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A retrospective comparison of hyperbaric oxygen and core decompression for mild to moderate avascular necrosis of the femoral head

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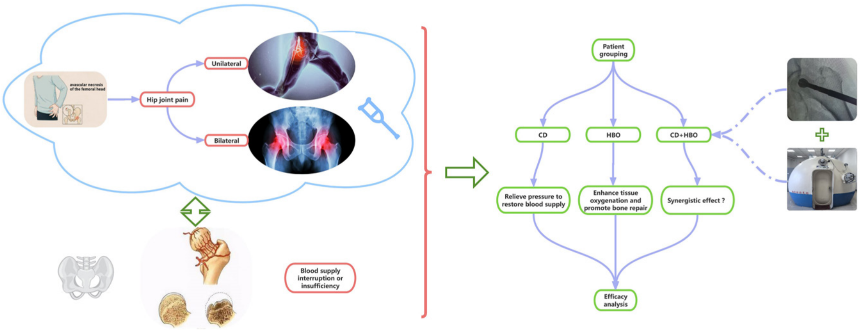
From the Contents

Graphical Abstract

Symptoms, main causes, and comparison of HBO and CD for ANFH treatment.



Abstract

Avascular necrosis of the femoral head is a condition resulting from disrupted blood supply, leading to ischemia and bone tissue necrosis. Core decompression (CD) restores the blood supply through pressure relief, whereas hyperbaric oxygen (HBO) enhances tissue oxygenation and promotes bone repair. Their combined use may complement each other in improving blood supply, promoting bone healing, and inhibiting disease progression, thus achieving a better therapeutic effect. To assess and compare the efficacy of HBO and/or CD for treating mild to moderate femoral head avascular necrosis, a retrospective study was conducted on patients diagnosed with Ficat stage II non-traumatic osteonecrosis between January 2017 and January 2022 at the Affiliated Central Hospital of Shenyang Medical University, China. A total of 72 patients were divided into HBO, CD, and combination groups, with 24 patients in each group. After 1 year of follow-up, 90% of patients in the HBO group, 85% in the CD group, and 95% in the combination group showed satisfactory improvements in hip joint function. The SF-36 quality of life questionnaire scale scores also significantly improved in all three groups, with the combination group showing the most significant improvement. These findings suggest that HBO offers promising potential for treating non-traumatic femoral head necrosis, with efficacy similar to that of CD. The combination group showed the most significant improvement in both hip joint function and quality of life.

Key Words: clinical practice; combination therapy; core decompression; efficacy; Ficat classification; hip joint function; hyperbaric oxygen therapy; non-invasive treatment; non-traumatic femoral head necrosis; quality of life

Introduction

Avascular necrosis of the femoral head (ANFH) is a potentially severe disabling condition that significantly impacts hip joint function and quality of life. The pathogenesis of this disease is complex and involves several known risk factors, such as long-term use of corticosteroids, alcohol abuse, smoking, trauma, and metabolic diseases.[1-5] As a progressive and degenerative joint disease, femoral head necrosis is widely recognized as an important precursor to hip osteoarthritis.[6,7] As the disease progresses, the blood supply to the femoral head is compromised, leading to gradual bone collapse, which results in the progressive loss of hip joint function. This severely affects daily activities and causes intense pain and discomfort for patients. Therefore, early diagnosis and timely intervention are the key to improving patient prognosis, particularly in the early stages when the femoral head has not yet collapsed. Performing hip joint-preserving surgery at this stage can significantly improve the success rate of treatment, delay disease progression, and greatly enhance the patient's quality of life.[8,9]

Core decompression (CD) has long been considered the classic joint-preserving treatment for pre-collapse femoral head necrosis. This procedure works by reducing intraosseous pressure, restoring blood flow dynamics, and promoting bone repair, which can effectively delay or prevent femoral head collapse and even halt further deterioration.[10,11] In patients with Ficat stage I–II femoral head necrosis, CD has good clinical outcomes, with many patients able to delay or avoid the need for joint replacement surgery. However, some patients still face the risk of disease progression post-surgery, suggesting

