Efficacy of Selective Arterial Perfusion Combined With Core Decompression in Managing Osteonecrosis of the Femoral Head

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AIM: To compare the effectiveness and safety of selective arterial perfusion (SAP) combined with core decompression (CD) versus CD alone for treating osteonecrosis of the femoral head (ONFH) at association research circulation osseous (ARCO) stages 1–2.

METHODS: Overall, 102 individuals (involving 130 hips) diagnosed with nontraumatic ONFH at ARCO stages 1–2 and admitted into Beijing Jishuitan Hospital Guizhou Hospital (Guizhou Orthopedic Hospital) between January 2021 and December 2023 were enrolled in this retrospective study. They were assigned to two groups based on the treatment protocol: the experimental group (56 patients, 72 hips) treated with SAP combined with CD, and the control group (46 patients, 58 hips) receiving CD only. Both groups were supplemented with conventional treatment: oral aescuven forte (1 tablet/time, 2 times/day for 12 weeks), extracorporeal shock wave therapy (once per week for 4 weeks), nerve block (lateral femoral cutaneous nerve block for visual analogue scale (VAS) >5 points), and rehabilitation training (30 minutes/day, 5 days/week for 12 weeks). All participants were followed up for 12 months, with key outcomes such as effective rate, femoral head collapse rate, lesion size, bone marrow edema grading, VAS score, harris hip score (HHS) score, and complication rate recorded.

RESULTS: No statistically significant differences in baseline data (age, gender, disease duration, ARCO staging, etiology, etc.) were identified between the two groups ($p > 0.05$), indicating their comparability. Twelve months after treatment, the effective rate of the experimental group (91.7%) proved higher than that of the control group (63.8%), whereas the femoral head collapse rate in the experimental group (5.6%) was lower in comparison to that of the control group (19.0%). After treatment, the experimental group also showed more significant improvements in lesion size, bone marrow edema (BME) grading improvement rate, VAS score, and HHS score. The complication rates of the two groups were similar (7.1% vs. 6.5%, $p > 0.05$).

CONCLUSIONS: At 12 months of follow-up, compared with CD alone, SAP combined with CD demonstrated better clinical performance in nontraumatic ONFH patients at ARCO stages 1–2, accompanied by a higher effective rate, lower femoral head collapse rate, more significant reductions in lesion size and improved hip joint function, while maintaining a comparable safety profile. This combined regimen provides a valuable option for hip-preservation treatment in early-stage ONFH, with potential clinical implications for optimizing minimally invasive intervention strategies.

Keywords: osteonecrosis of the femoral head; selective arterial perfusion; core decompression; efficacy; safety

Introduction

Osteonecrosis of the femoral head (ONFH) is a frequently encountered refractory bone disorder in clinical settings, predominantly affecting young and middle-aged adults aged 20–50 years. Among them, ONFH accounts for more than 60%, and is mainly associated with factors such as long-term use of glucocorticoids, alcohol abuse, and autoimmune diseases [1–3]. The core pathological mechanism of ONFH is the interruption of blood supply to the femoral head, which leads to osteocyte necrosis and bone structure destruction. Without timely intervention, approximately 80% of patients will experience femoral head collapse within 3–5 years after onset, and eventually require total hip arthroplasty (THA) [4–6]. Young patients who undergo THA also face the risk of multiple revisions, which severely impairs their life quality and increases both the social and medical burdens [7,8].

Currently, approaches to treating early-stage (association research circulation osseous (ARCO) stages 1–2) ONFH are fundamentally grounded in hip preservation, with core decompression (CD) as the primary surgical method. It alleviates the condition by reducing intraosseous pressure and improving local microcirculation. However, simple CD is associated with risks such as subtrochanteric fracture and iatrogenic collapse, and has a low efficacy rate [9,10]. As a minimally invasive interventional method, selective arterial perfusion (SAP) therapy can directly perfuse multiple autologous stem cells into the blood-supplying arteries

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of the femoral head under digital subtraction angiography (DSA) guidance, thereby achieving targeted improvement of the femoral head's blood supply. Previous research has demonstrated that its application efficacy rate is approximately 90%, but a standardized treatment protocol involving this technique has not yet been established, and high-quality evidence regarding efficacy of its combined application with CD remains limited [11–13].

