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ARTICLE

The Effect of Intermittent Pneumatic Compression Device Combined with Low-Molecular-Weight Heparin on the Prevention of Deep Vein Thrombosis in Elderly Patients after Femoral Neck Fracture Surgery

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Abstract

Aims/Background Femoral neck fractures in elderly patients carry a high risk of developing deep vein thrombosis (DVT) due to prolonged immobilization and surgical intervention. This study examines the effectiveness of combining intermittent pneumatic compression (IPC) with low-molecular-weight heparin (LMWH) for preventing DVT in elderly patients following femoral neck fracture surgery.
Methods A total of 150 elderly patients with femoral neck fractures, admitted between January 2022 and January 2024, were retrospectively selected, and their clinical data were analyzed. Based on the treatment methods, the patients were divided into a control group (n = 71) and a study group (n = 79). The control group received LMWH treatment, while the study group received a combination of LMWH and IPC. The incidence of DVT, surgical outcomes, hip joint function, coagulation function indicators, hemodynamic indicators, and serum pro-inflammatory factors were compared between the two groups.
Results The results showed that the incidence of DVT in the study group was lower than in the control group ($p = 0.017$). There were no significant differences between the two groups in terms of intraoperative blood loss, postoperative drainage volume, or Harris scores ($p > 0.05$). After the intervention, the study group demonstrated higher levels of average velocity (Va), peak blood flow velocity (Vp), and blood flow (BF) compared to the control group ($p < 0.05$). Additionally, the activated partial thromboplastin time (APTT) and prothrombin time (PT) were longer, while the D-dimer (D-D) level was lower in the study group ($p < 0.05$). The study group also exhibited lower levels of tumor necrosis factor-α (TNF-α), interleukin-6 (IL-6), and interleukin-8 (IL-8) ($p < 0.05$).
Conclusion The results indicate that combining IPC with LMWH effectively reduces the incidence of postoperative DVT in elderly patients with femoral neck fractures, improves venous blood flow in the lower limbs, reduces vascular inflammation, and ensures safety.

Key words: elderly femoral neck fracture; intermittent pneumatic compression device; low-molecular-weight heparin; deep vein thrombosis

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Introduction

Hip fractures are among the most common traumatic injuries in elderly patients, and are associated with high mortality and significant loss of function (Yoo et al, 2020). By 2050, the number of hip fractures in patients aged 65 and above is expected to reach 1.3 million (Gong et al, 2021). Among these patients, the mortality rate within the first year post-fracture ranges from 8% to 36% and continues to increase over the subsequent decade (Van Heghe et al, 2022). For those who survive, the long-term consequences of hip fractures are severe, with approximately half losing their previous functional independence and about one-third becoming completely dependent (Zhang et al, 2020). Femoral neck fractures, which primarily affect the elderly, account for 48–54% of all hip fractures (He et al, 2021). Internal fixation and joint replacement surgery are the main treatments for femoral neck fractures; however, due to trauma, immobility, advanced age, and comorbidities, some patients experience perioperative complications. Deep vein thrombosis (DVT) is a common complication in hip fracture patients, resulting from abnormal blood clotting in deep veins (Dou et al, 2022). DVT can lead to various adverse outcomes, such as pulmonary embolism, limb edema, superficial varicose veins, secondary ulcers, or necrosis (Wu et al, 2023). Despite thromboprophylaxis, 15% to 48% of elderly trauma patients develop perioperative DVT, making it a persistent challenge (Zuo and Hu, 2020).

Currently, chemical and mechanical thromboprophylaxis are standard methods for preventing and treating DVT (Li et al, 2017). Low-molecular-weight heparin (LMWH) exerts anticoagulant and antithrombotic effects primarily by inhibiting thrombin production and is commonly used for DVT prevention (Tran et al, 2022). Intermittent pneumatic compression (IPC) is a physical therapy method that enhances venous blood circulation in the lower limbs by applying periodic pressure waves to the limbs, simulating the natural muscle pump action to push venous and lymphatic flow, thus reducing blood stasis in the veins (Wang et al, 2020). Previous study has shown that combining LMWH and IPC is more effective in preventing DVT than using either treatment alone in critically ill patients who are at high risk for both thrombosis and bleeding (Wan et al, 2015). However, there are few reports on the combined use of LMWH and IPC in elderly patients with femoral neck fractures.

