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Hip Arthroscopy With Triangular Drilling and Suction Decompression for Osteonecrosis of the Femoral Head: A Retrospective Study

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
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APPROVED GALLEY PROOF

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Background: ARCO stage IIIA osteonecrosis of the femoral head (ONFH) means early collapse, but total hip replacement may be premature in relatively young patients. This retrospective study aimed to compare outcomes between hip arthroscopy combined with triangular drilling and suction decompression versus standard drilling alone.

Material/Methods: We analyzed 63 patients (76 hips) with ARCO IIIA ONFH treated from January 2018 to October 2022. The triangular group (19 patients, 19 hips, all unilateral) received arthroscopy plus triangular drilling with suction decompression. The standard group (44 patients, 57 hips, including 13 bilateral) received standard drilling alone. Outcomes included visual analog scale (VAS) score, modified Harris Hip Score (mHHS), KaplanMeier femoral head survival, operative time, and postoperative hospital stay. No patients were lost to followup.

Results: At 3, 6, and 12 months postoperatively, the triangular group had lower VAS ($P=0.009$, 0.001, 0.004) and higher mHHS ($P=0.006$, <0.001, <0.001) than the standard group. Operative time was longer in the triangular group (142.23±22.64 vs 43.18±10.82 minutes, $P<0.001$), but hospital stay did not differ. During followup (1245 months), femoral head collapse occurred in 3 hips in the triangular group and 11 hips in the standard group. KaplanMeier survival was significantly better in the triangular group (logrank $P=0.040$).

Conclusions: Hip arthroscopy combined with triangular drilling and suction decompression was associated with better short to midterm pain relief, functional improvement, and femoral head survival in ARCO stage IIIA ONFH compared with standard drilling alone, although operative time was longer. These findings should be interpreted as unadjusted associations, and further prospective multicenter studies are needed.

Keywords: arthroscopy • decompression, surgical • femur head necrosis • hip joint • orthopedics

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Introduction

Osteonecrosis of the femoral head (ONFH) is a condition primarily characterized by impaired blood supply to the femoral head, leading to the death of bone marrow components and bone cells, which ultimately results in structural changes in the femoral head. Clinically, hip joint pain and functional impairment are the main manifestations [1]. Under weight-bearing stress, the structural integrity of the femoral head is compromised, often causing it to collapse and flatten. As ONFH progresses, this can lead to further deterioration of the acetabulum and eventually progress to osteoarthritis of the hip joint [2]. The prevailing theory suggests that ONFH results from impaired microvascular circulation, leading to osteocyte death, with primary etiologies including traumatic fractures, corticosteroid use, chronic excessive alcohol consumption, blood disorders, and decompression sickness [3].

The ARCO staging system for osteonecrosis of the femoral head was initially established in 1991 and revised in 2021, categorizing the disease from stage I to IV based on imaging changes, pain, crescent sign, collapse severity, and secondary osteoarthritis (**Table 1**) [4,5]. ARCO stage IIIA specifically denotes a subchondral fracture (crescent sign) with slight flattening of the femoral head up to 2 mm, indicating early structural collapse. The occurrence of femoral head collapse is a critical factor in the clinical decision-making process of treatment strategies. In 2019, the International Association for Bone Circulation proposed adding an early stage of femoral head collapse, ARCO IIIA, to the staging of ONFH progression and also suggested corresponding hip-preserving treatments. Despite these advancements, effective hip-preserving treatments for ARCO IIIA ONFH are still under investigation [6,7].

Hip arthroscopy-assisted core decompression surgery allows for both the reduction of intracapsular pressure by drilling and the resolution of intra-articular pathologies, such as labral tears, synovial hyperplasia, and loose bodies, which are sources of pain. Arthroscopy is considered the gold standard for diagnosing joint-related diseases as it can identify lesions that may be missed by X-rays, computed tomography (CT) scans, magnetic resonance imaging (MRI), and other imaging modalities due to various limitations. In addition, drilling under arthroscopic guidance helps prevent excessive penetration of Kirschner wires beyond the safe depth, thereby avoiding damage to the soft tissues and normal anatomical structures within the joint cavity [8-10]. Triangular drilling and aspiration decompression create a triangular support zone that provides fresh nourishment to the necrotic area and relieves negative pressure. A combination of these treatment methods can alleviate hip joint pain, reduce the size of the necrotic area, and improve bone stiffness. Zhao et al [11] reported 14 year follow up results of hip arthroscopy combined with multiple small diameter fan shaped low speed drilling decompression in ARCO stage II–IIIA ONFH. They found that adding arthroscopy improved Harris scores and femoral head survival compared with drilling alone, although survival in stage IIIA was lower than in stage II. Therefore, this retrospective study of 63 patients with ARCO stage IIIA ONFH aimed to evaluate outcomes following hip arthroscopy combined with triangular drilling and suction decompression compared with standard drilling alone.