To address the knowledge gap, this study was designed to retrospectively analyze the clinical data of 102 patients (130 hips) with early-stage (ARCO stages 1–2) nontraumatic ONFH admitted to Beijing Jishuitan Hospital Guizhou Hospital (Guizhou Orthopedic Hospital) between January 2021 and December 2023. By comparing the 12-month effectiveness (including effective rate, femoral head collapse rate, lesion size, bone marrow edema grading, visual analogue scale (VAS) score, and HHS score) and safety (complication rate) of SAP combined with core decompression versus CD alone, this study aims to provide evidence for optimizing clinical hip-preservation protocols and guide the selection of minimally invasive interventions for early ONFH.

Methods

Study Subjects

Individuals diagnosed with ONFH who received treatment in the Department of Pain, Beijing Jishuitan Hospital Guizhou Hospital (Guizhou Orthopedic Hospital) between 1 January 2021 and 31 December 2023 were retrospectively included. This study was conducted in compliance with the guidelines specified in the Declaration of Helsinki and was approved by the Ethics Committee of Beijing Jishuitan Hospital Guizhou Hospital (Guizhou Orthopedic Hospital) (approval number: 20210409). Informed consent was obtained from every participating patient after being informed the purpose of the study.

Diagnostic criteria: diagnosis was confirmed in accordance with the *guidelines for clinical diagnosis and treatment of osteonecrosis of the femoral head in adults (2019 version)* [14], in consideration of patients' medical history, clinical manifestations (hip pain, limited hip joint movement) and imaging examinations (X-ray, computed tomography (CT), magnetic resonance imaging (MRI)). Staging was determined in accordance with the 2019 staging system of the ARCO [15], and only patients with stage 1–2 ONFH were included. MRI manifestations were defined as: (1) low signal intensity in the femoral head on T1-weighted images; (2) the necrotic area on T2-weighted images shows a typical "double-line sign" (high signal intensity on the medial side, low signal intensity on the lateral side); (3) excluding patients with obvious osteoarthritis/late-stage collapse with secondary degeneration (such as significant joint space narrowing, osteophytes, etc.).

Inclusion criteria: ① age 20–70 years (patients under 20 years of age are excluded to limit the study to adults with ONFH and reduce heterogeneity associated with hip disease in adolescents; patients over 70 years of age are excluded because this age group represents a relatively small proportion of patients in our center, and to minimize potential confounding effects from age-related comorbidities and functional limitations; only non-traumatic ONFH patients are included, and individuals with a history of hip trauma are excluded); ② diagnosis of ONFH at ARCO stages 1–2; ③ no history of surgical treatment on the affected hip; ④ key outcome measures with complete clinical data and a follow-up period of $\geq$12 months.

Exclusion criteria: ① presence of underlying diseases that may affect treatment efficacy (e.g., liver disease, renal impairment); ② abnormal coagulation function, pregnancy, or critical conditions; ③ known allergy to drugs used in the treatment (e.g., papaverine, urokinase); ④ history of hip fracture or surgery; ⑤ inability or unwillingness to comply with follow-up requirements.

Grouping Method

Individuals were assigned to two groups according to the treatment protocol: the experiment group and the control group. In the experimental group, the patients were treated with SAP therapy combined with CD. Subjects in the control group were treated with CD alone.

Both groups of patients received identical routine adjuvant treatment, with standardized protocols: (1) oral medication: aescuven forte (ZJ20140002, Aescuven Pharma Deutschland Gmbh & Co. KG) (1 tablet/time, 2 times/day) for 12 consecutive weeks; (2) physical therapy: extracorporeal shock wave (energy density 0.18–0.25 mJ/mm^2, 2000 shocks/session) once a week for 4 weeks; (3) nerve block: 2% lidocaine (H41023668, Suicheng Pharmaceutical Co., Ltd.) (5 mL) for lateral femoral cutaneous nerve block, only when VAS score >5 points (max 3 times); (4) rehabilitation: hip range-of-motion training (passive flexion 90°, abduction 30°) + gluteal muscle training (clamshell exercise, 3 sets $\times$ 15 reps) for 30 minutes/day, 5 days/week for 12 weeks. Consistency was ensured by the same team of therapists and anesthesiologists.

