BMC Musculoskeletal Disorders

RESEARCH

Open Access

# Partial femoral head replacement: a new innovative surgical technique for precise minimally invasive treatment of association research circulation osseous stage III femoral head necrosis

Tianyu Wang[1,2†], Zhongzheng Wang[1†], Yuchuan Wang[1†], Changhui Li[1], Yining Lu[1], Yanbin Zhu[1], Wei Chen[1], Xuebin Zhang[1] and Yingze Zhang[1,2*]

## Abstract

**Background** Association Research Circulation Osseous (ARCO) stage III is the last chance for joint preservation in patients with osteonecrosis of the femoral head (ONFH). As the femoral head has collapsed at this stage, existing hip-preserving surgical treatments show limited success. We aimed to introduce a new surgical technique called partial femoral head replacement for the treatment of ARCO III femoral head necrosis and to evaluate its safety and efficacy.

**Methods** Between November 2022 and December 2022, 11 symptomatic hips from 11 patients were enrolled in this retrospective study. The surgeon precisely removed the necrotic area of the femoral head through a bone tunnel at the femoral neck and implanted a prosthesis that matched each patient's anatomy and femoral head contour. Details of the demographics, surgical information, imaging findings, and any complications were retrospectively collected. Clinical scores, including the visual analogue scale (VAS) score, Harris Hip Score (HHS), and 12-Item Short-Form Health Survey (SF-12) scores, were determined. Each patient was followed for at least one year.

**Results** The mean operative time per hip was 57.27 ± 15.23 min, the mean estimated blood loss was 110 ± 60.62 ml, and the mean incision length was 3.35 ± 0.38 cm. The VAS score at the one-year follow-up showed great pain relief (7.5 ± 0.9 vs. 1.6 ± 1.2, $P < 0.01$). The HHS improved significantly compared to the preoperative score (90.3 ± 3.7 vs. 42.9 ± 4.4, $P < 0.01$). The SF-12 scores also showed that all patients experienced varying degrees of physical (42.1 ± 5.1 vs. 27.7 ± 7.1, $P<0.01$) and mental (44.3 ± 4.7 vs. 36.4 ± 3.8, $P<0.01$) health improvement. Radiologically, there were no abnormalities on the latest imaging examination. Clinically, no serious postoperative complications occurred during the treatment.

†Tianyu Wang, Zhongzheng Wang and Yuchuan Wang contributed equally to this work and should be regarded as co-first authors.

*Correspondence:
Yingze Zhang
yzling_liu@163.com

Full list of author information is available at the end of the article

**Conclusions** Our preliminary clinical results showed that partial femoral head replacement was a safe and effective method for the treatment of ARCO III femoral head necrosis. With the trend of younger ONFH patients and increasing emphasis on hip preservation, partial femoral head replacement may provide a new minimally invasive hip-preserving option for these patients.

**Keywords** Osteonecrosis of the femoral head, Association research circulation osseous (ARCO) stage III, Partial femoral head replacement, Minimally invasive treatment

## Introduction

Osteonecrosis of the femoral head (ONFH) is a refractory and disabling orthopaedic disease mainly affecting those aged 30–50 years [1, 2]. To date, ONFH has become a serious global health problem, and it is estimated to affect more than 20 million people worldwide [3–5]. In the absence of effective intervention, approximately 94% of asymptomatic patients will develop symptomatic ONFH within 5 years and finally end up with the occurrence of subchondral collapse, severe destruction of the hip joint and loss of mobility, which places serious physical, mental, and financial burdens on family and society [2]. Based on the newly released updated version of Association Research Circulation Osseous (ARCO) staging system, multiple clinical guidelines have achieved consensus on the treatment plans for ONFH [6]. However, the current management of ONFH patients in ARCO stage III remains controversial and challenging [7, 8].

ARCO stage III is a stage that necrotic area of the femoral head has developed stubborn collapse. At this stage, conservative treatments such as the use of pharmacological agents, physical therapy, and protected weight bearing have been proven to be hardly successful [7, 9, 10]. Clinically, surgical treatment remains the mainstay. Traditional hip-preserving surgeries, including core decompression, vascularized or nonvascularized bone grafting, tantalum rod therapy, and osteotomy, etc., aim to restore blood supply to or remove the necrotic area. However, a lot of studys suggest that these techniques can only achieve satisfactory results in pre-collapse stages of ONFH [11–13]. Although total hip arthroplasty (THA) is generally associated with pain relief and mobility improvement at the collapse stage, the major trauma and a large number of potential complications cannot be ignored. Moreover, when performed in younger, highly active patients, THA often requires at least one revision due to common issues like aseptic component loosening, prosthesis wear, and periprosthetic joint infection [14, 15]. In recent years, with the trend of younger ONFH patients, the importance of hip-preserving surgery has been more and more frequently stressed [16]. Thus, it is quite necessary to find a reliable hip-preserving surgery that can effectively treat the collapsed area of ARCO III femoral head necrosis and delay or even stop the progression of the disease.

Based on this, our team innovatively performs a new minimally invasive hip-preserving surgery named "partial femoral head replacement" for ARCO stage III patients. Using this technique, the necrotic area of the femoral head is precisely removed through a bone tunnel at the femoral neck. A specially designed prosthesis is then implanted according to the anatomical curvature of each patient's femoral head to provide biomechanical support. In our previous study, we have confirmed the reliable stability of this structural support using finite element analysis and individual cases [17, 18]. The aim of this study is to introduce this new technique in detail and report the preliminary results to confirm its safety and efficacy.