This study aims to explore the clinical value of IPC combined with LMWH in preventing DVT in elderly patients undergoing surgery for femoral neck fractures.

Methods

Study Subjects

A total of 150 elderly patients with femoral neck fractures who underwent surgical treatment between January 2022 and January 2024 were retrospectively selected for this study, and their clinical data were analyzed. The patients were divided into a control group (n = 71) and a study group (n = 79). The control group received LMWH treatment, while the study group received a combination of LMWH and IPC.

Inclusion criteria: Age $\geq$75 years; confirmed femoral neck fracture by X-ray; undergoing dual-motion femoral head replacement surgery.

Exclusion criteria: Severe active bleeding; coagulation disorders; surgery within the last three months; malignant tumors; dermatitis or gangrene unsuitable for mechanical prevention in the lower limbs; heart, liver, or kidney insufficiency; thrombotic phlebitis or lower limb edema.

Intervention

Upon admission, both groups completed the necessary examinations and underwent spinal anesthesia. Surgery was performed by the same team of surgeons using a lateral approach for dual-motion femoral head replacement. Standard preventive measures were implemented, including careful intraoperative vascular protection, health education on thrombosis, elevation of the affected limb postoperatively, and early functional exercises.

The control group received LMWH (Qilu Pharmaceutical Factory, specification: 5000 IU, 0.4 mL/ampule, Jinan, China) administered subcutaneously at a dose of 0.4 mL once daily, starting on the first day of admission, pausing one day before surgery, and resuming 12 hours postoperatively until 10 days after surgery.

The study group received the same LMWH treatment as the control group, in addition to IPC (Venaflow Elite, DJO™, Vista, CA, USA) starting 12 hours postoperatively. The IPC was applied with a pressure intensity of 40–60 mmHg, adjusted according to patient tolerance, with inflation occurring every 45 seconds for 15 seconds, for 3 hours per session, twice daily, continuing until 10 days post-surgery.

Observation Indicators

DVT detection: Color Doppler ultrasound was used to examine the lower limb veins, assessing the venous lumen's size, vessel wall smoothness, presence of abnormal echoes, compressibility by the probe, color blood flow filling, and venous spectrum to determine the presence of thrombosis. Venography was performed if necessary. Patients were followed up for four weeks post-surgery, with D-dimer (D-D) levels, bilateral lower limb venous ultrasound, and venography repeated if symptoms appeared seven days after surgery. All evaluations were conducted by experienced radiologists.

Surgical indicators: Intraoperative blood loss and postoperative drainage volume were recorded by the surgical team.

Hip joint function: Hip joint function was evaluated using the Harris scale (**Supplementary Table 1**), which scores pain, function, deformity, and range of motion, with higher scores indicating better hip joint function (Stirling et al, 2021). These assessments were performed by orthopedic specialists.

Coagulation function: Coagulation function indicators, including activated partial thromboplastin time (APTT), prothrombin time (PT), and D-dimer levels, were measured using a fully automatic coagulation analyzer. These tests were conducted by certified laboratory technicians.

Hemodynamic indicators: Hemodynamic indicators, including average velocity (Va), peak blood flow velocity (Vp), and blood flow (BF), were measured using a color Doppler ultrasound instrument, with the probe angle maintained at 50° to the common femoral vein. Measurements were conducted by professional sonographers.

Serum inflammatory factors: Morning venous blood samples were collected before and after the intervention, centrifuged to obtain serum, and tumor necrosis factor-α (TNF-α), interleukin-6 (IL-6), and interleukin-8 (IL-8) levels were measured using enzyme-linked immunosorbent assays. These assays were performed by trained laboratory personnel.

Quality Control

In this study, we identified several potential biases and confounding factors. Selection bias might arise from the participant recruitment process, while information bias could result from inconsistencies in data collection methods. Observer bias might occur due to different interpretations of outcome measurements by various observers. Additionally, confounding factors such as participants' age, gender, and underlying health conditions could influence the study results. To minimize the impact of these biases and confounding factors, we implemented a rigorous randomization process. Specifically, we used computer-generated random number tables to assign participants to either the experimental or the control group, ensuring that each participant had an equal chance of being allocated to either group. To control for information and observer biases, we employed a double-blind method where both researchers and participants were unaware of the group assignments. Furthermore, all personnel involved in the study received uniform training and used standardized procedures for data collection and outcome measurement to reduce variability.