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that single-treatment approaches may have limitations when addressing the complex pathological mechanisms of femoral head necrosis.[12,13] Therefore, exploring alternative treatment methods or combined treatment strategies has become an effective way to improve treatment outcomes and reduce disease progression.[14]

In recent years, hyperbaric oxygen (HBO) therapy has gained attention in the orthopedic field as a non-invasive treatment option. Research has shown that HBO therapy, by increasing local oxygen partial pressure and improving the bone microenvironment, can effectively reduce intraosseous pressure, alleviate bone edema, promote venous return, and stimulate angiogenesis, thereby providing significant support for femoral head repair.[15-19] Animal studies and clinical research have demonstrated the significant efficacy of HBO therapy in treating femoral head necrosis, promoting bone healing, and improving local ischemia.[20-27] Furthermore, HBO therapy has been successfully applied in the treatment of various related conditions, such as poor wound healing, tissue ischemia, and musculoskeletal injuries.[28-30] However, systematic and validated comparative studies on the role of HBO therapy in treating femoral head necrosis, particularly its effects on pain relief, functional improvement, and disease progression, are still lacking.[31] Additionally, whether HBO therapy combined with CD can produce a synergistic effect to further optimize treatment outcomes remains an important question to explore.

Based on the above background, this study aims to systematically evaluate the clinical efficacy and radiographic changes of HBO, CD, and their combination in patients with Ficat stage II non-traumatic femoral head necrosis. By comparing the efficacy of different treatment strategies, we aimed to reveal the differences between the treatment methods and explore whether combined therapy can produce a synergistic effect. These findings provide scientific evidence for optimizing treatment plans and improving patient outcomes and prognoses. We will further analyze the impact of different treatment methods on hip joint function improvement, pain relief, and disease progression, providing new insights into future treatment strategies for non-traumatic femoral head necrosis.

Methods

Subjects

A retrospective analysis was conducted on 120 patients with non-traumatic femoral head necrosis who were hospitalized at the Affiliated Central Hospital of Shenyang Medical University between January 2017 and January 2022. Based on inclusion and exclusion criteria, a total of 72 patients with Ficat stage II (graded as mild to moderate injuries) femoral head necrosis were included and divided into three groups (n = 24 per group): HBO group, CD group, and combination group. In cases of bilateral involvement, both sides were treated simultaneously, but only the right hip joint was evaluated before and after treatment to reduce bias.

The inclusion criteria were as follows: (1) patients who were diagnosed with non-traumatic osteonecrosis of the femoral head and classified as Ficat stage II[32] and (2) patients aged 20 to 65 years with fully mature skeletal development.

The exclusion criteria were as follows: (1) patients with rheumatic or rheumatoid diseases, such as rheumatoid arthritis or systemic lupus erythematosus, to eliminate the interference of immune-related diseases in the progression and treatment outcomes of osteonecrosis of the femoral head; (2) patients who previously received intra-articular injections or underwent other joint surgeries, such as hyaluronic acid, corticosteroid, or platelet-rich plasma injections, as well as prior hip surgeries (e.g., hip arthroscopy); and (3) patients with trauma-induced osteonecrosis of the femoral head, such as osteonecrosis secondary to severe hip fractures or hip dislocations.

This study was approved by the Medical Ethics Committee of the Affiliated Central Hospital of Shenyang Medical University (approval No. Ke-2017-207 (02); on January 1, 2017), and informed consent was obtained from all patients and their families. This study was performed in accordance with the *Declaration of Helsinki* developed by the World Medical Association.

Preparation and management

Before treatment, all patients were assessed for Ficat staging, and baseline data were collected via the Oxford Hip Score (OHS) and the Short From-36 (SF-36) quality of life questionnaire scale (SF-36). The CD and combination groups underwent preoperative examinations, including biochemical tests and cardiopulmonary function assessments. Thirty minutes prior to surgery, all patients received a single dose of intravenous cefazolin (1 g; Shijiazhuang Zhongnuo Pharmaceutical Co., Ltd. of the CSPC Group, Shijiazhuang, China) for infection prevention. The Ficat stage was evaluated by a radiologist and three orthopedic surgeons based on X-ray, computed tomography, and magnetic resonance imaging images.