Material and Methods

Ethics statement

This retrospective study was approved by the Medical Ethics Review Board of the Affiliated Traditional Chinese Medicine Hospital of Southwest Medical University (Approval No. BY2022024, dated 2022/9/22). The approved protocol was entitled "Efficacy of Hip Arthroscopy Combined with Triangular Drilling and Suction Decompression for ARCO Stage IIIA Osteonecrosis of the Femoral Head: A Retrospective Study." This protocol is distinct from any previously approved studies involving different interventions. All procedures were conducted in accordance with the Declaration of Helsinki. Written informed consent for treatment was obtained from all patients before surgery.

Inclusion and Exclusion Criteria

Inclusion Criteria

1) Diagnosed with ONFH and meeting the surgical criteria [12]. 2) ARCO stage IIIA defined as subchondral fracture (crescent sign) with femoral head flattening of ≤ 2 mm on radiography or CT. 3) Age 18 to 60 years. 4) Non-traumatic ONFH associated with steroid use or alcohol consumption. 5) Completed follow-up ≥ 12 months.

Exclusion Criteria

1) Traumatic ischemic necrosis of the femoral head. 2) Concomitant ankylosing spondylitis and rheumatoid arthritis. 3) Severe metabolic disease or other systemic disorders affecting bone metabolism. 4) Concomitant tumor-related diseases.

Patients and Group Allocation

A retrospective analysis was conducted on 63 patients (76 hips) diagnosed with ischemic necrosis of the femoral head and admitted to the Department of Orthopedics at the Traditional Chinese Medicine Hospital affiliated with the Southwest Medical University between January 2018 and October 2022. The triangular group consisted of 13 males and 6 females (average age 51.84 ± 9.39 years) with 19 hips (all unilateral). The standard group consisted of 32 males and 12 females (average age 54.25 ± 9.39 years)

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Table 1. ARCO staging system for osteonecrosis of the femoral head.

Stage	Imaging findings	Key features	Clinical implication
0	Xray, CT, MRI: normal	Abnormal only on histology	Incidental, rarely diagnosed
I	Xray: normal; MRI: positive	Bone marrow edema or necrotic focus on MRI	Best window for hippreserving treatment
II	Xray: sclerosis, cysts, or mixed changes; no collapse	Necrotic area visible; subchondral bone intact	Precollapse stage; core decompression or grafting indicated
III	Xray: crescent sign or flattening	Subchondral fracture and/or collapse	Collapse stage; outcomes of hippreserving surgery decline
IIIA	Collapse < 2 mm	Early collapse; subchondral fracture may be present	Still suitable for hippreserving procedures (focus of this study)
IIIB	Collapse 2-4 mm	Moderate collapse	Success rate of joint preservation decreases significantly
IIIC	Collapse > 4 mm	Advanced collapse	High risk of treatment failure; arthroplasty often considered
IV	Joint space narrowing, acetabular sclerosis, osteophytes	Osteoarthritis changes	Endstage; total hip arthroplasty is the mainstay

Abbreviations: ARCO, Association Research Circulation Osseous; MRI, magnetic resonance imaging; CT, computed tomography.
Source: adapted from Koo et al (2022) and Hines et al (2021) [4,5].

Table 2. Comparison of general information provided by 2 groups of patients.

Targets	Triangular group (n = 19)	Standard group (n = 44)	Statistical value	*P*
Sex (M/F)	13/6	32/12	0.121	0.728
Age (age, x ± s)	51.84 ± 9.39	54.25 ± 9.39	0.472	0.362
BMI (x ± s, kg/m²)	22.4 ± 2.1	21.9 ± 2.2	0.166	0.237
Type (hormone/alcohol)	3/16	5/39	0.234	0.628
Surgical side (single/double)	19/0	13/31	4.527	0.033

Abbreviations: M, male; F, female; BMI, body mass index.

with 57 hips, including 13 patients with bilateral disease. Patients were assigned based on surgeon preference and patient choice; therefore, selection bias cannot be excluded. Baseline characteristics were summarized at the patient level, while clinical outcomes and survival analyses were performed at the hip level. Baseline characteristics of the 2 groups are summarized in **Table 2**.

Surgical Procedures

Triangular Group (Hip Arthroscopy Combined With Triangular Drilling and Suction Decompression)

All Kirschner wires were 2.5 mm in diameter (Double Medical Technology Inc., Xiamen, China). The arthroscope system used was from CONMED Corporation (Largo, FL, USA). All surgeries were performed by the same physician from our department. After administering general anesthesia, the patient was positioned supine on a traction table, with the affected limb maintained at 10° abduction and slight internal rotation. Following routine disinfection and draping, anatomical landmarks and incision points were marked on the patient's skin. The hip joint space was widened to approximately 1 cm using traction under fluoroscopic guidance. After ensuring expansion of the channel through the puncture needle into the joint cavity, the arthroscope sheath and camera were inserted. The anterior portal was established using an arthroscope and the joint capsule was opened using a plasma cutter. The arthroscopic shaver entered through the anterior portal while the hip was