Statistical Analysis

Data were analyzed and graphs were plotted using GraphPad Prism 6 (GraphPad Software, Inc., San Diego, CA, USA). Chi-square tests were applied to categorical data, such as DVT incidence, to identify significant differences between groups. Independent t-tests were used to compare continuous variables between the control and study groups, ensuring the detection of differences in baseline characteristics and outcomes such as blood loss and drainage volume. Paired t-tests assessed within-group changes before and after treatment, evaluating the intervention's impact on variables like coagulation and hemodynamic indicators. A p-value of less than 0.05 was considered statistically significant.

Results

Baseline Information

Table 1 presents the baseline characteristics of the two groups, including gender, age, body mass index (BMI), systolic blood pressure (SBP), diastolic blood pressure (DBP), and comorbidities. Differences between the groups were compared using t-tests and chi-square tests. The results indicated no significant differences in baseline characteristics between the groups ($p > 0.05$), suggesting that the two groups were comparable.

Table 1. Baseline information.

Variables	Control group (n = 71)	Study group (n = 79)	t/χ^2	p
Age, years	79.09 ± 2.86	79.31 ± 3.45	–0.422	0.673
Gender, n (%)			0.307	0.579
Male	48 (67.60)	50 (63.30)		
Female	23 (32.40)	29 (36.70)		
BMI, kg/m^2	24.65 ± 2.78	24.99 ± 3.14	–0.699	0.486
SBP, mmHg	140.83 ± 15.03	137.76 ± 16.48	1.187	0.237
DBP, mmHg	81.75 ± 9.29	80.86 ± 8.87	0.600	0.549
Hypertension, n (%)	41 (57.70)	42 (53.20)	0.318	0.573
Diabetes, n (%)	22 (31.00)	25 (31.60)	0.008	0.931
CHD, n (%)	21 (29.60)	22 (27.80)	0.055	0.815

Note: BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; CHD, coronary heart disease.

Table 2. Comparison of deep vein thrombosis (DVT) incidence and distribution.

Group	Femoral vein	Popliteal vein	Calf vein	Total incidence
Control group (n = 71)	6 (8.45)	2 (2.82)	1 (1.41)	9 (12.68)
Study group (n = 79)	1 (1.27)	1 (1.27)	0 (0.00)	2 (2.53)
χ^2				5.663
p				0.017

Comparison of DVT Incidence and Distribution

The incidence of DVT in the study group was lower than in the control group ($p < 0.05$) (Table 2). This suggests that the intervention in the study group may be effective in reducing the risk of DVT.

Comparison of Surgical Indicators

There were no significant differences in intraoperative blood loss and postoperative drainage volume between the two groups ($p > 0.05$) (Table 3). This indicates that the intervention has no statistically significant impact on these parameters.

Comparison of Joint Function

Before the intervention, there was no significant difference in Harris scores between the two groups ($p > 0.05$). After the intervention, Harris scores improved significantly in both groups ($p < 0.05$); however, there was no significant difference in Harris scores between the two groups ($p > 0.05$) (Table 4). This indicates that both intervention methods have similar effects on improving patients' Harris scores.

Comparison of Coagulation Indicators

Before the intervention, there were no significant differences in D-D, APTT, and PT levels between the two groups ($p > 0.05$). After the intervention, APTT and PT levels increased, and D-D levels decreased in both groups ($p < 0.05$). Additionally, APTT and PT levels in the study group were longer than those in the control

Table 3. Comparison of intraoperative blood loss and postoperative drainage volume.

Group	Intraoperative blood loss	Postoperative drainage volume
Control group (n = 71)	362.54 ± 98.86	398.86 ± 113.45
Study group (n = 79)	342.37 ± 97.62	400.73 ± 110.21
t	1.256	0.102
p	0.211	0.919

Table 4. Comparison of joint function.

Group	Before intervention	After intervention
Control group (n = 71)	62.20 ± 6.40	75.85 ± 6.33*
Study group (n = 79)	62.39 ± 5.62	76.72 ± 6.31*
t	0.194	0.842
p	0.847	0.401

Note: Compared with before treatment, *$p < 0.05$.

group, and D-D levels were lower in the study group compared to the control group, with significant differences ($p < 0.05$) (Fig. 1). This demonstrates that the intervention has a more pronounced effect on improving coagulation parameters in the study group compared to the control group.