## Materials and methods

### Participants

This retrospective study was approved by the ethics committee of the Third Hospital of Hebei Medical University. All methods conformed to the ethical standards of the Declaration of Helsinki from 1964. This study included 11 hips of 11 patients (3 females, 8 males) who were treated with partial femoral head replacement by the same senior surgeon from November 2022 and December 2022. The above patients who were selected met the following criteria: (1) 18 to 50 years old; (2) ARCO stage III (IIIA and IIIB) in the weight-bearing zone of the femoral head; (3) strong desire for hip-preserving surgery; (4) written informed consent; (5) at least 12 months of follow-up; and (6) complete imaging data, including preoperative, immediate postoperative and follow-up X-rays, preoperative and final follow-up computed tomography (CT) scans, and magnetic resonance imaging (MRI) scans.

### Preoperative Preparation

Preoperative CT and MRI data were used to identify the necrotic area of the femoral head(Fig. 1a, b). Images of patients' the femoral head were obtained through CT scan and saved in Digital Imaging and Communications in Medicine (DICOM) format. And imported them into Materialise Interactive Medical Image Control System (MIMICS) to reconstructe the femoral head and the precise location of the ischemic areas and acquire their three-dimensional (3D) informations. A 3 mm K-wire was inserted 1 cm above the lesser trochanter of the femur on the model, directed towards the centre of the area of femoral head necrosis. On this basis, a 20 mm

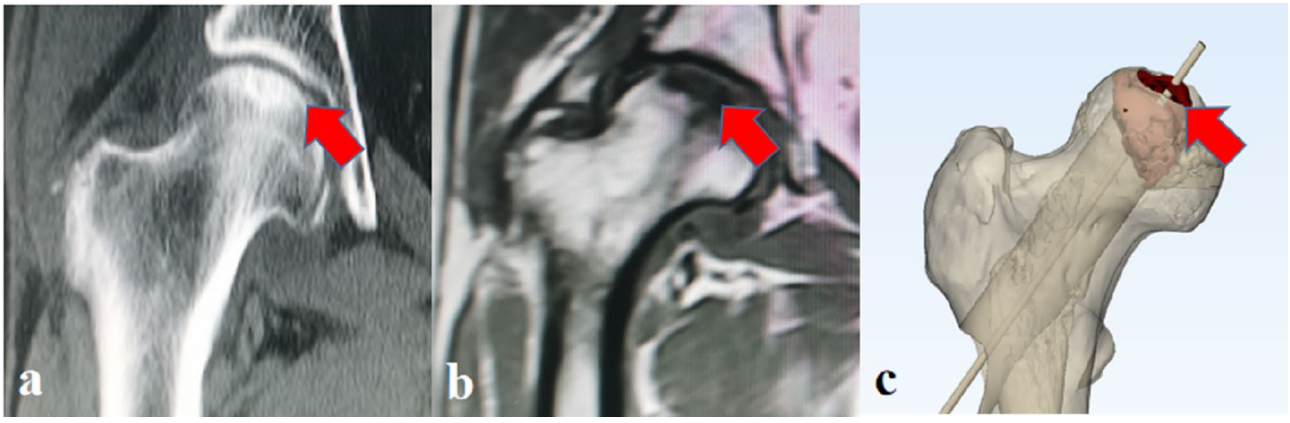


**Fig. 1** A 44-year-old woman with ARCO stage III of the right hip. **(a)** The preoperative CT. **(b)** The preoperative MRI. **(c)** The 3D reconstruction

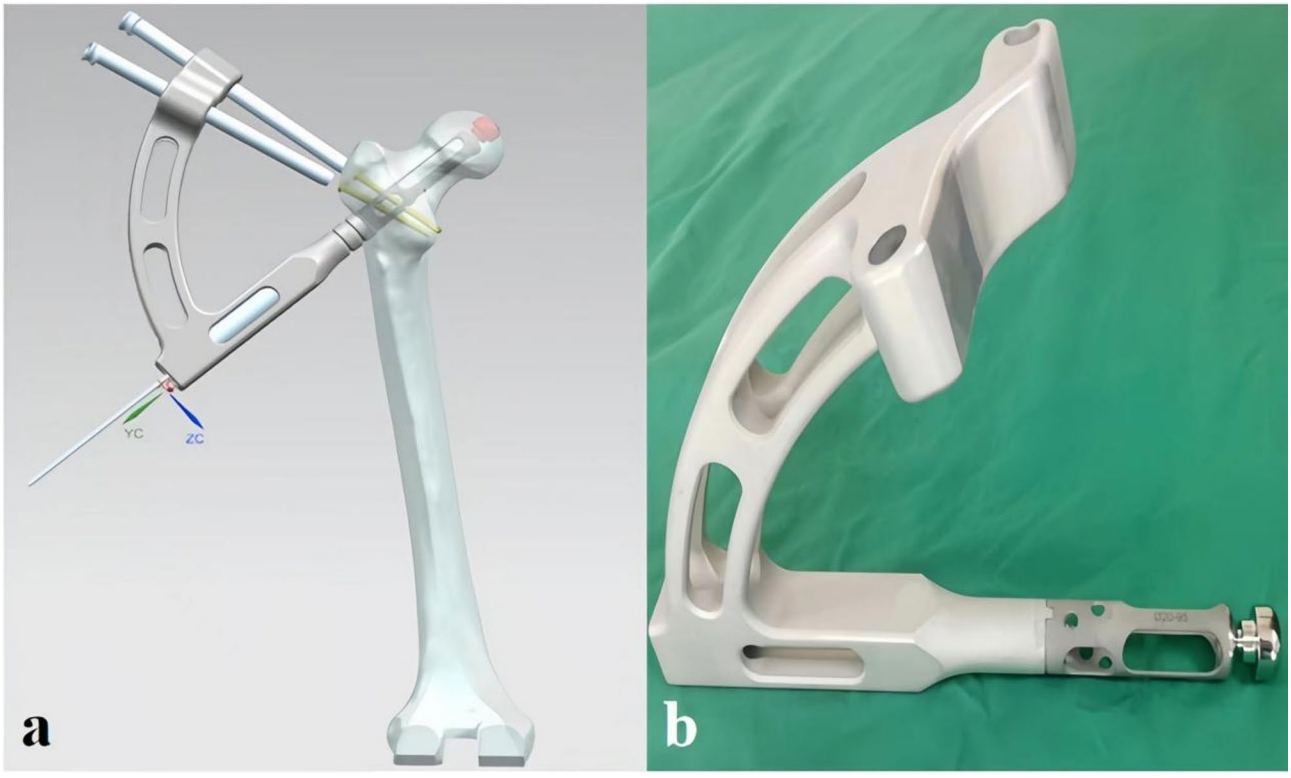


**Fig. 2** The design scheme of the ancillary tool of partial femoral head replacement. (**a**) The model figure of the ancillary tool. (**b**) The physical view of the ancillary tool