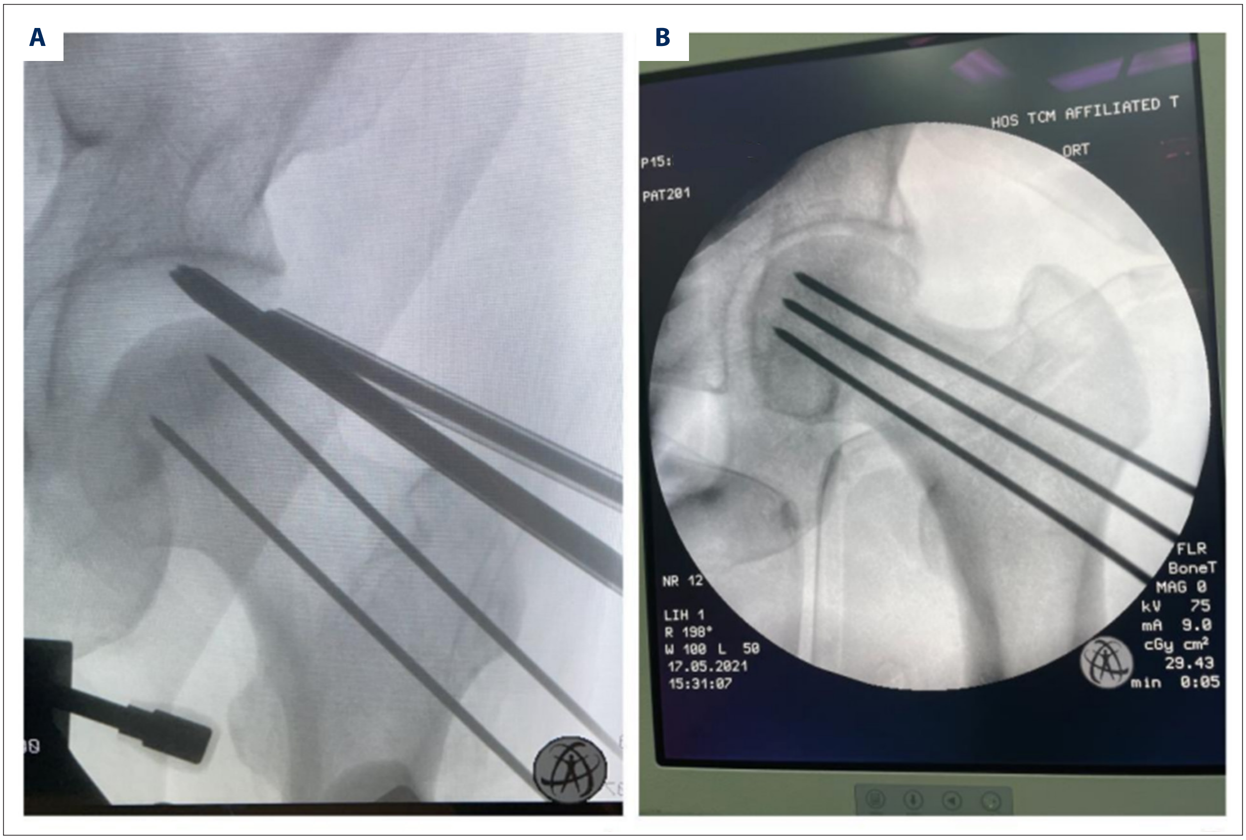

Figure 1. Arthroscopic views of the triangular drilling procedure. (**A**) Necrotic area on the femoral head surface seen through the arthroscope. (**B**) Three Kirschner wires inserted in a triangular configuration into the necrotic area. Abbreviations: ARCO, Association Research Circulation Osseous; ONFH, osteonecrosis of the femoral head. All images are original and were obtained during the study procedures.

slightly flexed and the proliferative synovium on the capsular side of the peripheral compartment was cleared. The traction weight was gradually increased and the arthroscope was rotated into the central compartment for inspection of the acetabular labrum and fossa. The abnormal synovium around the ligamentum teres and anterior-inferior areas was removed using a shaver. The necrotic area of the femoral head was probed, and the floating articular cartilage could be palpated in some patients. After marking the area with the probe tip, a 2.5 mm Kirschner wire was drilled directly into the center of the necrotic area from below the greater trochanter, avoiding articular cartilage penetration under fluoroscopic guidance. Three Kirschner wires were inserted in a triangular configuration above and below the area, followed by decompression with a 50 ml syringe and thorough irrigation before wound closure.