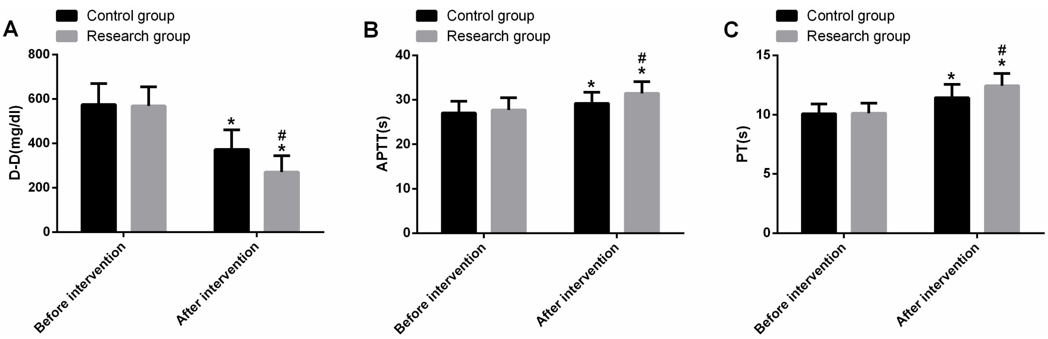

Fig. 1. Comparison of coagulation indicators. (A) Comparison of D-dimer (D-D) changes. (B) Comparison of activated partial thromboplastin time (APTT) changes. (C) Comparison of prothrombin time (PT) changes. Note: Compared with pre-treatment within the same group, *$p < 0.05$; Compared with the control group at the same time, $^{\#}p < 0.05$.

Comparison of Hemodynamic Indicators

Before the intervention, there were no significant differences in the levels of Vp, Va, and BF between the two groups ($p > 0.05$). After the intervention, the levels of Vp, Va, and BF increased in both groups, with the study group showing significantly higher levels of these indicators compared to the control group ($p < 0.05$) (Fig. 2). This indicates that the intervention is effective in significantly increasing the levels of Vp, Va, and BF.

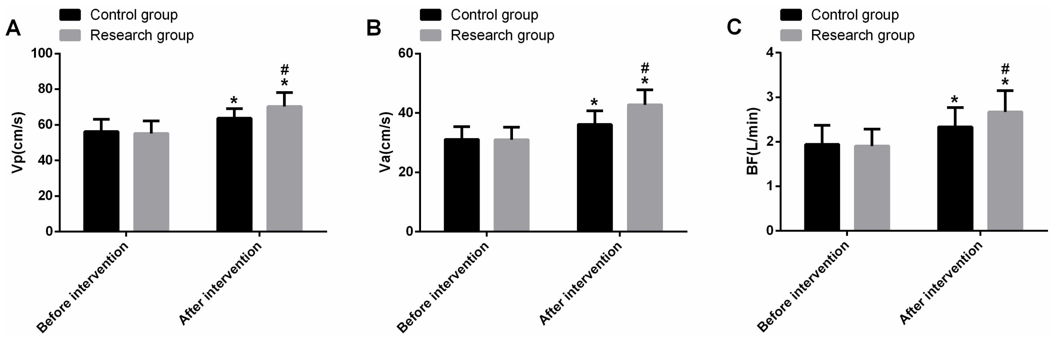

Fig. 2. Comparison of coagulation indicators. (A) Comparison of changes in peak blood flow velocity (Vp). (B) Comparison of changes in average velocity (Va). (C) Comparison of changes in blood flow (BF). Note: $*p < 0.05$ compared with the same group before treatment; $^{\#}p < 0.05$ compared with the control group at the same time point.

Comparison of Inflammatory Indicators

Before the intervention, there were no statistically significant differences in TNF-α, IL-6, and IL-8 levels between the two groups ($p > 0.05$). After the intervention, TNF-α, IL-6, and IL-8 levels decreased in both groups, with the study group showing significantly lower levels of these inflammation markers compared to the control group ($p < 0.05$) (Fig. 3). This indicates that the intervention is more effective in reducing inflammation markers in the study group compared to the control group.