diameter bone tunnel centred on this K-wire towards an antero-superior segment of the head was then designed (Fig. 1c). The segmentation module in Mimics was used to calculate the profile curve of the femoral head in the bone tunnel, and a prosthesis matching the patient's original anatomy was then designed according to the profile curve. Auxiliary tools were designed to simplify the surgical procedure, including fixators for screws and an implant delivery system (Fig. 2a, b). The prosthesis, consisting of a head, stem, and closure cap, was made of titanium alloy (Ti6Al4V) material (Fig. 3a, b, c).

### Surgical procedures

Patients were operated on under general anaesthesia, as monitored by the anaesthesiologist on the side. With the patient in a horizontal position, the lower limb was placed under traction using a traction bed to enlarge the hip space significantly, widening it by approximately 5 mm (Fig. 4a). With the aid of C-arm fluoroscopy, a 3-mm-diameter K-wire was inserted 1 cm above the lesser trochanter of the femur, directed towards the centre of the area of femoral head necrosis, and confirmed by anteroposterior and lateral radiographs. After the

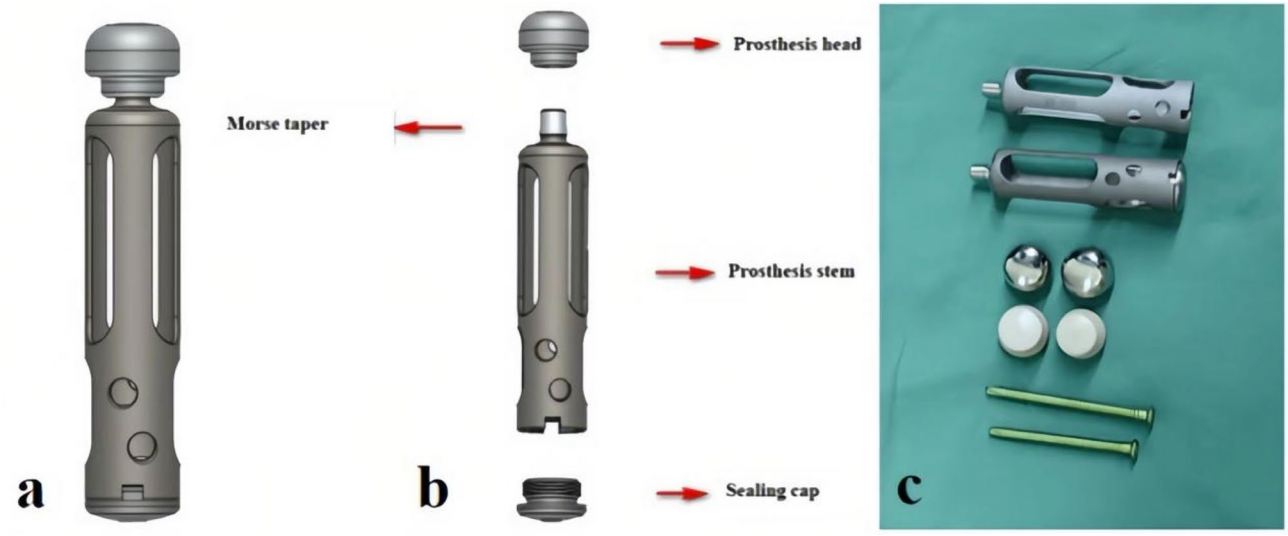


**Fig. 3** The design scheme of the prosthesis of partial femoral head replacement. **(a)** The model figure of the prosthesis. **(b)** The compositions of the prosthesis. **(c)** The physical view of the prosthesis

K-wire reached the predetermined osteonecrotic area, an approximately 3-cm-long skin incision was made; subcutaneous fascia and muscle were carefully cut layer by layer until reaching the bone. The trephine was then placed in the same direction as the K-wire and gradually pushed inwards (Fig. 4b). After drilling through the collapsed femoral head, the bone column, which showed markedly degenerated and collapsed articular cartilage and relatively good-quality cancellous bone, was removed (Fig. 4c). Irrigation was used to clean up the hip joint.

The cancellous bone, containing mesenchymal stem cells, stromal cells, and blood cells, was cut into small fragments and inserted into the prosthesis stem through the bottom hole (Fig. 4d). The prosthesis was then pushed down in the direction of the bone tunnel (Fig. 4e). At this point, the widened joint gap allowed the head of the prosthesis to be slightly higher than the cartilage of the femoral head (Fig. 4f). The traction force was gradually reduced until the acetabulum pressed against the prosthesis and the head of the prosthesis matched the curvature of the articular surface (Fig. 4g). C-arm fluoroscopy was used to confirm correct positioning of the prosthesis, and arthroscopy was used to confirm that the surface of the prosthesis head matched well with the remaining articular cartilage of the femoral head. Two crossed screws were placed along the interrotor direction to fix the prosthesis (Fig. 4h). The surgery was completed after closing the incision (Fig. 4i).