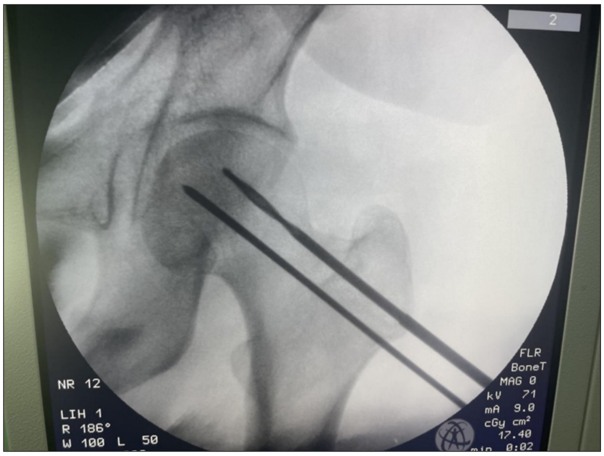

Figure 2. Standard drilling procedure under fluoroscopic guidance. Drilling of a single Kirschner wire into the necrotic area. Abbreviations: ARCO, ONFH. All images are original and were obtained during the study procedures.

Standard Drilling Group

All surgeries were performed by the same physician under general anesthesia. The patient was placed supine, disinfected, and draped. Marking was performed at the tip of the greater trochanter and at its anterior and posterior edges. The entry

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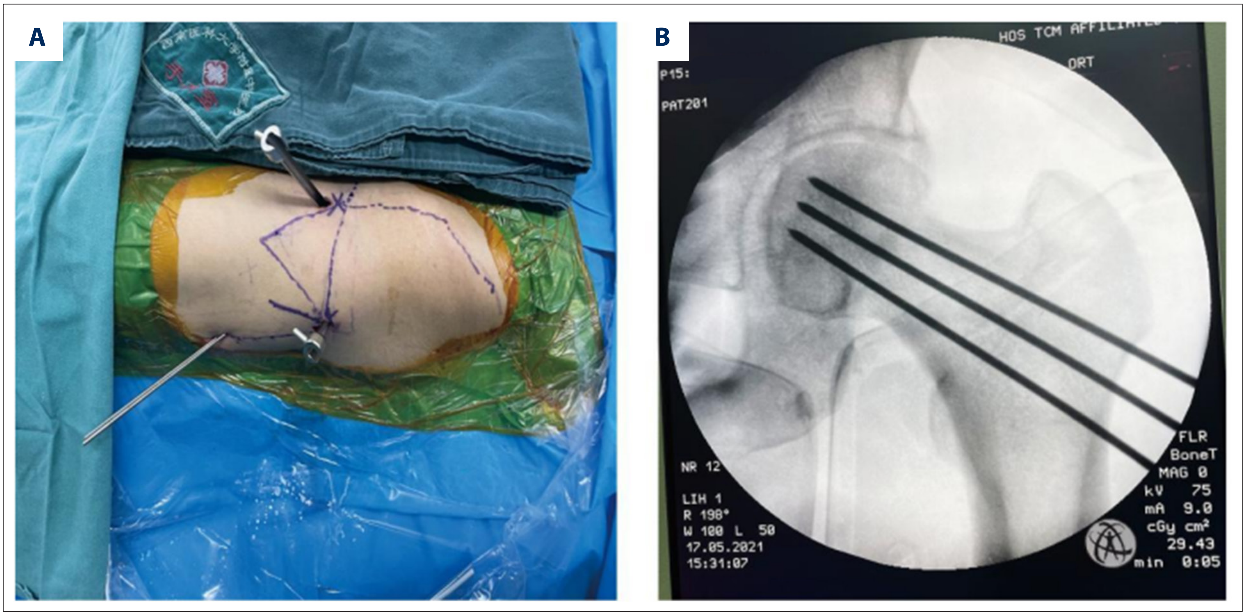

Figure 3. Intraoperative Carm fluoroscopy. (**A**) Carm image showing Kirschner wire position in anteroposterior view. (**B**) Lateral view confirming wire depth. Abbreviation: Carm, fluoroscopic imaging device. All images are original and were obtained during the study procedures.

