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Enhanced external counterpulsation-assisted cannulated screw fixation promoted femoral neck fracture healing: a pilot randomized controlled trial

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Abstract

Background Femoral neck fractures often lead to complications such as delayed union or nonunion due to limited blood supply to the femoral head. Enhanced external counterpulsation (EECP) is a non-invasive method that improves peripheral and tissue perfusion. This study aimed to evaluate whether postoperative EECP could promote fracture healing and improve hip function recovery after cannulated screw fixation for femoral neck fractures.

Methods This single-center, prospective, randomized controlled trial included patients with acute femoral neck fractures eligible for cannulated screw fixation. Participants were randomized in a 1:1 ratio into two groups using a computer-generated random sequence. Group assignments were sealed in opaque envelopes to ensure allocation concealment. Baseline characteristics were comparable between groups. Three weeks postoperatively, patients in the EECP group underwent daily 1-hour EECP sessions for 7 consecutive weeks, while the control group received standard care without EECP. Color Doppler ultrasound was used to measure the peak systolic velocity (PSV), end-diastolic velocity (EDV), and resistance index (RI) of the medial femoral circumflex artery on the ipsilateral fracture side. Fracture union time, as well as the incidences of avascular necrosis of the femoral head (ANFH) and nonunion, were recorded. The Harris Hip Score (HHS) was assessed at 3, 6, and 12 months postoperatively.

Results A total of 64 patients completed at least 24 months of follow-up, including 31 in the EECP group and 33 in the control group. After the final EECP session, the EECP group demonstrated significantly higher PSV and EDV values

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compared to the control group (both $p < 0.0001$; 95% CI: -10.55 to -7.42, -3.83 to -3.22, respectively), while RI values were significantly lower ($p < 0.0001$, 95% CI: 0.04 to 0.06). All fractures healed in both groups, but the mean healing time was significantly shorter in the EECP group ($p < 0.0001$, 95% CI: 1.24 to 2.72). There was no significant difference between the two groups in the occurrence rate of ANFH ($p = 0.615$, 95% CI: -3.08 to 0.54). At 3 months postoperatively, there was no significant difference in HHS between the two groups ($p = 0.165$, 95% CI: -3.08 to 0.54). However, at 6 and 12 months, the EECP group showed significantly higher HHS values compared to the control group ($p < 0.0001$, 95% CI: -10.91 to -7.36; $p = 0.0006$, 95% CI: -10.81 to -3.12, respectively).

Conclusions Enhanced external counterpulsation appears to be a safe and potentially beneficial adjunctive strategy for the management of femoral neck fractures treated with cannulated screw fixation. The application of enhanced external counterpulsation may promote fracture healing and facilitate hip function recovery by improving blood perfusion of the femoral head and the fracture site.

Name of trial registry Chinese Clinical Trial Register (ChiCTR); Registration number: ChiCTR2000034312; Date of registration: 01/07/2020.

Keywords Femoral neck fracture, Enhanced external counterpulsation, Treatment outcome, Harris hip score, Fracture healing, Randomized controlled trial

Introduction

Femoral neck fractures (FNFs), accounting for 3.6% of all fractures and nearly half of hip fractures, constitute one of the most challenging injuries in orthopedic trauma due to their high rates of disability and mortality among adults and the elderly [1]. Once diagnosed, achieving anatomic reduction and stable internal fixation is crucial for a satisfactory prognosis. Internal fixation is generally considered appropriate for patients under 65 years of age and is the preferred treatment for elderly patients with poor physiological status [2]. Over the past decades, significant efforts have been made to develop various fixation devices and techniques to address the inherent instability of FNFs [3–5]. Although multiple cannulated screw fixation provides satisfactory mechanical stability, it exerts minimal effect on vascular regeneration or microcirculatory improvement at the fracture site. The fragile blood supply to the femoral head remains a major limiting factor for successful healing. Even with satisfactory reduction, high rates of nonunion (2%–22%) and avascular necrosis of the femoral head (ANFH) (10%–43%) have been reported [6–8]. These severe complications can result in femoral head collapse and subsequent osteoarthritis, often necessitating salvage procedures such as osteotomy, vascularized or nonvascularized bone grafts, or total hip arthroplasty. Such interventions impose significant medical and economic burdens on both patients and society [9–12]. Therefore, in addition to achieving anatomical reduction and stable fixation, preserving and restoring femoral head perfusion is a crucial prerequisite for long-term joint integrity and functional recovery.

Although various pharmacologic and physical approaches have been explored to enhance angiogenesis, their clinical efficacy remains uncertain. Non-invasive hemodynamic therapies that improve local microcirculation may therefore offer a promising adjunct

to conventional fixation. Enhanced external counterpulsation (EECP) is a U.S. FDA-approved, non-invasive mechanical circulatory support device consisting of specially designed cuffs wrapped around the lower limbs, which are inflated sequentially in synchronization with the patient's electrocardiogram [13]. During cardiac diastole, the device applies compression to the lower limbs, increasing venous return to the heart and reducing systolic afterload. This process enhances aortic diastolic pressure and cardiac output, thereby improving blood flow to ischemic tissues and organs [14]. EECP has been widely used as an adjunctive therapy for ischemic conditions, including myocardial ischemia [15], ischemic stroke [16], rotational vertebrobasilar insufficiency resulting from cervical spondylosis [17] and ischemic optic neuropathy [18]. Given the critical role of vascularization in bone healing, the application of EECP as an adjunctive therapy in orthopedic conditions, such as femoral neck fractures, is a promising area of investigation.