Treatment

Core decompression surgery

All surgeries were performed by the same team of experienced orthopedic surgeons. The patient was positioned supine on a traction table and received either spinal anesthesia or general anesthesia. A 2 cm lateral incision was made for the hip joint approach. The surgeon, wearing a lead apron, performed the procedure with the assistance of a C-arm X-ray machine. The steps included locating the area, creating an access channel, gradually scraping out necrotic tissue with a reamer, and completing femoral head decompression using a curette. The area was then irrigated with normal saline, and beta-tricalcium phosphate (Beijing Xinkangchen Medical Technology Development Co., Ltd., Beijing, China) was used to fill the lesion area for compaction (**Figure 1**).

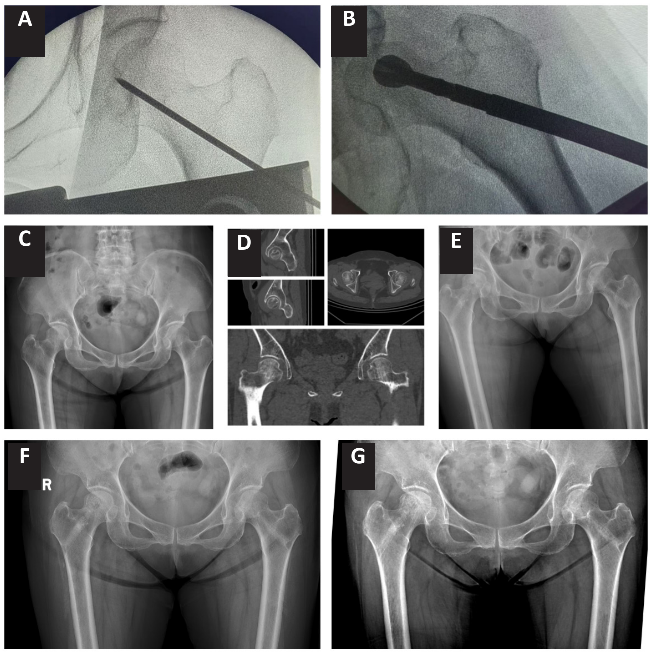

Figure 1 | Treatment progress of a patient in the combination group.
The 50-year-old patient was male, had Ficat stage II disease, a BMI of 22.5 kg/m^2, a baseline OHS score of 27, and an SF-36 score of 63. (A, B) Intraoperative fluoroscopic images. (C) Preoperative bilateral hip anteroposterior X-ray. (D) Preoperative CT scans, including axial, coronal, and sagittal views. (E) Bilateral hip anteroposterior X-ray on the first postoperative day. (F) Bilateral hip anteroposterior X-ray 1 month postoperatively. (G) Bilateral hip anteroposterior X-ray 3 months postoperatively. BMI: Body mass index; CD: core decompression; CT: computed tomography; OHS: Oxford Hip Score; R: right; SF-36: SF-36 quality of life questionnaire scale.

Hyperbaric oxygen therapy

Patients underwent a total of 36 sessions of HBO therapy, with three treatments per week to minimize the risk of oxygen toxicity. The treatment protocol (**Table 1**) was designed and administered by specialized physicians from the HBO Department.

For the combination group, HBO treatment began the day after CD surgery, following the second postoperative dressing change.

Postoperative management and follow-up

At 30 minutes after surgery, patients received a single intravenous antibiotic preoperatively for infection prevention. Active range-of-motion exercises for the knee and hip joints were encouraged. Patients were allowed to gradually increase their weight-bearing activities, starting with protective weight-bearing for at least 6 weeks, followed by partial weight-bearing for another 6 weeks. Full weight-bearing was permitted 12 weeks after surgery.

Clinical follow-up was scheduled at 12 months post-surgery, during which X-rays were taken to assess the imaging results.

Clinical efficacy evaluation

Hip joint function assessment

The OHS was used to evaluate hip joint function before and after treatment in the three groups.[33] The OHS consists of 12 items, each assessing the patient's subjective perception of pain, activity limitation, and daily function. The score for each item ranges from 0 to 4, with a total score ranging from 0 to 48. A higher score indicates better hip joint function and a higher quality of life for the patient.