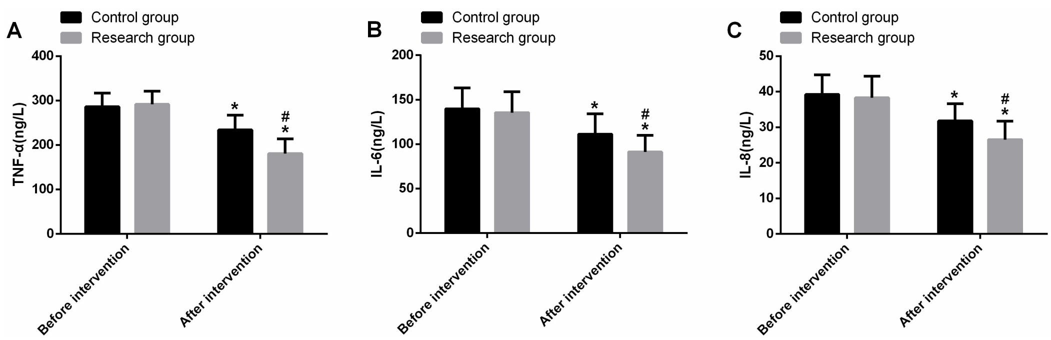

Fig. 3. Comparison of inflammatory indicators. (A) Comparison of tumor necrosis factor-α (TNF-α) changes. (B) Comparison of interleukin-6 (IL-6) changes. (C) Comparison of interleukin-8 (IL-8) changes. Note: $*p < 0.05$ compared with pre-treatment within the same group; $^{\#}p < 0.05$ compared with the control group at the same time.

Discussion

This study evaluated the effect of IPC combined with LMWH on the prevention of DVT in elderly patients following femoral neck fracture surgery. The results indicated that the incidence of DVT was significantly lower in the study group compared to the control group, demonstrating the effectiveness of the combined treatment. This finding highlights the synergistic role of IPC and LMWH in preventing blood stasis and promoting venous return.

Specifically, the incidence of DVT decreased in the femoral vein, popliteal vein, and calf vein, with a total incidence of 2.53% in the study group compared to 12.68% in the control group. IPC mimics the natural muscle pump mechanism, reducing venous stasis, while LMWH inhibits clot formation through its anticoagulant properties (Herring et al, 2023; Li et al, 2023). The significant reduction in DVT incidence underscores the potential of this combined therapy to enhance patient outcomes post-surgery.

Furthermore, the comparison of surgical indicators revealed no significant differences between the two groups in terms of intraoperative blood loss and postoperative drainage volume. This suggests that the addition of IPC did not increase the risk of bleeding, which is a crucial consideration for managing elderly patients with multiple comorbidities and frailty. The safety profile of the combined treatment is further supported by the lack of significant differences in these indicators, demonstrating that IPC can be safely integrated into the standard prophylactic regimen for DVT without compromising surgical outcomes.

Additionally, before the intervention, there was no significant difference in Harris scores between the two groups. After the intervention, both groups showed significant improvements in Harris scores, but there was no significant difference between the groups. This indicates that while both treatments were effective in improving joint function, the addition of IPC did not provide additional benefits in terms of functional recovery. However, the significant improvement within each group underscores the importance of DVT prevention in facilitating rehabilitation and functional recovery post-surgery (Chen et al, 2020).

Further analysis of coagulation indicators revealed that, before the intervention, there were no significant differences in D-D, APTT, and PT levels between the two groups. After the intervention, these indicators improved significantly in both groups, with APTT and PT levels increasing and D-D levels decreasing compared to pre-treatment values. Notably, the study group exhibited longer APTT and PT levels and lower D-D levels compared to the control group. These results suggest that the combination of IPC and LMWH enhances anticoagulation efficacy, reducing hypercoagulability and the risk of thrombus formation (Maier and Sniecinski, 2021; Saito et al, 2023).

Equally important, hemodynamic indicators (Vp, Va, and BF) were similar between the groups before the intervention. After the intervention, these indicators improved significantly in both groups, with the study group showing higher levels than the control group. The increased levels of Vp, Va, and BF in the study group suggest that IPC, in conjunction with LMWH, more effectively enhances blood flow velocity and volume, thereby reducing venous stasis (Tan et al, 2023). Improved hemodynamics are critical in preventing DVT, as they help maintain adequate blood flow and reduce the likelihood of clot formation.

Similarly, before the intervention, there were no significant differences in TNF-α, IL-6, and IL-8 levels between the groups. After the intervention, these inflammatory markers were significantly lower in the study group compared to the control group. This indicates that the combined use of LMWH and IPC can reduce lower limb inflammation, thereby lowering the incidence of DVT. Additionally, the reduction in these inflammatory cytokines suggests that the treatment may modulate the inflammatory response, which is a critical factor in the development and progression of DVT (Jia et al, 2023). Therefore, controlling inflammation may be an essential mechanism by which LMWH and IPC prevent DVT in elderly patients after surgery.