Nevertheless, the clinical value of EECP as an adjunct therapy for fracture healing—especially in femoral neck fractures—remains underexplored. Therefore, this randomized controlled trial was designed to evaluate the efficacy of EECP combined with cannulated screw fixation in promoting bone healing and improving functional outcomes after femoral neck fracture. We hypothesized that EECP could enhance postoperative microcirculation, accelerate fracture healing, and improve recovery of hip function compared with conventional fixation alone.

Materials and methods

Study design and participants

This single-center, prospective, randomized, controlled clinical trial compared postoperative EECP with standard management in FNFs patients undergoing cannulated screw fixation. The study was initiated and conducted by

the Zhongnan Hospital of Wuhan University, in compliance with the Declaration of Helsinki. Ethical approval was obtained from the Medical Ethics Committee for Clinical Research Projects of Zhongnan Hospital of Wuhan University (Approval No. 2020135), and the trial was registered with the Chinese Clinical Trial Registry (ChiCTR2000034312). Written informed consent was obtained from all participants prior to enrollment. This trial adhered to the Consolidated Standards of Reporting Trials (CONSORT) guidelines (Supplemental Material). A flow diagram illustrating the study design is presented in Fig. 1.

Inclusion and exclusion criteria

The inclusion criteria were: (1) acute FNFs; (2) Garden's classification III and IV type FNFs; (3) ages 18–80 years; (4) unilateral fracture; (5) complete clinical data and written informed consent from the patient. The exclusion criteria were: (1) multiple or compound injuries; (2) Garden I and II type FNFs; (3) pathological FNFs; (4) previous hip deformation or surgery; (5) deep vein thrombosis of the lower extremities; (6) smoking, diabetes mellitus, or vascular disease affecting the lower extremities. The diagnosis of FNFs was established based on clinical presentation and radiographic confirmation (anteroposterior and lateral hip radiographs, and computed tomography when necessary). All participants were evaluated and approved for study enrollment by two senior orthopedic surgeons (each with more than 10 years of specialized

experience in trauma and hip surgery) from the Department of Orthopedics Trauma and Microsurgery, Zhongnan Hospital of Wuhan University. To ensure diagnostic consistency, both surgeons independently reviewed the imaging findings and clinical data before confirming patient eligibility for cannulated screw fixation and EECP intervention.

Randomization and blinding

Patients who met the inclusion criteria and were eligible for cannulated screw fixation were randomly assigned to either the EECP group or the control group in a 1:1 ratio. The randomization sequence was generated in advance by an independent data manager using a computer-based random number table. Allocation concealment was maintained through the use of sequentially numbered, opaque, sealed envelopes, which were opened only after participant enrollment. The assignment was executed by an investigator (X.W.) who was not involved in outcome assessment or data analysis. Due to the nature of the EECP intervention, blinding of participants and surgeons was not feasible. To reduce potential assessment bias, independent reviewers (orthopedic consultants who did not participate in the randomization, surgery, or EECP therapy) conducted all postoperative evaluations. These reviewers were blinded to group allocation and assessed clinical outcomes, radiographs, and complications using predefined criteria.