### Postoperative management and evaluations

Prophylactic antibiotics were administered perioperatively and continued for 24 h. Thromboprophylaxis with third-generation low-molecular-weight heparin was administered at 12 h postoperatively and continued for two weeks. After the surgery, all patients followed the same rehabilitation and training program. They walked with two crutches with no weight-bearing on the affected limb for the first one months and exercised regularly in bed to prevent thrombosis, muscle atrophy, and osteoporosis. The patients were then allowed to walk with a single crutch for the next two to three months depending on radiographic evidence of bone healing. Three months later, the patients were allowed to walk without assistance. Follow-up examinations were scheduled at one, three, six, and twelve months and then once every a year thereafter.

Surgical efficacy was evaluated according to hip joint survival, postoperative imaging findings, and clinical scores (visual analogue scale (VAS) score for pain, Harris Hip Score (HHS) for hip function, and 12-Item Short-Form Health Survey (SF-12) scores for quality of life). The VAS score was divided into five grades, with 0 indicating no pain, 1–3 indicating mild pain, 4–6 indicating moderate pain, 7–9 indicating severe pain, and 10 indicating the worst pain imaginable [19]. The HHS was divided into four grades: excellent (HHS > 90), good (HHS = 80–90), average (HHS = 70–80), and poor (HHS < 70) [20]. The SF-12 Health Survey included two major items, i.e., physical health and mental health scores [21]. These assessments were carried out both preoperatively and postoperatively on all 11 hips in 11 patients and by three researchers to reduce personal bias. Any complications during treatment or follow-up were accurately recorded.

### Statistical analysis

Descriptive statistics were used to summarize the patients' demographic and operation-related data. Data are presented as the mean and standard deviation.

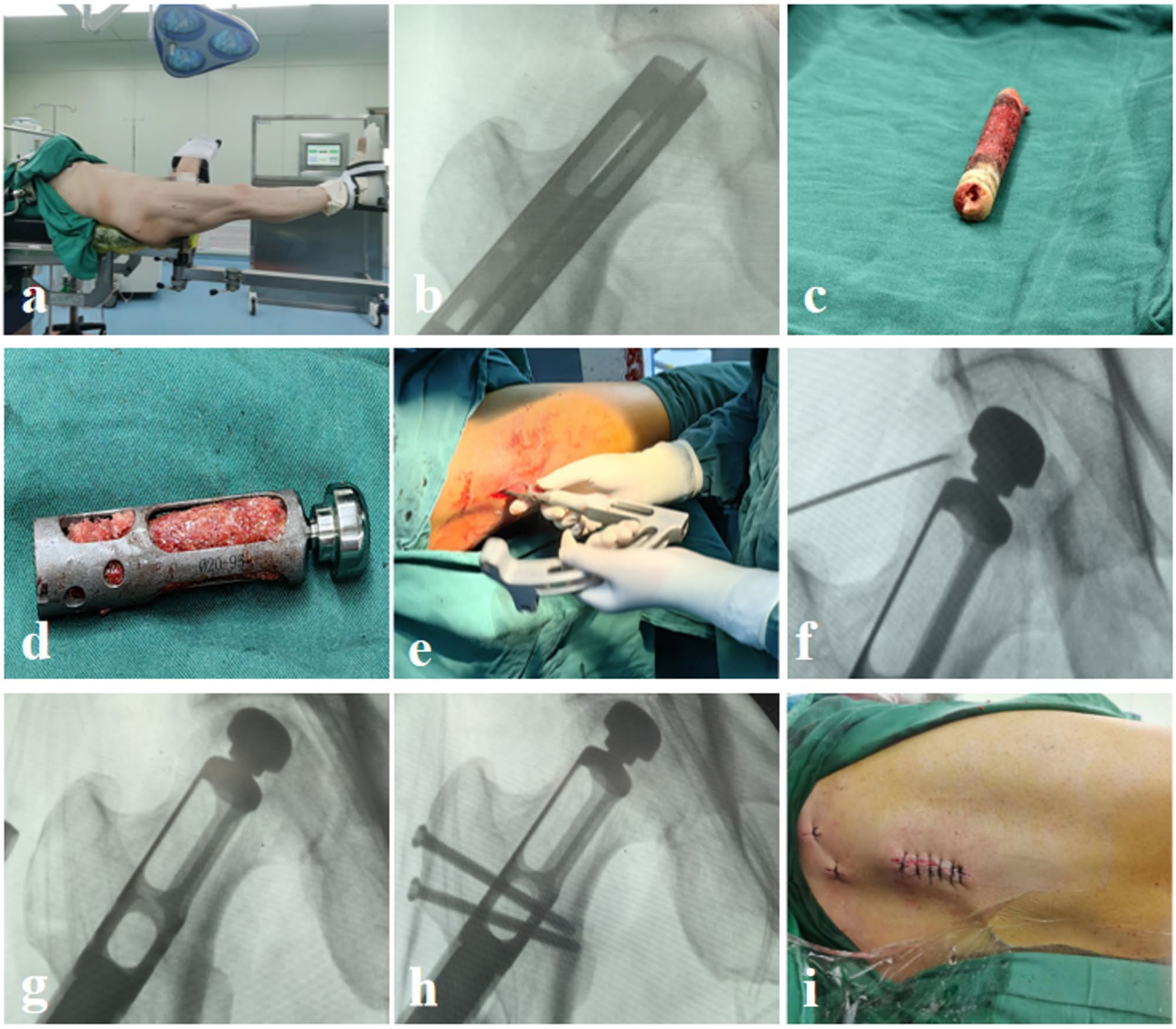


**Fig. 4** **(a)** The patient positioning. **(b)** The insertion of guide. **(c)** The bone column. **(d)** The combination of autologous cancellous bone. **(e)** The prosthesis implantation. **(f)** The determination of prosthesis position. **(g)** The relaxation of traction. **(h)** The fixation of the prosthesis. **(i)** The closed incision

Statistical analyses were performed using the Wilcoxon test and Spearman correlation test, for comparison between preoperative and postoperative values and for correlation of VAS, HHS, and SF-12 scores, respectively. The statistical significance was determined at p value < 0.05. All statistical analyses were conducted with the Statistical Package for Social Sciences (SPSS) software (version 26.0, Chicago, USA).