Treatment Methods

Core Decompression

Core decompression was performed in both groups, and in the experimental group, CD was completed before the initiation of perfusion therapy. To conduct CD, the patient was positioned in the lateral position, with the healthy limb flexed and the affected limb extended, and received continuous epidural block anesthesia. Under the direction of a C-arm X-ray machine, a 4-mm incision was fashioned 1–2 cm inferior to the greater trochanter of the affected-side femur. A 4.0 mm bone puncture needle was employed to puncture the cortical bone, and a 3.5 mm solid drill was utilized to penetrate this cortical bone. After confirming that the needle insertion direction was aimed at the center of the femoral head necrotic area, a hollow drill was used to pen-

etrate the necrotic area and remove part of the bone tissue. Subsequently, a solid drill was placed into the necrotic lesion, and 1.0 g of calcium sulfate cement MIIG X3 (Wright Medical Technology, Inc.) was injected through an injector (withdrawing the needle while injecting). As the needle was retracted to the base of the femoral neck, gelatin sponge was administered to achieve hemostasis. The same procedure was used to create three decompression channels (posteromedial and anteromedial aspects of the femoral head). After the operation, a compressive dressing was applied with sterile gauze. All patients in both groups received standardized deep vein thrombosis (DVT) prevention after CD surgery: (1) Mechanical prophylaxis: Intermittent pneumatic compression (IPC) of the lower extremities was initiated within 24 hours postoperatively, continued for 7 days (2 hours/time, 3 times/day); (2) Pharmacological prophylaxis: Low-molecular-weight heparin (enoxaparin sodium injection, 4000 IU, subcutaneous injection, once daily) was administered starting from 12 hours after surgery, continued for 10 days. Contraindications to anticoagulants (e.g., abnormal coagulation function, active bleeding) were excluded preoperatively, and coagulation function (PT, INR, APTT) was monitored on postoperative days 1, 3, and 7 to adjust the dosage if necessary.

Selective Arterial Perfusion Therapy

Selective arterial perfusion therapy was performed only in the subjects of the experimental group. The first perfusion treatment was initiated 3–5 days after CD, followed by repeated treatments at 1-, 3-, and 6-month postoperatively, totaling four treatment courses. Under local anesthesia, puncture was performed at 1.5–2 cm below the midpoint of the ipsilateral inguinal ligament (at the common femoral artery pulsation site, 0.5 cm lateral to the femoral artery pulse). Under the guidance of digital subtraction angiography (DSA), the catheter was advanced along the vascular course: common femoral artery → external iliac artery → internal iliac artery → obturator artery or lateral femoral circumflex artery → medial femoral circumflex artery. Drugs were infused sequentially at specified rates: (1) papaverine hydrochloride injection (Chengdu Better Pharmaceutical Co., Ltd., H32021764) (30 mg + 100 mL normal saline, 2 mL/min) to relieve vascular spasm; (2) urokinase (Livzon Group Livzon Pharmaceutical Factory, H44020646) (150,000 U + 100 mL normal saline, 1 mL/min) to dissolve microthrombi; (3) ozagrel (Hainan Better Pharmaceutical Co., Ltd., H20093200) (80 mg + 100 mL normal saline, 2 mL/min) to inhibit platelet aggregation; (4) alprostadil (Beijing Tide Pharmaceutical Co., Ltd., H10980023) (30 μg + 100 mL normal saline, 1 mL/min) to protect endothelial cells. The procedure lasted approximately 60 minutes. Intraoperative safety monitoring involved the following: (1) continuous monitoring of vital signs (blood pressure, heart rate, oxygen saturation); (2) real-time observation of the puncture site for bleeding/swelling; (3) detection of fibrinogen (FIB) and D-dimer levels before and after perfusion: if FIB <1.5 g/L, urokinase infusion was terminated immediately. Postoperatively, hemostasis method was applied. Following removal of the puncture needle, a sterile compression bandage (elastic bandage, width 8 cm) was used for layered compression at the puncture site, with a compression force of 30–40 mmHg, verified with a pressure sensor. The affected limb was kept straight, and the patient was required to stay in bed for 6 hours (ambulation allowed with assistance after 6 hours). The puncture site was inspected every 30 minutes within 2 hours postoperatively, and then every 1 hour for 6 hours to observe for bleeding, hematoma, or pseudoaneurysm formation. No additional postoperative anticoagulants were used within 24 hours after perfusion to avoid synergistic bleeding risk with CD postoperative anticoagulation. Patients were monitored for 24 hours postoperatively.