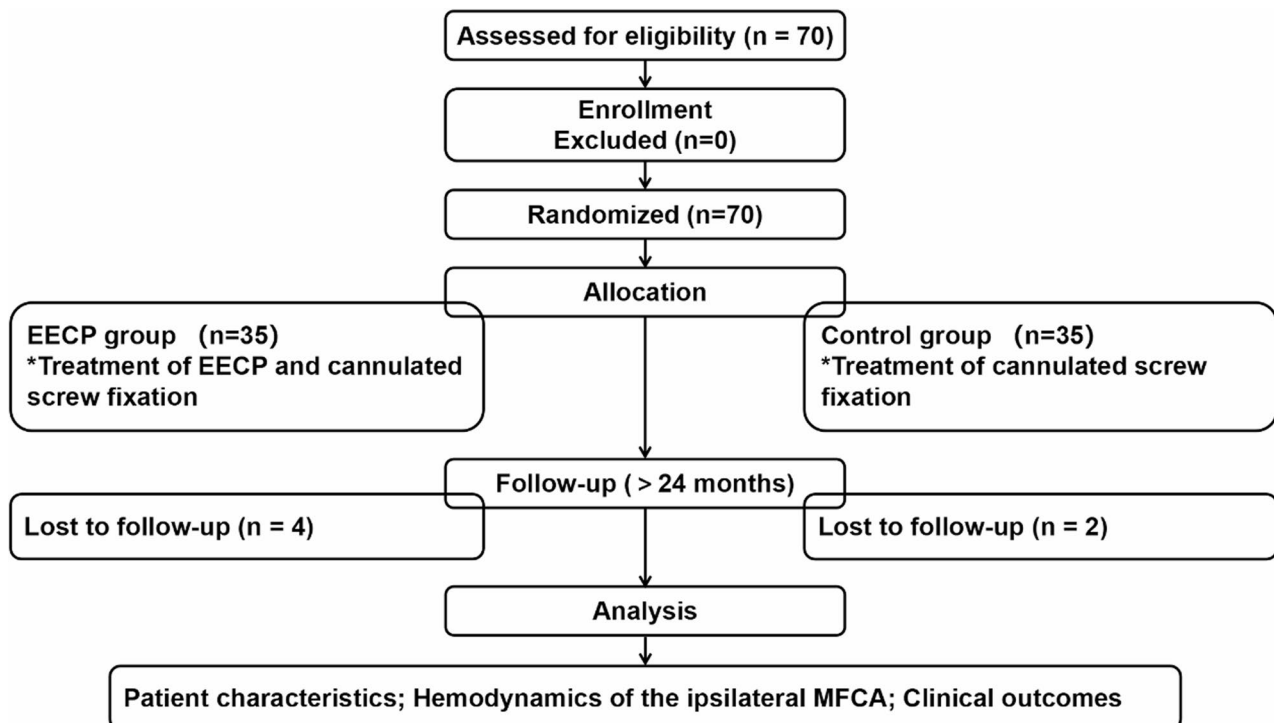


Fig. 1 Flow chart of the study design. EECP, enhanced external counter pulsation; MFCA, medial femoral circumflex artery

Interventions

Operative procedure

The FNFs were fixed using three cannulated cancellous screws, arranged in a triangular configuration, with two superior screws and one inferior screw parallel to each other. Under general or epidural anesthesia, patients were positioned supine on a fracture table. Fracture reduction was performed under fluoroscopic guidance using a C-arm X-ray machine to ensure proper alignment of the fracture. Once satisfactory alignment was achieved, a Kirschner wire (K-wire) was used for surface localization. After confirming the position of the K-wire, a mark was made on the skin, and the surgical area was routinely disinfected. Following the direction of the localized K-wire, three guide pins were percutaneously inserted from the lateral thigh, below the greater trochanter, into the femoral neck. After confirming the proper positioning of the guide pins, a small skin incision of approximately 4 cm was made at the entry point of the proximal guide pin, extending distally. A cannulated drill was then advanced over the guide pin to create a screw channel. A suitable cannulated compression screw (DOUBLE MEDICAL, Xiamen, China) was selected and inserted. As the cannulated screw approached the fracture site, the guide pin was removed. Recombinant human bone morphogenetic protein-2 (rhBMP-2; Jiuyuan Gene, Hangzhou, China) was shaped into strips and inserted into the screw channel. Using the tail end of the guide pin, the rhBMP-2 was pushed into the fracture site. The guide pin was then reinserted, and the cannulated compression screw was further advanced into the femoral head. The second and third cannulated compression screws were inserted using the same technique. A total of 2 mg of rhBMP-2 was delivered to the fracture site through the three screw channels (Fig. 2A). After confirming the proper

positioning of the screws via X-ray, the surgical site was thoroughly irrigated, and the skin was sutured. Postoperatively, all patients followed a standardized rehabilitation protocol. On the first postoperative day, ankle pump exercises and isometric quadriceps contractions were started. Passive and active-assisted hip and knee mobilization were encouraged from day 2 to 3.

Postoperatively, all patients followed a standardized rehabilitation protocol. On the first postoperative day, ankle pump exercises and isometric quadriceps contractions were started. Passive and active-assisted hip and knee mobilization were encouraged from day 2 to 3. Partial weight-bearing with crutches was initiated at 6 weeks post-surgery and gradually progressed to full weight-bearing based on radiographic evidence of healing and clinical evaluation. Patients in the EECP group additionally received EECP therapy during the early postoperative period to promote circulation and bone healing.

Postoperative EECP

Considering the limited mobility of patients in the early postoperative period, patients in the EECP group began receiving 1-hour EECP treatments daily, starting 3 weeks after surgery, for 7 consecutive days, while the control group received no EECP intervention. The EECP treatment duration was based on previous clinical studies on chronic angina (35 1-hour daily sessions) [19]. The EECP device (Aomai OM-A-I, Guangzhou, China) was composed of an air compressor, a set of cuffs, a computer module, and a treatment table. The cuffs were connected by air hoses to the air compressor unit, and were wrapped around the calves and upper thighs (including the buttocks) of patients (Fig. 2B). The pressure applied to the cuffs was set at 300 mm Hg. During treatment, the EECP