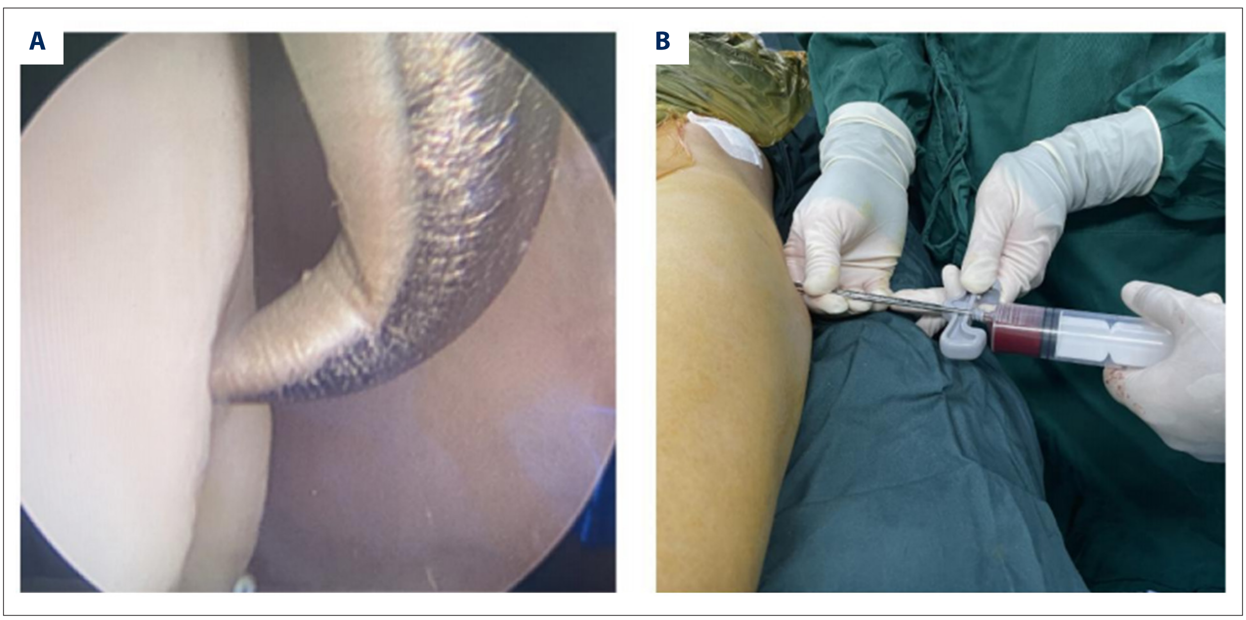

Figure 4. Arthroscopic debridement and suction decompression. (**A**) Arthroscopic view of cartilage debridement within the joint cavity. (**B**) Suction decompression using a 50 mL syringe. Abbreviation: mL, milliliter. All images are original and were obtained during the study procedures.

point was located approximately 6 cm distal to the tip of the greater trochanter, slightly posterior to the midpoint on the lateral side of the femoral shaft. Targeting the center of the necrotic area in the femoral head, a 2.5 mm Kirschner wire was drilled at low speed directly into the necrotic area under fluoroscopic guidance, reaching the subchondral bone of the femoral head in both the anteroposterior and lateral positions. Kirschner wires were drilled into different parts of the necrotic area for decompression, followed by thorough irrigation before wound closure. For intraoperative images, see **Figures 1-5**. The control group received standard drilling alone without arthroscopic intervention, while the triangular group underwent arthroscopy followed by triangular drilling. No sham procedure was performed.

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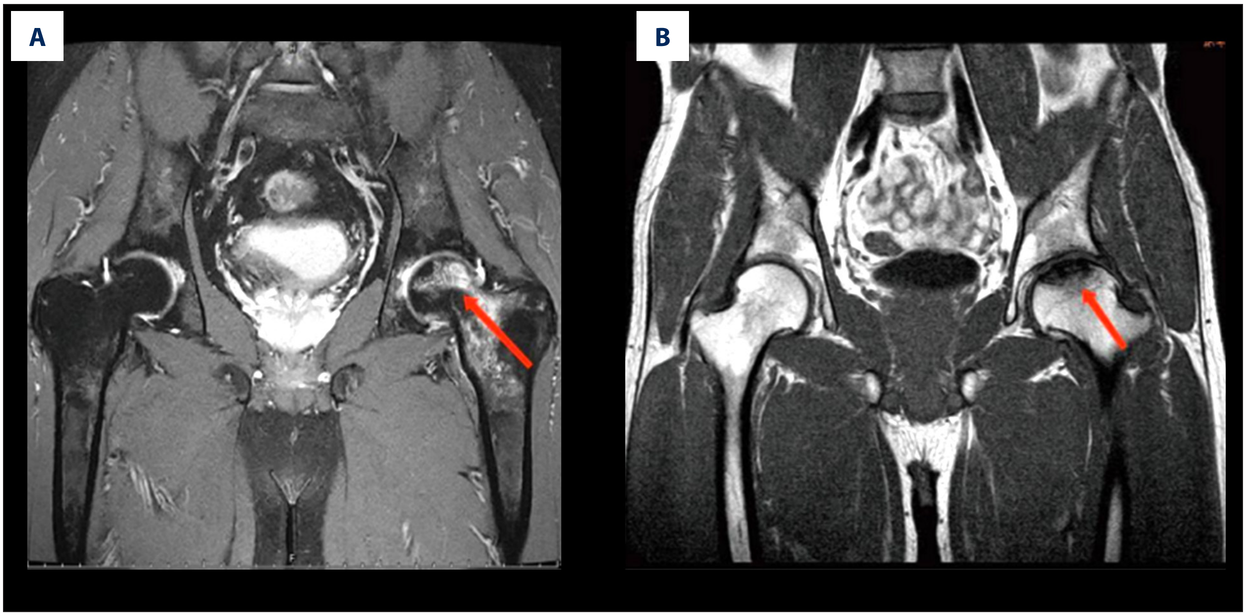

Figure 5. Preoperative and postoperative magnetic resonance imaging (MRI) in the triangular group. (**A**) Preoperative MRI showing the necrotic area. (**B**) MRI taken 2 years after surgery, showing improvement. All images are original and were obtained during the study procedures.