## Results

### General information

A total of 11 patients (11 hips) were included in this study. Of all patients, 3 were female and 8 were male, with a mean age of 41.2 years. The aetiologies of osteonecrosis were alcohol abuse in 4 patients, corticosteroid use in 1 patient, and previous trauma in 2 patients, and ONFH was idiopathic in 4 patients. According to the ARCO classification, the preoperative imaging data showed 6 hips in stage IIIA and 5 hips in stage IIIB. All patients suffered from varying degrees of pain, movement disorders, and reduced quality of life. The detailed characteristics of the patients are shown in Table 1.

### Clinical outcomes

Table 2 details the surgical characteristics and final follow-up clinical scores of the 11 patients. The mean operative time per hip was 57.27 ± 15.23 min, the mean estimated blood loss was 110 ± 60.62 ml, and the mean incision length was 3.35 ± 0.38 cm. Patients continued to follow up for a minimum of 12 months. The VAS scores

**Table 1** Patient characteristics preoperatively

| NO. | Age (years) | Sex (M/F) | Risk factors | Collapse side | ARCO stage | Preoperative VAS | Preoperative HHS | Preoperative SF12 PCS | Preoperative SF12 MCS |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 37 | Male | Alcohol | Right | IIIA | 8 | 41 | 25.4 | 42.4 |
| 2 | 46 | Male | Idiopathic | Right | IIIA | 7 | 46 | 25.4 | 32.0 |
| 3 | 54 | Female | Traumatic | Right | IIIB | 8 | 49 | 21.7 | 34.0 |
| 4 | 45 | Male | Alcohol | Right | IIIB | 6 | 43 | 35.9 | 37.4 |
| 5 | 41 | Male | Idiopathic | Right | IIIA | 9 | 35 | 19.8 | 37.2 |
| 6 | 32 | Male | Idiopathic | Left | IIIB | 8 | 43 | 20.5 | 35.8 |
| 7 | 49 | Male | Steroid use | Left | IIIB | 7 | 42 | 33.8 | 40.3 |
| 8 | 44 | Female | Alcohol | Right | IIIA | 8 | 38 | 38.5 | 36.4 |
| 9 | 39 | Female | Traumatic | Right | IIIA | 7 | 44. | 20.5 | 29.3 |
| 10 | 34 | Male | Idiopathic | Right | IIIA | 6 | 41 | 36.2 | 35.8 |
| 11 | 32 | Male | Alcohol | Left | IIIB | 8 | 50 | 27.2 | 39.9 |

ARCO stage: Association Research Circulation Osseous stage; VAS: Visual Analogue Score; HHS: Harris Hip Score; SF-12 PCS: 12-item short form survey physical component; SF-12 MCS: 12-item short form survey mental component

**Table 2** Surgical characteristics and postoperative scores

| NO. | Operation side | Blood loss (ml) | Operation time (minutes) | Incision length (cm) | Postoperative VAS | Postoperative HHS | Postoperative SF-12 PCS | Postoperative SF-12 MCS |
|---|---|---|---|---|---|---|---|---|
| 1 | Right | 50 | 50 | 4.0 | 1 | 97 | 50.7 | 50.6 |
| 2 | Right | 150 | 70 | 3.5 | 3 | 93 | 41.0 | 42.8 |
| 3 | Right | 35 | 60 | 3.1 | 2 | 91 | 47.6 | 35.4 |
| 4 | Right | 140 | 65 | 3.8 | 1 | 95 | 46.3 | 39.1 |
| 5 | Right | 100 | 55 | 3.2 | 4 | 92 | 35.9 | 45.7 |
| 6 | Left | 135 | 40 | 3.0 | 2 | 86 | 41.0 | 50.6 |
| 7 | Left | 20 | 35 | 3.1 | 0 | 86 | 44.6 | 40.5 |
| 8 | Right | 90 | 45 | 3.9 | 1 | 89 | 45.3 | 48.3 |
| 9 | Right | 100 | 60 | 3.0 | 2 | 90 | 38.3 | 43.5 |
| 10 | Right | 170 | 90 | 3.0 | 2 | 86 | 36.0 | 45.2 |
| 11 | Left | 220 | 60 | 3.3 | 1 | 88 | 36.3 | 45.1 |

VAS: Visual Analogue Score; HHS: Harris Hip Score; SF-12 PCS: 12-item short form survey physical component; SF-12 MCS: 12-item short form survey mental component

**Table 3** Changes in clinical function

| Outcomes | Pre-operation | Final follow-up | *P* value |
|---|---|---|---|
| VAS score | 7.5 ± 0.9 | 1.6 ± 1.2 | **< 0. 01** |
| HHS score | 42.9 ± 4.4 | 90.3 ± 3.7 | **< 0. 01** |
| SF12 PCS | 27.7 ± 7.1 | 42.1 ± 5.1 | **< 0. 01** |
| SF12 MCS | 36.4 ± 3.8 | 44.3 ± 4.7 | **< 0. 01** |

*Significant variables; VAS: Visual Analogue Score; HHS: Harris Hip Score; SF-12 PCS: 12-item short form survey physical component; SF-12 MCS: 12-item short form survey mental component

showed that after surgery, pain was reduced from severe to mild in seven hips (63.6%), from moderate to mild in two hips (18.2%), and from severe to moderate in two hips (18.2%). HHS improved with excellent results in 2 (18.2%) hips, good results in 5 (45.4%) hips, and average results in 4 (36.4%) hips, and no poor results (0.0%).