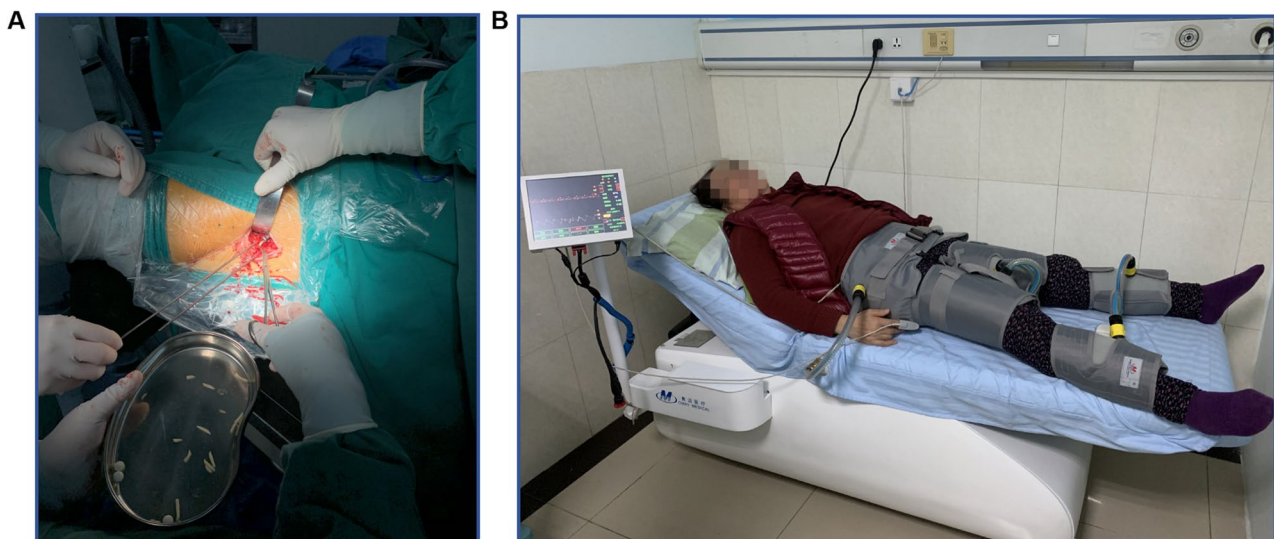


Fig. 2 **A** Operative procedure. **B** EECP treatment scenario. EECP, enhanced external counter pulsation

device sequentially inflated the cuffs with compressed air, starting from the distal areas of the body and progressing proximally during early ventricular diastole. The cuffs were then rapidly deflated just before ventricular systole.

Outcomes

Hemodynamics of the medial femoral circumflex artery

Velocities of blood flow in the medial femoral circumflex artery (MFCA) of the affected hips were measured using a color Doppler unit (iU22, Philips, Netherlands) by an experienced radiologist who was blinded to the condition of each patient. The first measurement was performed prior to the initiation of the first EECF session, and the second measurement was conducted after the completion of the final EECF session. The procedures of color Doppler flow imaging were described previously [20–22]. Briefly, patients were examined in the supine position, with their legs extended and slightly externally rotated. A 10 MHz linear-array transducer (5–12 MHz) was placed slightly below the inguinal ligament to detect blood flow signals. The peak systolic velocity (PSV) and end diastolic velocity (EDV) of the MFCA were obtained. The resistance index (RI) values of the MFCA were calculated automatically by the preestablished algorithms: $RI = PSV - EDV/PSV$. Each parameter was measured three times and the mean value was used.

Clinical outcomes

The primary procedure-related outcomes in this study included operative time and intraoperative blood loss. Operative time was recorded from the initiation of the skin incision to the completion of surgical closure. Intraoperative blood loss was measured by weighing the difference between pre- and post-operative sterile gauzes used during the procedure on digital electronic scales. The Harris hip score (HHS) was calculated to assess the patient's hip function before surgery and at 3, 6 and 12 months post-operation [23]. The evaluation content includes pain, function, deformity, and joint range of motion. Anteroposterior and lateral hip X-rays were performed to evaluate the fracture reduction using the method proposed by Garden [24], as well as fracture healing time and complications including nonunion and ANFH. The follow-up was conducted at 6 weeks, 3 months, 12 months, and 24 months. Nonunion was defined as a fracture that had not healed for at least 6 months after fracture and showed no further signs of healing over an additional 3-month period. ANFH was assessed according to the criteria of Ficat [25].

Sample size and power

The sample size was estimated based on the hypothesis that EECF could promote fracture healing in FNFs patients after cannulated screw fixation, which was the

primary endpoint. The sample size was calculated using PASS (version 11; NCSS, LLC, Ltd.) with a two-sided significance level ($\alpha = 0.05$) and a statistical power of 80%. The estimation was referenced from a previous study on postoperative outcomes in femoral neck fracture patients [26]. Considering potential attrition, a total of 35 patients were enrolled in each group.

Statistical analysis

Data analysis was performed using GraphPad Prism 7.0 (GraphPad Software, San Diego, CA, USA). The normality of continuous variables was assessed using the Shapiro–Wilk test. Normally distributed data were expressed as mean \pm standard deviation (SD) and compared using the Student's t-test, whereas non-normally distributed data were presented as median (interquartile range) and analyzed using the Mann–Whitney U-test. Categorical variables were expressed as numbers and percentages (N, %) and analyzed using the χ^2 test or Fisher's exact test, as appropriate. A p-value < 0.05 was considered statistically significant.