Postoperative Rehabilitation

All patients followed the same postoperative protocol. Patients were required to rest in bed for 2 weeks after surgery, and weight-bearing walking was allowed after 3 months. The average hospital stay was 1 week, with a follow-up appointment scheduled 1 week after discharge for suture removal and examination. Postoperatively, all patients followed a standardized rehabilitation program including range-of-motion exercises, quadriceps strengthening, and skin traction during bed rest to reduce joint pressure. All patients included in this study underwent the rehabilitation treatment and care program described above.

Evaluation Criteria

Perioperative indicators were recorded for all patients, including preoperative, 3, 6, and 12 months postoperative VAS scores, and modified Harris Hip Score (mHHS) to evaluate clinical outcomes. Kaplan-Meier survival curves were used to compare the occurrence of femoral head collapse between the 2 groups. Failure was defined as radiographic evidence of femoral head collapse progression (≥ 2 mm increase on follow-up radiographs compared with immediate postoperative imaging) or persistent significant pain (VAS ≥ 4) requiring additional surgical intervention.

Statistical Analyses

All analyses were performed at the hip level. To account for within-patient correlation in patients with bilateral disease, linear mixed-effects models were used to compare VAS and mHHS over time between groups. Categorical data were analyzed using the chi-square test. Kaplan-Meier survival analysis was performed with the date of surgery as the starting point; patients who did not experience the failure event were censored at the last follow-up. Survival curves were compared using the log-rank test. $P < 0.05$ was considered significant. No multivariable adjustment was performed; findings should be interpreted as unadjusted associations. No patients were lost to follow-up. All analyses were performed using SPSS version 26.0

Results

Surgical-Related Indicators of Both Groups

No postoperative complications related to the surgery were observed in any patient. The surgery duration for the triangular group was significantly longer (142.23 ± 22.64 minutes) compared to the standard group (43.18 ± 10.82 minutes), with a significant difference ($t = 22.9153$, $P < 0.001$). The hospital stay after surgery was 1 week for both groups, with no significant difference in the time for follow-up and suture removal. There was a significant difference in the proportion of bilateral disease between the 2 groups ($P = 0.033$), which was accounted for by using mixedeffects models in the statistical analysis.

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Table 3. Comparison of VAS scores between 2 groups of patients before and after surgery.

Timetable	Triangular group (n=19 hips)	Standard group (n=57 hips)	*t*	*P*
Pre-surgery	4.28±0.86	4.31±1.00	-0.125	0.9
3 months after surgery	2.02±0.62	2.34±0.37	-2.687	0.009
6 months after surgery	1.30±0.28	1.57±0.30	-3.434	0.001
12 months after surgery	1.11±0.16	1.30±0.26	-2.991	0.004
F	130.797	324.01		
P	<0.05	<0.05		

Abbreviation: VAS, visual analog scale.

Table 4. Comparison of Harris scores between 2 groups of patients before and after surgery.

Timetable	Triangular group (n=19 hips)	Standard group (n=57 hips)	*t*	*P*
Pre-surgery	69.49±13.10	70.57±8.62	-0.414	0.68
3 months after surgery	81.71±9.45	74.82±9.02	2.849	0.006
6 months after surgery	88.88±8.32	79.39±8.43	4.265	0.000
12 months after surgery	96.00±7.44	84.54±7.24	5.932	0.000
F	25.211	29.489		
P	<0.05	<0.05		

Abbreviation: mHHS, modified Harris Hip Score.

Comparison of Preoperative and Postoperative VAS and Harris Scores Between Both Groups

Over time, both groups showed significant decreases in the VAS scores and significant increases in the Harris scores ($P<0.05$). There was no significant difference in the preoperative VAS and Harris scores between the 2 groups ($P>0.05$). However, at 3, 6, and 12 months postoperatively, the VAS and Harris scores in the triangular group were significantly better than those in the standard group ($P<0.05$) (**Tables 3, 4**).

Postoperative Follow-Up of Both Groups

The follow-up period for both groups exceeded 12 months, with the triangular group ranging from 12 to 45 months for 19 hips and the standard group from 14 to 45 months for 57 hips. In the triangular group, 3 cases of necrotic area collapse occurred, leading to total hip arthroplasty on the affected side at our hospital. In the standard group, 11 cases of collapse occurred, with 7 undergoing total hip arthroplasty at our hospital and 4 at other hospitals. As shown in **Figure 6**, Kaplan-Meier analysis demonstrated significantly better femoral head survival in the triangular group than in the standard group (log-rank $P=0.040$). All hips were included in the analysis and no patients were lost to follow-up.