Observation Indicators

Baseline Data

Information such as the patient's age, gender, disease duration, ARCO staging (stage 1/stage 2), etiology (alcoholism/hormone use/idiopathic) and others was recorded.

Efficacy Indicators

The primary endpoint is 12-month treatment response rate, defined as no radiographic/MRI evidence of enlargement of necrotic lesions compared to baseline, and no progression in ARCO staging. Follow-up imaging data obtained during routine clinical practice should be independently reviewed by two experienced reviewers; any disagreements should be resolved through consultation.

Secondary indicators included the following: ① femoral head collapse rate, defined as the presence of subchondral fracture or flattening of the femoral head articular surface on X-ray or computed tomography imaging; ② lesion size, assessed by MRI and calculated as: lesion size (%) = (total necrotic area on each coronal plane / total area of the femoral head on each coronal plane) × 100, using coronal sections showing the maximum necrotic area; ③ grading of bone marrow edema (BME), defined as follows: grade 0, no edema; grade 1, edema localized around the necrotic region; grade 2, edema affecting the femoral head; grade 3, edema involving the femoral neck; grade 4, edema extending to the intertrochanteric region of the femur. Improvement was defined as a reduction of at least one BME grade; ④ harris hip score (HHS), with a total score of 100 points, categorized as excellent (90–100 points), good (80–89 points), fair (70–79 points), and poor (<70 points); ⑤ visual analogue scale for pain assessment, ranging from 0 to 10 points, with higher scores indicating greater pain intensity.

Safety Indicators

The safety indicators evaluated in this study included puncture-related adverse reactions: hematoma, puncture

Table 1. Comparison of baseline data between the experimental and control groups.

Indicators	Experimental group (56 cases, 72 hips)	Control group (46 cases, 58 hips)	χ^2/Z	*p*
Age (years)	45 (37, 52)	46 (38, 53)	0.382	0.702
Gender (male/female), *n*	32/24	26/20	0.004	0.950
BMI (kg/m^2)	24.5 (22.1, 26.8)	24.8 (22.3, 27.1)	0.412	0.680
Comorbidities, *n* (%)	12 (21.4)	10 (21.7)	0.002	0.964
Course of disease (months)	8 (5, 12)	8 (4, 12)	0.513	0.608
Affected side (left/right hips)	38/34	26/32	0.812	0.367
ARCO staging (stage 1/stage 2), *n*	32/40	28/30	0.190	0.663
Etiology, *n*			0.024	0.988
Alcoholism	19	15		
Hormone use	17	14		
Idiopathic	20	17		

BMI, body mass index; ARCO, association research circulation osseous.

Table 2. Comparison of treatment effective rate between the groups.

Indicator	Experimental group (72 hips)	Control group (58 hips)	χ^2	*p*
Effective treatment	66 (91.7)	37 (63.8)	15.167	<0.001

Note: Data are expressed as *n* (%).

site bleeding, pseudoaneurysm, and arteriovenous fistula. Pseudoaneurysm and arteriovenous fistula are arterial puncture/perfusion-related events, which, theoretically, could only occur in the experimental group since no arterial puncture was performed in the control group; for ease of comparison, the corresponding events in the control group are recorded as 0. The overall incidence rate is calculated based on the number of patients experiencing any of the above adverse reactions.

Statistical Methods

R 4.2.2 software (R Foundation for Statistical Computing, Vienna, Austria) was employed for data analysis. Quantitative data that did not conform to normal distribution are expressed as median and interquartile range (M [P25, P75]), and inter-group comparison was conducted using the Mann–Whitney U test. Use a chi-square test for comparison of categorical variables; when the expected cell count is less than 5, use a Fisher exact test. The Kaplan–Meier method was employed to estimate femoral head non-collapse survival, and inter-group differences were compared using the log-rank test. Kaplan–Meier analysis for femoral head non-collapse involved the following: (1) event definition: femoral head collapse, defined as the presence of subchondral fracture or articular surface flattening on X-ray or CT imaging; (2) unit of analysis: each hip, comprising 72 hips in the experimental group and 58 hips in the control group; bilateral ONFH was present in 28 and 22 patients, respectively; (3) censoring: no patients were lost to follow-up; hips without collapse at 12 months were censored; (4) statistic comparison: survival curves were compared using the log-rank test ($\chi^2 = 5.689$, df = 1). Multivariate analysis was performed using a Cox proportional hazards regression model. A two-sided p-value < 0.05 was considered statistically significant. The sample size was determined by the number of eligible patients treated during the study period (January 2021 to December 2023), as formal sample size calculation is not routinely performed in retrospective studies.