Results

General characteristics and operative information of the patients

Between June 2020 and June 2021, a total of 70 patients were screened for eligibility and randomly assigned to either the EECF group or the control group. During follow-up, 4 patients in the EECF group and 2 in the control group were lost to follow-up. Ultimately, 64 patients (31 in the EECF group and 33 in the control group) completed at least 24 months of follow-up. All 31 patients in the EECF group successfully completed the full treatment course with 100% adherence, and no interruptions were reported. A few participants in the EECF group reported mild leg discomfort, which resolved spontaneously after treatment and required no intervention.

The baseline characteristics of the two groups showed no significant differences, including age ($p = 0.640$, 95% CI: -5.91 to 9.52), gender ($p = 0.625$, 95% CI: 0.47 to 3.43), fracture side ($p = 0.317$, 95% CI: 0.21 to 1.45), and fracture type ($p = 0.322$, 95% CI: 0.61 to 4.43) (Table 1). The time from injury to surgery was 38.01 ± 5.30 h in the EECF group and 37.98 ± 4.20 h in the control group ($p = 0.979$, 95% CI: -2.41 to 2.35). No adverse events were reported during the care of these patients. Operative time and blood loss were 59.84 ± 11.57 min and 77.10 ± 8.83 mL in the EECF group, compared to 59.79 ± 9.76 min and 75.15 ± 9.06 mL in the control group ($p = 0.985$, 95% CI: -5.39 to 5.29 ; $p = 0.388$, 95% CI: -6.42 to 2.53 , respectively). Postoperative anteroposterior and lateral radiographs were used to assess the accuracy of femoral neck fracture reduction using the Garden Index. The Garden Index is defined as the angle between the trabecular

Table 1 General characteristics and operative information of the patients in two groups

Variables	EECP group (n=31)	Control group (n=33)	p-value	95% CI
Mean age (years)	57.61 ± 18.87	59.42 ± 11.30	0.640	-5.91 to 9.52
male/female	18/13	22/11	0.625	0.47 to 3.43
Left/right	13/18	19/14	0.317	0.21 to 1.45
Garden's classification				
III	20	17	0.322	0.61 to 4.43
IV	11	16		
Time between injury and surgery (hours)	38.01 ± 5.30	37.98 ± 4.20	0.979	-2.41 to 2.35
Operation time (min)	59.84 ± 11.57	59.79 ± 9.76	0.985	-5.39 to 5.29
Blood loss (mL)	77.10 ± 8.83	75.15 ± 9.06	0.388	-6.42 to 2.53
Quality of fracture reduction				
Garden index grade 1	12	17	0.328	0.23 to 1.63
Garden index grade 2	19	16		
Follow-up time (months)	26.16 ± 2.07	25.91 ± 1.76	0.600	-1.21 to 0.70

EECP Enhanced external counter pulsation

pattern of the femoral head and the femoral shaft axis, with a normal range of 160°–180° on the anteroposterior view and 170°–190° on the lateral view. According to the degree of alignment, reductions were classified as Garden Index grade I (anatomical reduction, both angles within the normal range) and grade II (slight varus or valgus deviation). In the EECP group, 12 reductions were classified as Garden Index grade I and 19 as grade II, while in the control group, 17 reductions were classified as grade I and 16 as grade II. There was no significant difference between the two groups in the quality of fracture reduction ($p=0.328$, 95% CI: 0.23 to 1.63). Following surgery, patients were monitored for an average of 26.16 ± 2.07 months in the EECP group and 25.91 ± 1.76 months in the control group ($p=0.600$, 95% CI: -1.21 to 0.70).

Effect of EECP on hemodynamics of the ipsilateral MFCA

Representative Color Doppler imaging images and Doppler spectrums of the ipsilateral MFCA before the first EECP session and after the final EECP session for both the control and EECP groups are shown in Fig. 3. Before the initiation of EECP treatment, there were no significant differences in the peak systolic velocity (PSV), end-diastolic velocity (EDV), and resistive index (RI) values between the EECP group and the control group ($p=0.264$, 95% CI: -3.23 to 0.90; $p=0.057$, 95% CI: -0.66

to 0.01; $p=0.224$, 95% CI: -0.01 to 0.02, respectively) (Table 2). After the final EECP session, both groups showed improvements in PSV, EDV, and RI values compared to baseline. However, the EECP group demonstrated significantly greater improvements in PSV and EDV values compared to the control group (43.06 ± 4.30 vs. 34.24 ± 2.23 cm/s, 8.78 ± 0.70 vs. 5.26 ± 0.51 cm/s; both $p < 0.0001$; 95% CI: -10.55 to -7.42, -3.83 to -3.22, respectively). Additionally, the RI value in the EECP group was significantly lower than that in the control group (0.79 ± 0.03 vs. 0.84 ± 0.02 , $p < 0.0001$, 95% CI: 0.04 to 0.06, respectively).