SF-36 quality of life questionnaire

The SF-36 includes eight dimensions: physical functioning, role limitations due to physical health, bodily pain, general health, social functioning, emotional well-being, and mental health. The total score of these dimensions represents the overall score of the questionnaire.[34] A high score indicates better health status and higher quality of life.

Patient satisfaction

Patient satisfaction was assessed based on clinical efficacy and functional recovery. A satisfactory clinical outcome was defined as an OHS of 30 or higher, indicating good hip joint function with minimal limitations in daily activities. Furthermore, patients who did not require additional pain management or surgical intervention were considered to have a successful treatment outcome, reflecting patient satisfaction with the treatment results.

Imaging progress evaluation

Imaging progress was primarily assessed through regular follow-up X-rays after treatment, and structural changes in the hip joint were observed. The Ficat grading system was used to evaluate imaging progression.[35] The Ficat classification is a classic method for assessing ANFH, reflecting disease progression or relief based on changes in imaging features, such as bone density abnormalities, joint space alterations, and the degree of collapse. If patients experienced significant pain exacerbation or restricted joint mobility during follow-up, higher resolution imaging, such as computed tomography or magnetic resonance imaging, was performed to assess bone details or early lesions.

Statistical analysis

Data analysis for this study was performed using GraphPad Prism (version 10.1.2 (Windows), GraphPad Software, Boston, MA, USA; www.graphpad.com). Descriptive statistics are presented as the means ± standard deviation (SD) for continuous variables and as frequencies and percentages for categorical variables. The normality of continuous variables was assessed using the Shapiro–Wilk test, and categorical variables were analyzed using the chi–square test.

For continuous variables that followed a normal distribution, comparisons among the three groups were made via one-way analysis of variance. Significant results ($P < 0.05$) were further analyzed using the Bonferroni *post hoc* test. For continuous variables that did not follow a normal distribution, inter-group comparisons were performed using the Kruskal–Wallis H test, with *post hoc* analysis conducted using the Dunn test. The significance level for all analyses was set at $P < 0.05$ to ensure the scientific rigor and validity of the data analysis.

Results

Baseline characteristics of patients

There were no statistically significant differences among the groups in terms of age, sex distribution, body mass index, hip joint involvement, follow-up duration, baseline OHS score, and SF-36 score ($P > 0.05$), indicating that the groups were comparable at baseline. The shortest follow-up duration was 19.10 ± 2.15 months. **Table 2** summarizes the baseline characteristics and follow-up information of the patients.

One-year follow-up outcomes

During the 1-year follow-up, the OHS and SF-36 scores improved significantly in all three groups ($P < 0.05$). The OHS score of the HBO group increased from a baseline of 26.50 ± 2.33 to 37.00 ± 3.20, and the SF-36 score improved from 58.50 ± 5.52 to 77.40 ± 4.41. The OHS score of the CD group increased from 25.95 ± 2.44 to 36.20 ± 4.40, and the SF-36 score improved from 55.85 ± 5.91 to 74.45 ± 4.98. The combination group's OHS score increased from 27.05 ± 1.70 to 38.75 ± 2.88, and the SF-36 score improved from 54.70 ± 5.15 to 78.15 ± 2.54.

After 1 year of treatment, the patients in each group presented varying OHS

Table 1 | The protocol of hyperbaric oxygen therapy

Phase	Duration	Description
Compression phase	5–10 min	The pressure was gradually increased to the target level of approximately 2.2 atmospheres to allow the patient to adjust.
Pure oxygen inhalation phase 1	30 min	The patient inhaled 100% oxygen through a tightly sealed, professional-grade face mask to enhance treatment efficacy.
Air rest phase	5–10 min	Pure oxygen inhalation was stopped, and the patient breathed regular air to reduce the potential risk of oxygen toxicity.
Pure oxygen inhalation phase 2	30 min	The patient resumed inhaling pure oxygen to reinforce the therapeutic effects.
Decompression phase	5–10 min	The pressure was gradually reduced back to normal atmospheric pressure, ensuring a smooth transition to avoid discomfort or complications.