Results

Comparison of Baseline Data

A total of 102 individuals (130 hips) were enrolled in this study, among whom 56 participants (72 hips) were assigned to the experimental group and 46 participants (58 hips) to the control group. No significant differences in baseline data between groups were observed, including age, gender, body mass index (BMI), comorbidities, disease duration, etiology, affected hip side, and ARCO staging (all $p > 0.05$), indicating that the baseline data were balanced and comparable (Table 1).

Comparison of Efficacy Indicators

Primary Indicator

At 12 months after treatment, the combined treatment was found to be effective in 66 hips of the experimental group, with an effective rate of 91.7% (66/72). Meanwhile, only 63.8% of the subjects in the control group (37/58) reported CD as effective. The experimental group's effective rate turned out notably higher than that of the control group ($\chi^2 = 15.167$, $p < 0.001$) (Table 2).

Secondary Indicators

① Femoral head collapse rate: during the 12-month follow-up, 4 out of 72 hips in the experimental group developed femoral head collapse, with a collapse rate of 5.6%; 11 out of 58 hips in the control group developed collapse, with a

Table 3. Comparison of femoral head collapse rate between the groups.

Indicator	Experimental group (72 hips)	Control group (58 hips)	χ^2	p
Femoral head collapse	4 (5.6)	11 (19.0)	4.422	0.035

Note: Data are expressed as n (%).

Table 4. Comparison of lesion size, BME grading improvement rate, HHS score and VAS score prior to and following treatment between the groups.

Indicator	Time point	Experimental group	Control group	Z/χ^2	p
Lesion size (per-hip basis, %)	Before	32.5 (28.0, 37.8)	33.0 (27.6, 38.5)	0.291	0.771
	After	18.8 (15.5, 22.5)	30.0 (25.5, 34.8)	7.650	<0.001
BME grading improvement rate (per-hip basis, %)	Change/improved	61.0 (84.7)	32.0 (55.2)	13.776	<0.001
HHS score (per-patient basis, points)	Before	65.0 (58.0, 72.0)	65.0 (58.0, 71.0)	0.423	0.675
	After	89.0 (82.0, 94.0)	76.0 (69.0, 82.0)	6.774	<0.001
VAS score (per-patient basis, points)	Before	7.0 (4.0, 8.0)	6.0 (5.0, 8.0)	0.584	0.557
	After	2.0 (1.0, 3.0)	4.0 (2.0, 5.0)	6.245	<0.001

Notes: lesion size was analyzed on a per-hip basis (72 hips in the experimental group and 58 hips in the control group), whereas the HHS score and VAS score were analyzed on a per-patient basis (56 patients in the experimental group and 46 cases in the control group).

BME, bone marrow edema; HHS, harris hip score; VAS, visual analogue scale.

collapse rate of 19.0%. The collapse rate of the experimental group was significantly lower than that of the control group (p = 0.035) (Table 3). The Kaplan–Meier survival analysis showed that the non-collapse rate of the affected hips in the experimental group was significantly higher than that in the control group (log-rank χ^2 = 5.689, p = 0.017) (Fig. 1).

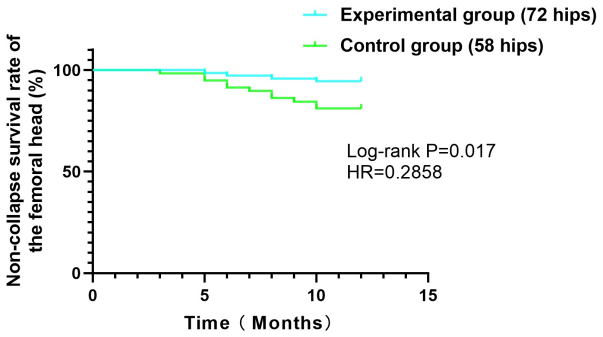

Fig. 1. Kaplan–Meier curves for femoral head non-collapse survival in the two groups. During the 12-month follow-up, 4 hips (5.6%) in the experimental group (72 hips) and 11 hips (19.0%) in the control group (58 hips) developed collapse. Number at risk (n) at each time point: 0 months (72/58), 3 months (72/57), 6 months (70/53), 9 months (69/49), 12 months (68/47). Log-rank χ^2 = 5.689, p = 0.017, hazard ratio (HR) = 0.2858.