Clinical outcomes

During the follow-up period, all fractures in the EECP group and the control group healed. The mean fracture healing time was lower in patients in the EECP group than that in the control group (3.02 ± 1.05 vs. 5.00 ± 1.80 months, $p < 0.0001$, 95% CI: 1.24 to 2.72) (Table 3). The occurrence rate of ANFH in the EECP group was 3.23% (1/31), while in the control group it was 9.09% (3/33). There was no significant difference between groups in the occurrence rate of ANFH ($p = 0.615$, 95% CI: 0.03 to 2.46). At 3 months postoperatively, there was no significant difference in HHS between the EECP and control groups ($p = 0.165$; 95% CI: - 3.08 to 0.54). However, at 6 and 12 months, the HHS in the EECP group was significantly higher than that in the control group (6 months: 81.19 ± 3.60 vs. 72.06 ± 3.51 , $p < 0.0001$; 95% CI: - 10.91 to - 7.36; Cohen's $d = 2.56$; 12 months: 88.45 ± 6.56 vs. 81.48 ± 8.40 , $p = 0.0006$; 95% CI: - 10.81 to - 3.12; Cohen's $d = 0.93$). According to Rice et al. [27], an improvement of 7–9 points in HHS represents the minimal clinically important difference (MCID). In our cohort, the between-group HHS differences at 6 months ($\Delta = 9.13$ points) and 12 months ($\Delta = 6.97$ points) met or exceeded this MCID threshold and demonstrated large to very large effect sizes (Cohen's $d > 0.8$). These results indicate that EECP treatment not only produced statistically significant improvements but also yielded clinically meaningful functional recovery.

Discussion

Currently, the conventional surgical treatment of internal fixation with three screws is the most commonly used method for the treatment of FNFs patients under 65 years and is the preferred treatment for elderly FNFs patients with poor physiological status [2]. Despite advances in fixation devices and surgical techniques, the healing of FNFs remains a clinical challenge due to compromised blood supply, delayed union, nonunion or ANFH [6–8]. To our knowledge, the present study was the first study to investigate the clinical effects of EECP in the treatment of FNFs with the cannulated screw fixation. The

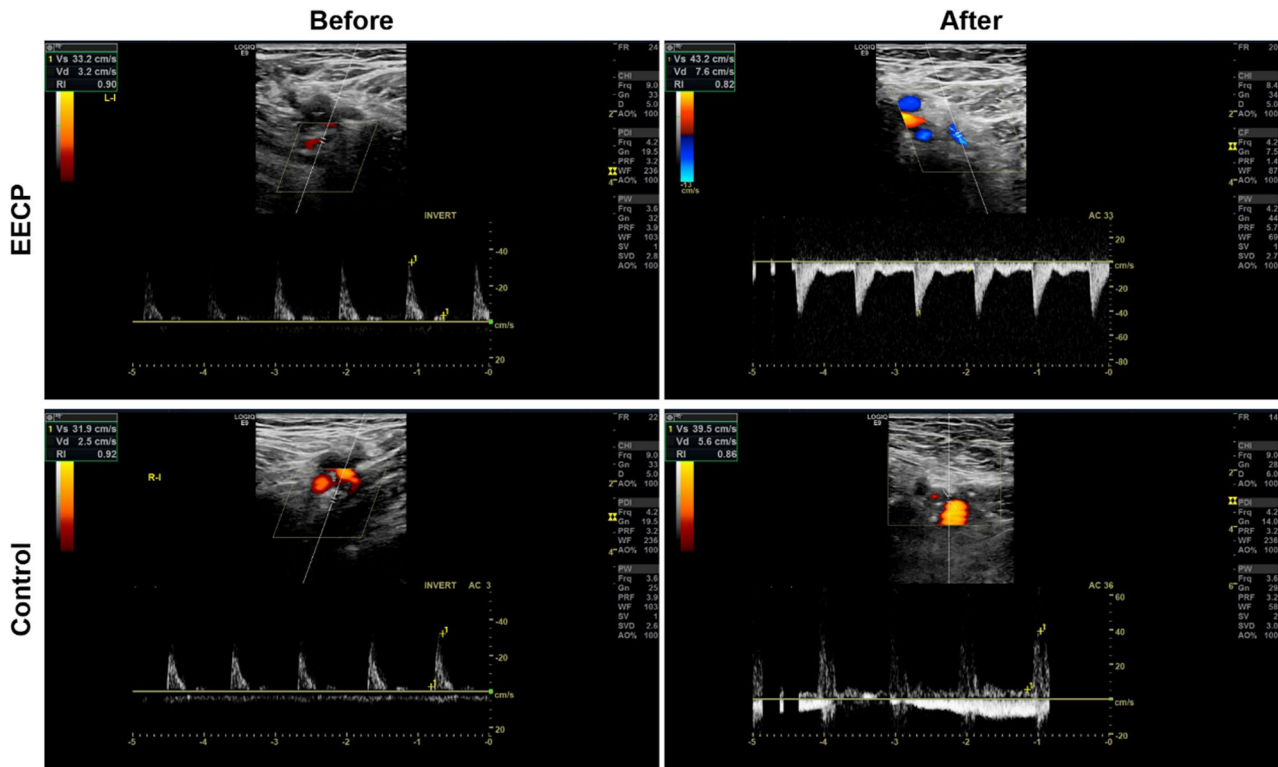


Fig. 3 Representative Color Doppler imaging images and Doppler spectrums of the ipsilateral MFCA before the first EECP session and after the final EECP session for both the control group and the EECP group. MFCA, medial femoral circumflex artery; EECP, enhanced external counter pulsation