Table 3 shows the differences between preoperative and postoperative clinical scores. The mean VAS score at the final follow-up was obviously lower than the mean preoperative VAS score (1.6 ± 1.2 vs. 7.5 ± 0.9, $P < 0.01$). The mean postoperative HHS was significantly improved compared to the mean preoperative HHS (90.3 ± 3.7 vs. 42.9 ± 4.4, $P < 0.01$). The SF-12 scores showed that all patients experienced varying degrees of physical (42.1 ± 5.1 vs. 27.7 ± 7.1, $P<0.01$) and mental (44.3 ± 4.7 vs. 36.4 ± 3.8, $P<0.01$) health improvement.

### Complications

The final follow-up results showed that no patient suffered a serious postoperative complication or death during treatment or follow-up. Only one patient presented with fever 30 days after discharge. The fever was resolved with regular wound dressing changes and the administration of intravenous antibiotics. According to the final imaging evaluation, X-ray radiographs showed adequate placement of all implants and no evidence of implant fracture, loosening, or sinking (Fig. 5a, b, c).

## Discussion

In the present study, one new surgical technique, named "partial femoral head replacement", was introduced. This technique showed great promise as a safe and effective surgical option for ARCO III femoral head necrosis, with

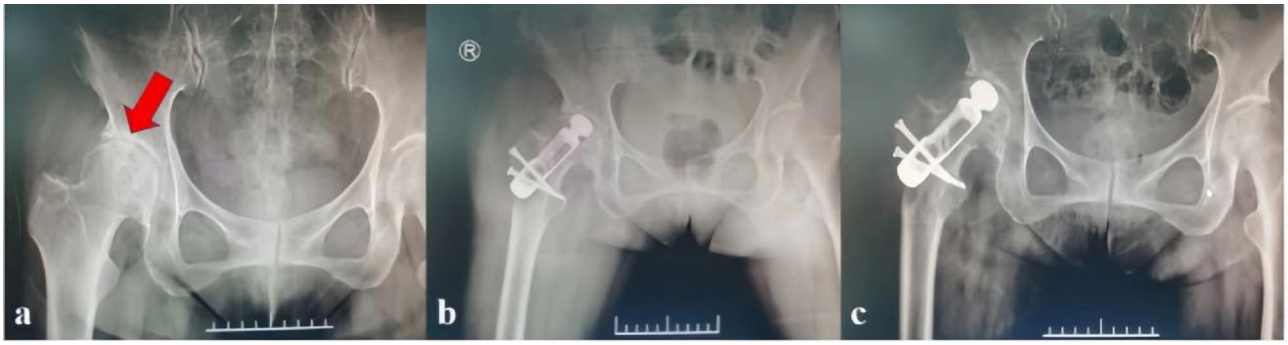


**Fig. 5** A 44-year-old woman with ARCO stage III of the right hip. **(a)** The preoperative X-ray. **(b)** Six-month follow-up. **(c)** Twelve-month follow-up

a short operative time, less trauma, a low rate of intra- and postoperative complications, and good functional recovery.

The key to treating ARCO III femoral head necrosis is proper management of the collapsed area. In this study, we used partial femoral head replacement to precisely remove the collapsed area through a bone tunnel at the femoral neck. Common hip-preserving surgeries, such as core decompression and tantalum rod therapy, are similarly performed through a core track or a window at the femoral neck [11, 22]. However, their results are not promising in patients with collapse of the femoral head. Because the principle of those procedures is the induction of new blood vessels and establishment of an adequate blood supply to the femoral head, promoting the remodelling and regeneration of the femoral head [23]. In accordance with research on the mechanism of femoral head repair, most induced new blood vessels can only grow into the surrounding collapsed areas, which means that the new blood supply is rather limited [24]. Under the action of new blood vessels, new bone tissue will grow around the collapsed region, eventually forming a sclerotic band over time, which may further limit the blood supply to the femoral head. In addition, these techniques are unable to restore the spherical shape of the femoral head and correct the stress distribution [7, 25].

Open surgery, including osteotomy and resurfacing arthroplasty etc., can be used to remove the collapsed segments and replace them with normal tissue or implants [12, 26]. However, this approach causes severe damage to the original blood supply and soft tissue, increases various potential complications, and even has an impact on subsequent total hip arthroplasty [27, 28]. Partial femoral head replacement, in contrast, has the advantages of a minimally invasive technique. The use of a minimally invasive approach without opening the hip joint, together with dedicated instruments, minimizes soft tissue damage and preserves the original blood supply to the femoral head, reducing both the operative time and blood loss during the procedure. Traditionally, minimally invasive hip surgery is often challenged by a small field of view and uncleaned necrotic tissue, which seriously limit the treatment. We designed the bone tunnel in advance by 3D reconstruction and removed necrotic areas precisely under image positioning [29]. In addition, this procedure preserves the most bone stock without compromising subsequent treatment. In the event of ONFH progression, implant failure, or major complications at any time, there is always the option of revision to THA.

Apart from the advantages of the surgical procedure, the short-term results of partial femoral head replacement in treating ARCO stage III ONFH patients are also impressive. The SF-12 scores showed that all patients reported improved physical (42.1 vs. 27.7) and mental (44.3 vs. 36.4) health after the surgery. In ARCO stage III, due to the obstruction or interruption of blood flow in the arteries and veins, there is high pressure and intramedullary oedema in the bone, which causes great pain to patients [30]. The bone tunnel that we designed releases intraosseous hypertension and effectively reduces the VAS score for pain (7.5 vs. 1.6). In terms of joint function, the prosthesis is custom-made to match each patient's anatomy and femoral head contour, which does not interfere with hip joint activity and minimizes changes in biomechanical conduction. Additionally, two crossed screws are inserted to prevent rotation of the prosthesis. The above configuration provides powerful mechanical support in the repair stage, preventing collapse of the femoral head secondary to creation of the tunnel [17]. Autologous cancellous bone implanted into the prosthesis can provide a highly osteoconductive, osteoinductive, and osteogenic substrate, enhancing the bioactivity of the implant for subsequent bone healing [31]. In this study, an apparent change in the HHS was obtained in the early postoperative period (38.3 vs. 83.3). It is also worth noting that no signs of aggravation of femoral head necrosis or femoral head collapse occurred during follow-up, suggesting that partial femoral head replacement may promote revascularization of the femoral head and prevent progression of ONFH to some extent.