In summary, the observed benefits of combined IPC and LMWH therapy can be attributed to several mechanisms. First, IPC mimics the muscle pump action, promoting venous return and reducing blood stasis, a key factor in DVT development. Second, LMWH inhibits factor Xa, enhances antithrombin III activity, and reduces clot formation. The combination with IPC further amplifies these effects by improving blood flow (Wang et al, 2018; Ye et al, 2020). Additionally, the reduction in inflammatory cytokines (TNF-α, IL-6, IL-8) in the study group indicates that IPC combined with LMWH can modulate the inflammatory response. Inflammation plays a crucial role in DVT formation by promoting endothelial activation, leukocyte adhesion, and coagulation cascade activation. By reducing inflammation, the combined therapy mitigates these pro-thrombotic processes (Colling et al, 2021; Galeano-Valle et al, 2021; Lee et al, 2022; Meng et al, 2021). The increased levels of Vp, Va, and BF in the study group reflect better blood flow dynamics, reducing the risk of clot formation and improving vascular health (Wootton and Ku, 1999). Finally, the longer APTT and PT and lower D-D levels indicate a better-managed coagulation system, reducing hypercoagulability and the potential for thrombus formation (Siriez et al, 2018).

Despite these positive findings, the study has several limitations. First, the relatively small sample size may limit the generalizability of the results. Larger studies are needed to confirm these findings. Second, the follow-up period was limited, preventing the assessment of long-term outcomes and potential late complications. Additionally, the study was conducted at a single center, which may limit the applicability of the results to other settings or populations. Finally, although the study design included randomization and blinding, there may still be unknown confounding factors and biases that were not accounted for.

Conclusion

In conclusion, this study compared the combined use of IPC and LMWH with their individual use, revealing that the combined treatment significantly reduces the incidence of DVT following surgery for elderly femoral neck fractures, without increasing the risk of bleeding. Additionally, the combined treatment group demonstrated notable improvements in coagulation markers, hemodynamic performance, and a reduction in inflammatory responses, thereby supporting the comprehensive benefits of the combined treatment strategy for DVT prevention.

However, the study has several limitations, including a small sample size, a short follow-up period, and its confinement to a single center. Future research should aim to expand the sample size and implement multi-center collaborations to enhance statistical power, reduce random errors, and ensure broader applicability and representativeness of the results. Extending the follow-up period is crucial for assessing the long-term effects and safety of the treatment, including rates of hospital readmission and mortality. Additionally, exploring treatment responses across diverse populations (e.g., varying ages, genders, and underlying health conditions) will promote the development of personalized treatment strategies and assess the economic feasibility of combining IPC and LMWH. Further molecular biological research into the specific pathways by which DVT reduction occurs, along with more rigorous experimental designs to control research biases, will ensure the accuracy and reliability of the findings. Through these comprehensive research directions, the application of combined treatment strategies in DVT prevention can be optimized, thereby enhancing clinical outcomes and advancing the field of medicine.

Key Points

- The combination of IPC and LMWH significantly reduces the incidence of deep vein thrombosis (DVT) in elderly patients following femoral neck fracture surgery compared to LMWH alone.
- The intervention did not significantly impact intraoperative blood loss or postoperative drainage volume, indicating that it is safe to use without affecting surgical outcomes.
- Both intervention methods similarly improved hip joint function, as measured by Harris scores, demonstrating comparable efficacy in functional recovery.
- The combined intervention of IPC and LMWH was more effective in improving coagulation parameters, hemodynamic indicators, and reducing inflammation markers compared to the control group, highlighting its comprehensive benefits in postoperative management.

Availability of Data and Materials

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

Author Contributions

CL designed the study and drafted the initial manuscript. XX and HTZ made substantial contributions to conception and design. CYL analyzed the data. XG made significant contributions to the interpretation of the data. All authors contributed to important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was approved by the ethics committee of the First Affiliated Hospital of Heilongjiang University of Chinese Medicine (No. 2024-107) and all patients provided informed consent. And this study was conducted in accordance with the principles of the Declaration of Helsinki.

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Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://www.magonlinelibrary.com/doi/suppl/10.12968/hmed.2024.0442.

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