② Lesion size: prior to treatment, no statistically significant difference in lesion size was observed between the groups ($p > 0.05$); at 12 months post-treatment, the lesion size in both groups was reduced in comparison to the pre-treatment period, yet the reduction extent in the experimental group was more pronounced, and its lesion size was notably smaller than that of the control group ($p < 0.001$) (Table 4).

③ BME grading improvement rate: among the 72 hips in the experimental group, 61 hips showed improvement in BME grading, with an improvement rate of 84.7% (61/72); among 58 hips in the control group, 32 hips showed improvement in BME grading, with an improvement rate of 55.2% (32/58). The improvement rate of BME in the experimental group was significantly greater than that in the control group's (χ^2 = 13.776, $p < 0.001$) (Table 4).

④ HHS score and VAS score: no statistically significant differences were observed in the HHS and VAS scores of the affected hips between the groups prior to treatment ($p > 0.05$). Twelve months following treatment, the HHS score showed an increase and the VAS score exhibited a decrease in both groups relative to the scores obtained before treatment. Moreover, compared to the control group, the experimental group exhibited a substantially higher HHS score and remarkably lower VAS score (both $p < 0.001$) (Table 4).

Comparison of Safety Profile of the Treatment Approaches

In the experimental group (n = 56), 4 cases (7.1%) experienced complications, including 2 cases of hematoma, 1 case of puncture-site bleeding, and 1 case of pseudoaneurysm; in the control group (n = 46), 3 cases (6.5%) had complications, including 1 case of hematoma and 2 cases of puncture-site bleeding. All complications in both groups resolved following symptomatic treatments such as local compression for hemostasis and anti-infective therapy. No serious adverse events, such as arteriovenous fistula formation or spread of infection, were observed. The incidence of

Table 5. Comparative analysis of adverse reactions occurring in the two groups.

Group (*n*)	Hematoma	Puncture-site bleeding	Pseudoaneurysm	Arteriovenous fistula	Total incidence
Experimental group (*n* = 56)	2 (3.6)	1 (1.8)	1 (1.8)	0	7.1 (4/56)
Control group (*n* = 46)	1 (2.2)	2 (4.3)	0	0	6.5 (3/46)
χ^2					-
p					1.000

Notes: Data are expressed as *n* (%).

complications did not differ significantly between the two groups ($p = 1.000$) (Table 5).

Discussion

Osteonecrosis of the femoral head is a primary contributory factor of hip dysfunction in young and middle-aged adults. Due to the high prevalence of risk factors such as glucocorticoid abuse and long-term alcoholism, this disease subtype has emerged as a key focus and challenge in hip-preserving orthopedic treatment [16,17]. The pathological basis of this disease lies in the progressive impairment of the femoral head blood supply network—starting from increased intraosseous pressure leading to vascular spasm in the early stage, to osteocyte apoptosis and trabecular bone collapse in the later stage. Without effective intervention at ARCO stages 1–2, 80% of patients will progress to the stage requiring THA within 3–5 years [4,18]. Moreover, young patients who undergo THA face challenges such as relatively high revision rates (approximately 6% at 15 years) and postoperative activity limitations, which further underscore the clinical significance of optimizing early hip-preservation regimens [19].

In this study, patients with ARCO stages 1–2 ONFH were selected because of three key considerations: (1) Pathological reversibility: Patients with stage 1–2 ONFH experience no femoral head collapse, with limited areas showing necrosis; therefore, improving blood supply can reverse osteocyte necrosis. However, patients at stage 3–4 are subject to irreversible collapse, which renders hip preservation ineffective. (2) Treatment responsiveness: CD is most effective in early-stage disease by reducing intraosseous pressure before trabecular destruction, while SAP enhances local blood supply—an effect that is more clinically significant in early lesions without irreversible bone loss. (3) Clinical demand: Young and middle-aged patients with early-stage ONFH have a critical need for hip-preserving treatment to avoid THA and subsequent revision surgery; therefore, studying this population could directly address clinical priorities.