Discussion

A total of 63 patients (76 hips) were included in this study. The triangular group (hip arthroscopy combined with triangular drilling and suction decompression) comprised 19 hips, and the standard group (drilling alone) comprised 57 hips. Postoperatively, both groups showed significant improvements in VAS scores and mHHS compared with preoperative values ($P<0.05$). However, at 3, 6, and 12 months postoperatively, the triangular group demonstrated significantly better VAS and mHHS scores than the standard group ($P<0.05$). Survival analysis showed that the 2year femoral head survival rate was 78.6% in the triangular group and 74.2% in the standard group, with a statistically significant difference between groups (logrank test, $P=0.040$). These findings suggest that for ARCO stage IIIA ONFH, hip arthroscopy combined with triangular drilling and suction decompression results in better functional recovery and higher shortterm survival compared with drilling alone.

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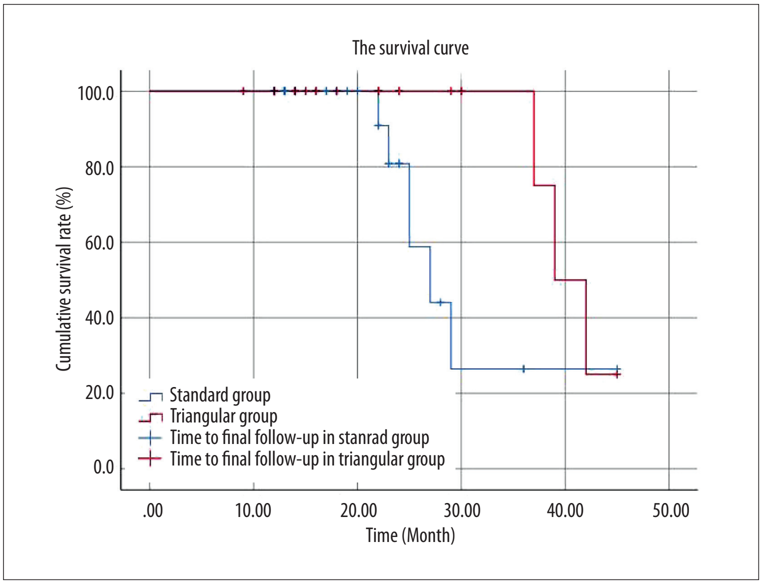

Figure 6. Kaplan-Meier survival curves comparing femoral head survival between the triangular group (hip arthroscopy combined with triangular drilling and suction decompression, n = 19 hips) and the standard group (drilling alone, n = 57 hips). Survival was defined as the absence of femoral head collapse progression (≥2 mm increase on radiographs) or persistent severe pain (VAS ≥4) requiring additional surgical intervention. The logrank test showed a significantly higher survival rate in the triangular group (*P* = 0.040). Followup period ranged from 12 to 45 months in both groups. All images are original and were obtained during the study procedures.

Core decompression is an important hippreserving treatment for earlystage ONFH. Current consensus indicates that core decompression is mainly applicable to precollapse ONFH, predominantly ARCO stages I and II, as it reduces intraosseous pressure, facilitates capillary reconstruction, and gradually restores blood supply. The efficacy of core decompression in treating precollapse ONFH and femoral head edema or elevated intraosseous pressure has been well established. However, the effectiveness of drilling alone for ARCO stage III ONFH remains controversial [13,14]. Beyond the unsatisfactory long-term outcomes of core decompression alone, controversy also exists regarding whether to combine it with other modalities and the complexity of patient selection. Contemporary clinical and basic research has increasingly focused on enhancing the repair capacity of core decompression through the addition of plateletrich plasma (PRP), bone graft materials, or vascular perfusion [6,15,16]. Regarding specific decompression techniques, particularly the comparison between multiple smalldiameter drilling and few largediameter Kirschner wire drilling, further investigation is needed. Nevertheless, the biomechanical advantages of multiplechannel decompression have been confirmed by finite element analysis and biomechanical studies. Using multiple smalldiameter drill holes distributes the stiffness loss caused by a largediameter hole across multiple smaller defects, thereby reducing the overall reduction in structural stiffness [6]. In this study, triangular drilling was employed, which distributes stress through a triangular configuration of the 3 channels. Compared with a single largediameter channel or linearly arranged multiple channels, the multiplechannel, smalldiameter triangular drilling design is better for maintaining subchondral bone support. Unlike fanshaped drilling, which covers the necrotic area within a single coronal plane, the triangular configuration provides threedimensional mechanical support. Our findings align with those reported by Zhao et al [11], who also found that arthroscopyassisted drilling improves mHHS scores and femoral head survival compared with drilling alone in ARCO stage II–IIIA ONFH. However, Zhao et al reported a 5year survival rate of 54% for stage IIIA, whereas our 2year survival rate in the triangular group was 78.6%. This difference likely reflects the shorter followup in our study rather than being a true contradiction in efficacy.