This retrospective study is the first to report partial femoral head replacement for precise minimally invasive treatment of ARCO III femoral head necrosis. Although preliminary clinical results have demonstrated its safety and efficacy, there are still several limitations that should be noted. Firstly, this study had a small sample size and a short follow-up period. Secondly, all reported operations were performed by the same surgeon at a single center. In addition, the titanium alloy prosthesis causes metallic artefacts on MRI imaging, which interferes with the assessment of post-operative conditions. These limitations may cast doubt on the validity of this technique. In the future, further trials including more patients and long-term results from multicentre studies will be needed to confirm the reliability of this new treatment.

## Conclusion

In conclusion, we designed partial femoral head replacement specifically for ARCO stage III patients and demonstrated its safety and promising short-term efficacy. Facing the great challenge of both a trend of ONFH younger patients and increasing emphasis on hip preservation, partial femoral head replacement may provide a new minimally invasive hip-preserving option for these patients, and it may be considered a potential treatment option in clinical practice in the future.

**Acknowledgements**
We are grateful to all patients who participated in this study.

**Author contributions**
Tianyu Wang, Zhongzheng Wang, and Yuchuan Wang: Collecting and analyzing the data, interpreting data, writing and editing the manuscript; Changhui Li: Collecting the data; Yining lu: Analyzing and interpreting the data, revising the manuscript; Yanbin Zhu and Wei Chen: Designing the study, revising the manuscript; Yingze Zhang: Designing and supervising the study, revising the final manuscript. All authors read and approved the final manuscript.

**Funding**
This study was funded by the 2024 Government-funded Clinical Medicine Talent Training Program of Hebei Province (ZF2024093) and Central Guidance Fund for Local Science and Technology Development of Hebei Province (246Z7758G). This study was also funded by Natural Science Foundation of Hebei Province No. H2024206050 and Hebei Provincial Medical Science Research Subject Programme (20250079).

**Data availability**
All the data used are available from the corresponding author on motivated requests.

## Declarations

**Ethics approval and consent to participate**
This study was approved by the ethics committee of the Third Hospital of Hebei Medical University. All procedures were performed according to the principles of the Declaration of Helsinki and in accordance with the guidelines of Strengthening the Reporting of Surgical Cohort Studies (STROCSS). Informed consent was obtained from patients involved in this study. All data were anonymized by removing sensitive personal information to protect privacy.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

**Author details**
[1]School of Medicine, Nankai University, Tianjin, 300071, People's Republic of China, [2]Department of Orthopaedic Surgery, Third Hospital of Hebei Medical University, Shijiazhuang, Hebei, People's Republic of China 050051.

**Author details**
[1]Department of Orthopaedic Surgery, Hebei Medical University Third Hospital, NO.139 Ziqiang Road, Shijiazhuang, Hebei 050051, People's Republic of China
[2]School of Medicine, Nankai University, Tianjin 300071, People's Republic of China

Received: 3 April 2024 / Accepted: 9 June 2025
Published online: 21 July 2025

**References**

1. Liu F, Wang W, Yang L, Wang B, Wang J, Chai W, Zhao D. An epidemiological study of etiology and clinical characteristics in patients with nontraumatic osteonecrosis of the femoral head. J Res Med Sci. 2017;22:15.
2. Nam KW, Kim YL, Yoo JJ, Koo KH, Yoon KS, Kim HJ. Fate of untreated asymptomatic osteonecrosis of the femoral head. J Bone Joint Surg Am. 2008;90(3):477–84.
3. Cooper C, Steinbuch M, Stevenson R, Miday R, Watts NB. The epidemiology of osteonecrosis: findings from the GPRD and THIN databases in the UK. Osteoporos Int. 2010;21(4):569–77.
4. Zhao DW, Yu M, Hu K, Wang W, Yang L, Wang BJ, Gao XH, Guo YM, Xu YQ, Wei YS, et al. Prevalence of nontraumatic osteonecrosis of the femoral head and its associated risk factors in the Chinese population: results from a nationally representative survey. Chin Med J (Engl). 2015;128(21):2843–50.
5. Wen Z, Li Y, Cai Z, Fan M, Wang J, Ding R, Huang C, Xiao W. Global trends and current status in osteonecrosis of the femoral head: A bibliometric analysis of publications in the last 30 years. Front Endocrinol (Lausanne). 2022;13:897439.
6. Zhao D, Zhang F, Wang B, Liu B, Li L, Kim SY, Goodman SB, Hernigou P, Cui Q, Lineaweaver WC, et al. Guidelines for clinical diagnosis and treatment of osteonecrosis of the femoral head in adults (2019 version). J Orthop Translat. 2020;21:100–10.
7. Cao H, Guan H, Lai Y, Qin L, Wang X. Review of various treatment options and potential therapies for osteonecrosis of the femoral head. J Orthop Translat. 2016;4:57–70.
8. Xia T, Liu J, Shi L, Zhang C, Yao C, Shen J. Comparison of surgical dislocation and impacting bone graft and surgical dislocation and rotational osteotomy for the treatment of ARCO III femoral head necrosis. Med (Baltim). 2020;99(20):e20215.
9. Salameh M, Moghamis IS, Kokash O, Ahmed GO. Hyperbaric oxygen therapy for the treatment of Steinberg I and II avascular necrosis of the femoral head: a report of fifteen cases and literature review. Int Orthop. 2021;45(10):2519–23.
10. Vulpiani MC, Vetrano M, Trischitta D, Scarcello L, Chizzi F, Argento G, Saraceni VM, Maffulli N, Ferretti A. Extracorporeal shock wave therapy in early osteonecrosis of the femoral head: prospective clinical study with long-term follow-up. Arch Orthop Trauma Surg. 2012;132(4):499–508.
11. Zeng YR, He S, Feng WJ, Li FL, Li J, Jian LY, Zeng JC, Fan YG. Vascularised greater trochanter bone graft, combined free Iliac flap and impaction bone grafting for osteonecrosis of the femoral head. Int Orthop. 2013;37(3):391–8.
12. Sugioka Y, Yamamoto T. Transtrochanteric posterior rotational osteotomy for osteonecrosis. Clin Orthop Relat Res. 2008;466(5):1104–9.
13. Ma J, Sun W, Gao F, Guo W, Wang Y, Li Z. Porous tantalum implant in treating osteonecrosis of the femoral head: still a viable option?? Sci Rep. 2016;6:28227.
14. Brinker MR, Rosenberg AG, Kull L, Galante JO. Primary total hip arthroplasty using noncemented porous-coated femoral components in patients with osteonecrosis of the femoral head. J Arthroplasty. 1994;9(5):457–68.