Table 2 | Baseline data of patients in the three groups

	HBO	CD	Combination	*P*-value
Age (yr)	45.05±4.88	44.30±4.58	44.10±4.33	0.79
Sex (*n*)				0.93
Male	14	15	16	
Female	6	5	4	
BMI (kg/m²)	22.82±1.04	22.71±1.08	22.54±0.96	0.72
Affected side of hip joint				0.91
Unilateral	18	16	19	
Bilateral	6	8	5	
Total number of hip joint involvement	30	32	29	
Baseline OHS	26.50±0.52	25.95±2.44	27.05±1.70	0.18
Baseline SF-36	58.50±5.52	55.85±5.91	54.70±5.15	0.09
Follow-up time (mon)	19.10±2.15	20.05±2.24	19.65±2.13	0.388

Descriptive statistics are presented as the mean ± SD for continuous variables. Data on age, baseline SF-36 score, and follow-up time were analyzed via one-way analysis of variance followed by the Bonferroni *post hoc* test, and data on BMI and baseline OHS were analyzed via the Kruskal–Wallis H test followed by the Dunn test. Data on the affected side of the hip joint and total number of hip joints involved were analyzed via the chi–square test. BMI: Body mass index; CD: core decompression; HBO: hyperbaric oxygen therapy; OHS: Oxford Hip Score.

and SF-36 scores, satisfaction, and radiographic progression. The OHS scores in the combination group were significantly higher than those in the HBO group and the CD group (both $P < 0.05$), indicating that combination therapy was slightly more effective in improving hip joint function. The SF-36 scores were significantly different among the three groups ($P = 0.0038$), with the combination group having the highest score, followed by the HBO group and the CD group.

The patient satisfaction rates were 95% (19 satisfied patients) for the combination group, 90% (18 satisfied patients) for the HBO group, and 85% (17 satisfied patients) for the CD group. However, no statistically significant difference was found ($P = 0.86$). Radiographic progression showed that the combination group had the highest no-progression rate (90%, 18 patients with no progression), followed by the HBO group (80%, 16 patients with no progression) and the CD group (75%, 15 patients with no progression), but the differences between the groups were not statistically significant ($P = 0.59$).

Discussion

ANFH is a complex and progressive bone disease, and its core pathological mechanism is impaired local blood supply, leading to osteocyte necrosis, trabecular collapse, and loss of joint function.[4,6] The pathogenesis involves multiple factors, including thrombosis, fat embolism, vascular dysfunction, and increased intramedullary pressure. These pathological changes interact with and accelerate the irreversible progression of the disease.[7,36,37] Therefore, understanding its pathophysiology is crucial for developing more effective treatment strategies.[38]

The treatment goals for ANFH currently focus on pain relief, maintaining femoral head stability, delaying disease progression, and avoiding or postponing the need for total hip arthroplasty.[39] Treatment options are divided into surgical and non-surgical categories, with CD being the traditional hip-preserving surgery for early ANFH. CD improves the local blood supply by reducing intraosseous pressure, resulting in a high success rate.[8,14] Additionally, non-surgical treatments such as HBO, pulsed electromagnetic fields, and extracorporeal shock wave therapy are increasingly gaining attention due to their minimal invasiveness, high repeatability, and good patient compliance. These methods improve local microcirculation, promote angiogenesis, and aid in bone tissue repair, indicating promising potential.[40-43] Notably, HBO has been widely used in orthopedic treatments for various conditions, including wound healing, delayed bone healing, bone necrosis, tissue ischemia, and musculoskeletal injuries.[20,21,44-48] A study has shown that HBO does not cause significant changes in blood rheological parameters, suggesting that HBO does not pose any issues for patients.[49] HBO enhances the oxygen supply, improves the hypoxic environment, alleviates oxidative stress, and promotes local blood circulation.[50,51] It increases the solubility of oxygen in the blood, aiding in tissue repair. It also regulates osteoblast function, promoting bone repair and regeneration. Additionally, HBO exerts immunomodulatory effects, reducing inflammation and stimulating angiogenesis to improve the tissue blood supply, further enhancing healing.[17,52-62] Therefore, as a non-invasive treatment, HBO has shown great potential in clinical practice and has become an adjunctive treatment for many orthopedic diseases.