Table 2 Comparison of the improvement rate for hemodynamic parameters of the ipsilateral MFCA in two groups

Variables	PSV (cm/s)		EDV (cm/s)		RI	
	Before	After	Before	After	Before	After
EECP group (n = 31)	31.73 ± 4.01	43.06 ± 4.30	4.42 ± 0.72	8.78 ± 0.70	0.86 ± 0.03	0.79 ± 0.03
Control group (n = 33)	30.92 ± 4.49	34.24 ± 2.23	4.05 ± 0.49	5.26 ± 0.51	0.87 ± 0.03	0.84 ± 0.02
p-value	0.264	< 0.0001	0.057	< 0.0001	0.224	< 0.0001
95% CI	-3.23 to 0.90	-10.55 to -7.42	-0.66 to 0.01	-3.83 to -3.22	-0.01 to 0.02	0.04 to 0.06

MFCA Medial femoral circumflex artery, PSV Peak systolic velocity, EDV Mean velocity, RI Resistance index, EECP Enhanced external counter pulsation

Table 3 Clinical outcomes of the patients in two groups

Variables	EECP group (n = 31)	Control group (n = 33)	p-value	95% CI
Fracture healing time (months)	3.02 ± 1.05	5.00 ± 1.80	< 0.0001	1.24 to 2.72
HHS after surgery 3 months	67.97 ± 2.48	66.70 ± 3.65	0.165	-3.08 to 0.54
6 months	81.19 ± 3.60	72.06 ± 3.51	< 0.0001	-10.91 to -7.36
12 months	88.45 ± 6.56	81.48 ± 8.40	0.0006	-10.81 to -3.12
Nonunion, N (%)	0	0		0 to 0
ANFH, N (%)	1 (3.23%)	3 (9.09%)	0.615	0.03 to 2.46

EECP Enhanced external counter pulsation, HHS Harris hip score, ANFH Avascular necrosis of femoral head

results demonstrated that a higher good-excellent rate of the Harris hip score could be obtained through EECP-assisted cannulated screw fixation compared to the conventional cannulated screw fixation. In addition, there was a shorter fracture healing time after EECP than without EECP. The improvement of clinical outcomes after EECP might be related to the enhancement of blood supply to the femoral head and fracture site, as the hemodynamics of the ipsilateral MFCA were improved after the intervention.

Given the high incidence of nonunion and osteonecrosis of the femoral head after femoral neck fractures, femoral neck fracture was previously referred to as an “unresolved fracture” [28]. When FNFs occurs, the blood flow of the femoral head is often obstructed due to the compression of the fracture site. In addition, the increased pressure of the joint capsule after trauma is also one of the important factors of posttraumatic nonunion

and ANFH. Measurements have shown the flow of the femoral head decreases with the increase in intracapsular pressure (258% increase with 60% decrease) [29, 30]. The blood supply of the femoral head derives primarily from the round ligament artery, the MFCA, lateral femoral circumflex artery (LFCA) and inferior gluteal artery [31]. Among them, for adults, the MFCA plays a crucial role in supplying blood to the femoral head, and its improved perfusion may facilitate the delivery of nutrients and oxygen necessary for bone healing [32]. Furthermore, previous studies have demonstrated that Doppler ultrasonography of the MFCA is a potential tool for the assessment and follow-up of hip vascularity [22]. In the present study, EECP treatment significantly increased the PSV and EDV of the ipsilateral MFCA in FNHs patients with cannulated screw fixation. In addition, the RI of the ipsilateral MFCA was significantly lower after EECP compared with the baseline. These findings suggest an enhancement in the vascular function of the MFCA and represent a critical improvement in the blood supply to the femoral head and fracture site facilitated by EECP.

EECP The therapy is noninvasive, well-tolerated, and has also been shown to increase shear stress on vascular endothelium, leading to the release of angiogenic factors such as vascular endothelial growth factor (VEGF) and nitric oxide (NO) [33]. These factors play a crucial role in promoting neovascularization and enhancing blood supply to ischemic tissues, which is particularly relevant in the context of femoral neck fractures, where compromised blood flow often impairs healing [34]. Additionally, improved oxygenation and nutrient delivery to the fracture site may accelerate the bone remodeling process, contributing to faster and more robust healing [35]. Furthermore, EECP can be performed postoperatively without interfering with fracture fixation stability, making it a safe complementary strategy for improving bone healing outcomes. During the follow-up period, the average healing time of FNF in the EECP group and control group was 3.02 ± 1.05 months and 5.00 ± 1.80 months, respectively. The fracture healing time of the EECP group was shortened, which is mainly related to the improvement of blood supply in the fracture site by EECP. However, the incidence of ANFH in the EECP group was slightly decreased compared to the control group but did not demonstrate a significant advantage. This may suggest that although EECP improves the initial healing process, it does not fully mitigate the multifactorial risks associated with ANFH, such as the extent of the initial trauma or biomechanical factors. Additionally, the relatively small sample size in this study may have limited the ability to detect potential advantages of EECP in preventing ANFH.

