoperative remifentanil dosage was significantly lower in Group F than in Group C Therefore, it may be that a reduction in the use of opioids by FICB reduces the incidence of postoperative delirium.

This study had limitations. First, HRV response to acute pain relief also varied among patients with chronic pain before surgery.

Although we did not use this as an exclusion factor in the selection of patients, the enrolled patients reported no history of this disease when asked about their medical history. Second, Group F received the anesthetic agent suprainguinally under ultrasound guidance, while Group C was administered saline based on the principle of a single variable (i.e., Group C should have ideally received ultrasound-guided puncture and saline injection rather than no puncture). However, this experimental design may have led to secondary injury to the patient, thereby compromising the complete blinding of the study. Consequently, the experimental results may exhibit a certain degree of bias. Third, the data analysis did not include stratification by fracture type because of the potential variation in pain and irritation levels according to the specific type of hip fracture. Therefore, future studies should be conducted to stratify fractures according to their specific characteristics to ascertain the optimal indication for FICB. Fourth, the practical limitations of this study prevented the objective measurement of muscle strength; thus, assessment of the block's effect was solely based on the loss of skin sensation. Preservation of motor function is important because many patients require physiotherapy during the initial postoperative phase, and the prompt implementation of postoperative physiotherapy further expedites the patient's recuperation following hospital discharge. Fifth, Studies have shown that the MMSE test can give inaccurate results, which may incorrectly conclude that you have dementia. Likely influenced by factors such as age, education, and race, it is more likely to be misclassified by a test [25]. Therefore, there is an urgent need for more accurate and less biased tests to detect dementia quickly in the clinic. Finally, the sample size of this study was limited. Further investigations with larger sample sizes are needed to comprehensively investigate the impact of FICB on perioperative HRV and adverse cardiac events in individuals with hip fractures.

In summary, the utilization of ultrasound-guided FICB combined with general anesthesia during hip fracture surgery has demonstrated efficacy in providing analgesia, mitigating the significant fluctuations in HRV induced by surgical stimulation, and preserving autonomic function stability to a certain degree. Furthermore, this approach has been found to yield favorable postoperative analgesic outcomes, thereby promoting patient recovery.

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Data availability statement

All the data supporting the findings of this study are available within the article and its Supplementary Information files and from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Xiaoqi Dai: Project administration, Methodology. **Dongxue Xing:** Writing – original draft, Project administration. **Juan Luo:** Methodology, Conceptualization. **Yi Yang:** Methodology, Investigation. **Jiayuan Zhai:** Formal analysis. **Tianwei Tang:** Data curation. **Wanchao Yang:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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