ANFH is a progressively deteriorating pathological condition, and as the disease progresses, damage to the function and structure of the femoral head becomes difficult to reverse. Early diagnosis and intervention are critical for delaying disease progression and improving treatment outcomes. Studies have shown that early CD in Ficat stage I and II patients has a success rate of 70–80%, significantly outperforming late interventions.[63] This finding underscores the importance of early treatment.[64]

Our study systematically compared the efficacy of HBO, CD, and their combination for early ANFH treatment. The results revealed that all three treatments significantly improved patients' function and quality of life, with similar effectiveness. After 1 year of follow-up, the OHS score in the combined treatment group was slightly higher than that in the HBO and CD groups, but the difference was only near statistical significance ($P = 0.05$). The SF-36 score was better in the combined treatment group than the HBO and CD groups ($P = 0.0038$).

Radiographic evaluation revealed that during the follow-up period, 90% of patients in the combined treatment group experienced no disease progression, which was slightly higher than that in the HBO group (80%) and the CD group (75%), but the difference did not reach statistical significance ($P = 0.59$). Additionally, the combined treatment group had the highest patient satisfaction (95%), but this improvement might be due to higher patient expectations of the combined treatment rather than a significant therapeutic advantage. Overall, our study demonstrated that HBO, CD, and combined treatment are effective options for early ANFH treatment. While the combined treatment showed some superiority, it was not significantly better than the other single therapies. This study confirms the importance of HBO in preserving the hip joint during ANFH treatment.

Although this study provides valuable preliminary evidence, there are several limitations. First, the relatively small sample size may limit the generalizability of the results. Second, the follow-up period was short and may not fully reflect long-term efficacy. Third, the study was retrospective, which could involve potential confounding factors. Additionally, the high cost and frequent treatment cycles of HBO may affect patient compliance. To address these limitations, future large-scale, multicenter, randomized controlled trials should be designed to validate these findings and further optimize treatment strategies.

Future research should further explore the synergistic effects of various treatment strategies, especially combining non-invasive therapies (such as HBO, platelet-rich plasma, pulsed electromagnetic fields, and extracorporeal shock wave therapy) with minimally invasive surgeries.[65,66] These technologies not only have good safety profiles but can also target the disease's multifaceted pathophysiology, optimizing treatment outcomes. Furthermore, research should focus on the combination of HBO with other innovative therapies, clarifying their best applicability in different disease stages. Additionally, a thorough evaluation of the long-term efficacy and cost-effectiveness of these therapies could offer more personalized treatment options for patients.

This study demonstrated that HBO shows promising potential in the treatment of non-traumatic ANFH, with its efficacy comparable to that of CD treatment. The combined treatment of HBO and CD has certain advantages in improving functional outcomes and quality of life in patients with early-stage non-traumatic ANFH. Future research should further explore multimodal combination treatment strategies, integrating non-invasive and minimally invasive approaches to promote personalized and precise treatment for femoral head necrosis to improve the long-term prognosis of patients. Incorporating HBO into future clinical studies may offer additional support for the clinical management of various pathological conditions, but further validation through higher-level, large-scale prospective trials is needed.

This study not only provides new theoretical foundations for the individualized treatment of femoral head necrosis but also lays the scientific groundwork for optimizing clinical decision-making, advancing the field of non-traumatic femoral head necrosis treatment. Through this research, we hope to provide clinicians with more scientific evidence to help them select the most appropriate treatment plan based on the patient's specific condition. By choosing precise individualized treatments, we aim to improve hip joint function, delay the progression of femoral head necrosis, and ultimately enhance the patient's quality of life. We believe that the findings from this study will provide new theoretical support for femoral head necrosis treatment and offer scientific guidance for developing more effective clinical treatment plans, thereby advancing the field of femoral head necrosis treatment.

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Conflicts of interest: *The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.*
Data availability statement: *The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.*

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