Arthroscopy also played an important role in the treatment of ONFH in this study. Elevated intraosseous pressure can lead to ischemia and hypoxia of bone tissue, while synovial hyperplasia induces synovitis and increased intracapsular pressure. Mechanical symptoms resulting from labral tears and cartilage delamination, together with hip joint pain, are important contributing factors in ONFH [17-19]. Patients with ARCO stage IIIA ONFH exhibit varying degrees of synovitis and cartilage damage. Ignoring these secondary intraarticular pathological changes after ONFH can compromise surgical outcomes and the ability to delay disease progression [20,21]. In clinical practice, advances in imaging techniques such as MRI have improved the diagnosis of hip soft tissue injuries and ONFH, but arthroscopy remains the gold standard for diagnosing and treating intraarticular pathologies. However, arthroscopy alone has limited efficacy for ONFH. From a technical perspective, the hip joint has complex anatomy and limited operative space, and the learning curve for hip arthroscopy is long [22]. Moreover, arthroscopic examination and debridement are only suitable for relatively earlystage ONFH, and debridement alone does not address the underlying pathological process of osteonecrosis [23,24]. Clinically, some studies have shown that arthroscopy alone provides only limited pain relief and is associated with a considerable risk of complications [13,24]. Therefore, in this study, due to the clear limitations of arthroscopy alone for ONFH and ethical considerations, we did not include a control group treated

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Table 5. Common associated complications of ONFH and their clinical features, classification, and prognosis.

Common complications of ONFH	Clinical features	Categorization	Prognosis	Correlation with hip mobility
Osteoporosis	Femoral head trabeculae thin and blurred, prone to fracture.	Bone tissue lesions	Prognosis general	Related
Muscular atrophy	Mostly in gluteus maximus, quadriceps femoris, biceps femoris and vastus coeruleus, with reduced muscle strength.	Muscle tissue lesions	Poor prognosis	Related
Soft tissue adhesion	Visible narrowing of the joint space, hyperplasia, sclerosis, collapse.	Soft tissue lesion	Prognosis general	Height-related
Stiffness of joints	The phenomenon of loss of joint space has been observed in conjunction with the destruction of the femoral head shape.	Soft and bone tissue lesions	Poor prognosis	Height-related
Osteoarthritis of the hip joint	The clinical signs observed included joint stiffness, flexion, external rotation and internal deformity.	Soft and bone tissue lesions	Poor prognosis	Height-related

Abbreviation: ONFH, osteonecrosis of the femoral head. Sources: compiled from references [1,3].

with arthroscopy alone. Despite these limitations and ongoing controversy regarding arthroscopy alone for ONFH, arthroscopy remains a valuable adjunct in ONFH treatment. Under arthroscopic visualization, intraarticular pathologies can be identified and treated with greater precision and directness. Using shavers, lowtemperature plasma probes, and other probes, conditions such as synovial hyperplasia, intraarticular hemorrhage, cartilage damage, and labral tears can be addressed in a timely manner, providing a better microenvironment for bone tissue repair and remodeling [25,26]. Common associated complications of ONFH, including osteoporosis, muscle atrophy, soft tissue adhesion, joint stiffness, and secondary osteoarthritis, are summarized in **Table 5**. In this study, arthroscopic exploration and debridement of the hip joint were performed to improve the intraarticular environment, thereby creating a more stable and favorable microenvironment for the absorption and repair of necrotic tissue, delaying cartilage degeneration and destruction, correcting soft tissue injury, promoting pain relief and functional improvement, and ultimately delaying the progression of ONFH.

This study has several limitations. First, it was a retrospective, non-randomized analysis, which may have introduced selection bias. Second, the sample size, particularly for the triangular group, was relatively small. Third, patients were allocated based on surgeon preference and patient choice. Fourth, follow-up duration varied, which may have influenced survival estimates. Fifth, bilateral hips were included, and although mixed-effects models were used, residual within-patient correlation may remain. Finally, no multivariable adjusted analysis was performed; therefore, findings should be interpreted as unadjusted associations. Future prospective multicenter studies with larger cohorts and standardized imaging assessments are needed. Additionally, the main methodological limitation is the nonrandomized, retrospective design, which may have introduced selection bias despite statistical adjustments. The use of mixedeffects models cannot fully eliminate confounding by indication.

Conclusions

Hip arthroscopy combined with triangular drilling and suction decompression was associated with better short to midterm pain relief, functional improvement, and femoral head survival in ARCO stage IIIA ONFH compared with standard drilling alone, although the operative time was longer. These findings should be interpreted as unadjusted associations, and further prospective multicenter studies are needed.

Acknowledgments

During the preparation of this manuscript, the authors used DeepSeek for language polishing and grammar checking. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the final version of the manuscript.

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Data Availability

All data in this study were obtained from the experiments. The data used and analyzed in this study are available from the corresponding author upon reasonable request.

Department and Institution Where Work Was Done

Department of Bone and Joint, the Affiliated Traditional Chinese Medicine Hospital, Southwest Medical University, Luzhou, Sichuan, PR China.

Ethic Statement

All methods and procedures used in this study were in accordance with the relevant guidelines and regulations (Declaration of Helsinki).

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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