15. Beaule PE, Dorey FJ. Survivorship analysis of cementless total hip arthroplasty in younger patients. J Bone Joint Surg Am. 2001;83(10):1590–1.
16. Leunig M, Ganz R. The evolution and concepts of joint-preserving surgery of the hip. Bone Joint J. 2014;96–B(1):5–18.
17. Yang Y, Cheng X, Chen W, Li G, Wang Y, Sun W, An W, Zhang Q, Zhang Y. Partial femoral head replacement: a new innovative hip-preserving approach for treating osteonecrosis of the femoral head and its finite element analysis. Front Bioeng Biotechnol 2024, 12.
18. Wang Z, Wang Y, Wang T, Lu Y, Lian X, Zhu Y, Chen W, Hou Z, Zhang Y. Micro femoral head prosthesis in applications to collapsed femoral head necrosis in the weight-bearing dome (ARCO III): A case series with short-term follow-up. Chin Med J 2024.
19. Hawker GA, Mian S, Kendzerska T, French M. Measures of adult pain: visual analog scale for pain (VAS pain), Numeric Rating scale for pain (NRS pain), McGill pain Questionnaire (MPQ), Short-Form McGill pain Questionnaire (SF-MPQ), Chronic pain Grade scale (CPGS), Short Form-36 Bodily pain scale (SF-36 BPS), and Measure of Intermittent and Constant Osteoarthritis pain (ICOAP). Arthritis Care Res (Hoboken). 2011;63(Suppl 11):S240–252.
20. Nilsdotter A, Bremander A. Measures of hip function and symptoms: Harris hip score (HHS), hip disability and osteoarthritis outcome score (HOOS), Oxford hip score (OHS), Lequesne index of severity for osteoarthritis of the hip (LISOH), and American academy of orthopedic surgeons (AAOS) hip and knee questionnaire. Arthritis Care Res (Hoboken). 2011;63(Suppl 11):S200–207.
21. Gandek B, Ware JE, Aaronson NK, Apolone G, Bjorner JB, Brazier JE, Bullinger M, Kaasa S, Leplege A, Prieto L, et al. Cross-validation of item selection and scoring for the SF-12 health survey in nine countries: results from the IQOLA project. International quality of life assessment. J Clin Epidemiol. 1998;51(11):1171–8.
22. Mont MA, Salem HS, Piuzzi NS, Goodman SB, Jones LC. Nontraumatic osteonecrosis of the femoral head: where do we stand today?? A 5-Year update. J Bone Joint Surg Am. 2020;102(12):1084–99.
23. Ficat RP. Idiopathic bone necrosis of the femoral head. Early diagnosis and treatment. J Bone Joint Surg Br. 1985;67(1):3–9.
24. Wang C, Meng H, Wang Y, Zhao B, Zhao C, Sun W, Zhu Y, Han B, Yuan X, Liu R, et al. Analysis of early stage osteonecrosis of the human femoral head and the mechanism of femoral head collapse. Int J Biol Sci. 2018;14(2):156–64.
25. Floerkemeier T, Lutz A, Nackenhorst U, Thorey F, Waizy H, Windhagen H, von Lewinski G. Core decompression and osteonecrosis intervention rod in osteonecrosis of the femoral head: clinical outcome and finite element analysis. Int Orthop. 2011;35(10):1461–6.
26. Hiranuma Y, Atsumi T, Kajiwara T, Tamaoki S, Asakura Y. Evaluation of instability after transtrochanteric anterior rotational osteotomy for nontraumatic osteonecrosis of the femoral head. J Orthop Sci. 2009;14(5):535–42.
27. Squire M, Fehring TK, Odum S, Griffin WL, Bohannon Mason J. Failure of femoral surface replacement for femoral head avascular necrosis. J Arthroplasty. 2005;20(7 Suppl 3):108–14.
28. Yasunaga Y, Hisatome T, Ikuta Y, Nakamura S. A histological study of the necrotic area after transtrochanteric anterior rotational osteotomy for osteonecrosis of the femoral head. J Bone Joint Surg Br. 2001;83(2):167–70.
29. Tonutti M, Elson DS, Yang GZ, Darzi AW, Sodergren MH. The role of technology in minimally invasive surgery: state of the art, recent developments and future directions. Postgrad Med J. 2017;93(1097):159–67.
30. Mukisi MM, Bashoun K, Burny F. Sickle-cell hip necrosis and intraosseous pressure. Orthop Traumatol Surg Res. 2009;95(2):134–8.
31. Myeroff C, Archdeacon M. Autogenous bone graft: donor sites and techniques. J Bone Joint Surg Am. 2011;93(23):2227–36.

## Publisher's note