In the present study, the 12-month effective rate of the experimental group, in which the subjects received SAP combined with CD, was measured 91.7%, which was significantly higher than that of the control group treated with CD alone (63.8%). Additionally, the experimental group exhibited markedly lower femoral head collapse rate (5.6%) compared to the control group (19.0%). These outcomes align with recent studies focusing on the application of combined treatments to achieve optimal and better therapeutic efficacy. For example, a study by Mao *et al*. [11] found that 92.31% of the hips in patients with ARCO stage 1–2 ONFH, who were treated with CD plus medial femoral circumflex artery perfusion, achieved satisfactory results within 5 years, with a collapse rate of 38.24%, validating the synergistic effect of arterial perfusion in improving the efficacy of CD. Consistent with our research results, Chen *et al*. [20] reported that the reduction rate of osteonecrosis area of the femoral head in patients receiving SAP plus CD was 37.93% at 6 months post-treatment, which was significantly higher than that reported in those receiving CD alone (11.9%). The utilization of four drugs in a particular sequence (papaverine→urokinase→ozagrel→alprostadil) offers a targeted approach to addressing blood supply interruption, which is the pathological core of ONFH. Specifically, papaverine relaxes vascular smooth muscle within 10–15 minutes, rapidly relieving spasm of the medial femoral circumflex artery (the main blood vessel supplying the femoral head). Then, urokinase dissolves microthrombi in 30–60 minutes, restoring blood flow to necrotic areas. Ozagrel inhibits platelet aggregation for 4–6 hours, preventing re-embolism. Lastly, alprostadil protects endothelial cells for 8–12 hours, promoting angiogenesis. CD complements this by reducing the intraosseous pressure from 80–100 mmHg to 30–40 mmHg prior to the initiation of SAP, creating a “pressure-free environment” for drug perfusion.

By analyzing the secondary indicators, we found that the post-treatment lesion size of the experimental group (18.8% [15.5%, 22.5%]) was substantially smaller than that of the control group (30.0% [25.5%, 34.8%]), and the BME grading improvement rate (84.7%) was markedly higher than that of the control group (55.2%). As a sensitive marker of ONFH disease activity, the reduction in BME grading reflects the resolution of local inflammatory response [21]. In terms of clinical symptoms and function, the HHS of the experimental group following treatment (89 [82–94] points) was significantly higher than that of the control group (76 [69–82]), and their VAS score (2 [1, 3] points) was substantially lower than that of the control group (4 [2, 5] points). This result is superior to the reported outcomes of CD in conjunction with platelet-rich plasma (PRP) [22], suggesting that the improved blood supply attributed to arterial perfusion can more effectively relieve the pain caused by increased intraosseous pressure. Meanwhile, this treatment establishes a favorable blood supply network that supports articular cartilage repair and facilitates the recovery

of hip joint range of motion. The dual improvement in patients' subjective symptoms and objective functional outcomes further substantiates the clinical value of the combined treatment regimen. Jin *et al*. [13] demonstrated that arterial perfusion of bone marrow mesenchymal stem cells (BMSCs) in ONFH models increased CD31-positive blood vessels (an angiogenic marker) and upregulated vascular endothelial growth factor (VEGF; an angiogenic factor). In addition, urokinase not only dissolves thrombi but also activates plasmin, degrading extracellular matrix to facilitate vascular ingrowth [23]. Taken together, these studies support the dual effects of SAP on angiogenesis and bone repair, providing a mechanistic rationale for its superior efficacy compared with CD alone.

In terms of safety, there was no statistically significant difference in the incidence of complications between the experimental group (7.1%) and the control group (6.5%). All observed complications were mild, puncture-related events, including hematoma, puncture-site bleeding, and pseudoaneurysm, which were resolved with local compression and anti-infective treatment. No serious adverse events such as arteriovenous fistula or infection spread occurred. This is consistent with the minimally invasive nature of SAP. In this study, arterial perfusion was deliberately performed 3–5 days after CD to avoid the potential risks of interventional operation during the early postoperative period, when the femoral head perfusion may be unstable, thereby ensuring procedural safety during the treatment process. Our findings indicate that the combined treatment regimen enhances treatment efficacy without imposing additional safety burdens and demonstrates good clinical tolerability.