The EECP group also demonstrated higher Harris Hip Scores at 6 and 12 months postoperatively compared to

the control group, while no significant difference was observed between the groups at 3 months postoperatively. This finding suggests that EECP may play a pivotal role in promoting mid- to long-term functional recovery following cannulated screw fixation for FNHs. The primary reason for this outcome is that EECP treatment accelerated fracture healing, likely by improving blood supply and enhancing oxygen and nutrient delivery to the fracture site. This accelerated healing process allowed patients in the EECP group to begin full weight-bearing activities earlier than those in the control group, which is a critical factor in restoring hip function and overall mobility [36]. Early full weight-bearing not only helps improve muscle strength and joint flexibility but also contributes to better functional outcomes over time [37]. However, during the first 3 months postoperatively, fractures in both groups had not yet fully healed, and neither group engaged in full weight-bearing exercises due to the risk of complications such as fracture displacement or delayed healing. As a result, no significant difference in hip function was observed during the early postoperative period.

Our study has several limitations. First, we assessed the hemodynamics of the MFCA using color Doppler flow imaging rather than directly evaluating the blood supply to the femoral head through angiography. As a result, our findings can only indirectly suggest that EECP improves the blood supply to the femoral head. Second, the sample size of our clinical control study was relatively small, and further validation is needed through multicenter studies with larger sample sizes. Third, patients with diabetes, vascular disease, or other systemic comorbidities were excluded to minimize hemodynamic confounding. While this approach enhanced the internal consistency of our analysis, it may limit the generalizability of the findings to real-world elderly hip fracture populations, in whom such comorbidities are common. Lastly, given that EECP is a long-term treatment modality, this study, as an initial trial of EECP therapy for FNHs, employed a limited but effective treatment protocol of seven sessions. Future studies should explore the effects of extended treatment durations to evaluate the sustained impact of EECP on patients with FNHs.

Conclusions

EECP appears to be a safe and potentially beneficial adjunctive strategy for the management of FNHs treated with cannulated screws. EECP may promote fracture healing and facilitate hip function recovery, possibly through improving blood perfusion of the femoral head and fracture site. For clinicians, this approach offers a non-invasive option to enhance bone healing and functional outcomes. For researchers, the study provides a framework for exploring the underlying mechanisms

of improved vascular perfusion and osteogenesis. For patients, this therapy has the potential to accelerate recovery and reduce complications associated with delayed fracture healing.

Abbreviations

FNFs	Femoral neck fractures
ANFH	Avascular necrosis of the femoral head
EECP	Enhanced external counterpulsation
PSV	Peak systolic velocity
EDV	End-diastolic velocity
RI	Resistance index
MCFA	Medial femoral circumflex artery
HHS	Harris Hip Score
RCT	Randomized controlled trial

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12891-025-09363-8>.

Supplementary Material 1

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Not applicable.

Authors' contributions

Zheng Wang and Xin Wang had accessed and verified all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Zheng Wang, Wang Zhang, and Changhuan Liu contributed equally to this study. Concept and design: Xin Wang, Zheng Wang, Aixi Yu, and Zhe Xie. Acquisition, analysis, or interpretation of data: Zheng Wang, Wang Zhang, Changhuan Liu, Qichao Zheng, Xue Fang, Zhenyu Pan, Weidong Xiao, Baiwen Qi, Min Zhou, Zonghuan Li, Pengcheng Li, Qingbiao Wei, Zhe Xie, Aixi Yu, and Xin Wang. Drafting of the manuscript: Zheng Wang, Wang Zhang, Changhuan Liu, and Qichao Zheng. Critical revision of the manuscript for important intellectual content: Zheng Wang, Xin Wang, Aixi Yu, and Zhe Xie. Statistical analysis: Wang Zhang, Changhuan Liu, and Qingbiao Wei. Supervision: Zhe Xie, Aixi Yu, and Xin Wang. All authors read and approved the final version of the manuscript.

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Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was initiated and conducted by the Zhongnan Hospital of Wuhan University, in compliance with the Declaration of Helsinki. Ethical approval was obtained from the Medical Ethics Committee for Clinical Research Projects of Zhongnan Hospital of Wuhan University (Approval No.2020135), and the trial was registered with the Chinese Clinical Trial Registry (ChiCTR2000034312). Written informed consent was obtained from all participants prior to enrollment.

Consent for publication

All authors agree to publish. We confirm that written informed consent for publication of clinical details and identifying images (including Fig. 2) was obtained from all participants.

Competing interests

The authors declare no competing interests.

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