As a retrospective analysis, this study faces several inherent limitations that need to be addressed in future investigative works: ① Selection bias and confounding factors: Although variables such as age, gender, and ARCO staging were controlled through baseline data balance analysis, the impact of potential confounding factors (e.g., differences in compliance with postoperative rehabilitation training, blood glucose control levels in patients with underlying diseases such as diabetes) cannot be completely ruled out due to the retrospective design of this study. These factors may potentially affect the lesion repair and functional recovery. ② Short follow-up duration: Patients were followed up for only 12 months in this study. Such a brief follow-up period may only reflect short-term efficacy and safety of the tested treatment regimens, but it is important to note that the progression of ONFH could be delayed, as some patients may experience femoral head collapse 12 months post-treatment. Therefore, an extended follow-up period, up to 2–5 years, is needed to monitor the effect of the combined regimen on the femoral head's long-term stability. ③ Lack of subgroup analysis: This study did not conduct stratified analysis for different etiologies (alcohol-induced vs. steroid-induced vs. idiopathic ONFH) or ARCO stages (stage 1 vs. stage 2). ④ Insufficient mechanistic research: This study only evaluated therapeutic efficacy through imaging and clinical scores, and did not analyze blood supply–related molecular indicators or bone metabolism markers. Without a comprehensive analysis of these markers, we are unable to decipher the specific mechanism of the combined treatment in promoting revascularization and bone repair at the molecular level. Thus, a range of laboratory tests can be conducted concurrently in future studies to delineate the mechanistic targets of the combined treatment. According to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement for observational studies, this paper presents key information, including enrollment criteria, outcome definitions, and statistical methods; limitations (retrospective design, single center) are also emphasized to ensure transparency. ⑤ Survival analysis was performed on a per-hip basis, and some bilateral cases may have resulted in non-independent observations. This study did not perform cluster correction for intra-patient correlations, which may have underestimated the standard error and affected the robustness of the *p*-value.

Several key practical considerations stemming from our clinical application of SAP combined with CD are summarized as follows: (1) SAP timing: SAP should be performed 3–5 days after CD, rather than immediately, to reduce bleeding risk by allowing adequate hemostasis of the decompression tract and stabilization of femoral head perfusion; (2) Patient selection: It is important to note that for ARCO stage 2 patients with necrotic lesions involving >30% of the femoral head, the combined regimen remains effective but necessitates close monitoring with monthly CT to detect collapse; (3) Postoperative rehabilitation: Guided hip range-of-motion exercise (passive flexion up to 90°) at 2 weeks postoperatively, accompanied by strict avoidance of weight-bearing for 3 months, could improve HHS by an additional 5–8 points; (4) complication resolution: for patients developing a pseudoaneurysm due to insufficient puncture site compression (6 hours), an extended period of compression up to 12 hours could help resolve the complication.

Conclusions

By leveraging the synergistic effects of mechanical decompression and targeted enhancement of local blood circulation, SAP combined with CD significantly improves the treatment effectiveness in patients with ARCO stage 1–2 ONFH, reduces the risk of femoral head collapse, and yields substantial benefits in hip joint functional improvement and pain relief, while ensuring a good therapeutic safety profile. Despite certain limitations, this combined regimen holds promise in providing effective treatment for hip preservation in early-stage ONFH. Further prospective, stratified studies with long-term follow-up are warranted to validate the current findings and elucidate the underlying mechanism of action.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

DDW: responsible for the overall study design, data collection and statistical analysis, and led the drafting and revision of the manuscript. YC, YPZ: responsible for clinical data collection, experimental operation and data validity verification, and assisted in organizing the original research data. WYMS, JYL: responsible for clinical case screening, relevant literature retrieval and collation, data collection and analysis and participated in the proofreading of manuscript details. DSW: responsible for the guidance and reviewing of the study design, coordinating the project implementation, and providing funding and technical support. All authors have been involved in revising the manuscript critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was conducted in compliance with the guidelines specified in the Declaration of Helsinki and obtained ethical approval from the Ethics Committee of Beijing Jishuitan Hospital Guizhou Hospital (Guizhou Orthopedic Hospital) (approval number: 20210409). Informed consent was obtained from every participating patient after being informed of the purpose of the study.

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Conflict of Interest

The authors declare no conflict of interest.

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