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NONTRAUMATIC OSTEONECROSIS OF THE FEMORAL HEAD: AN INTERNATIONAL EVIDENCE-BASED CLINICAL PRACTICE GUIDELINE
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ARCO
Association Research Circulation Osseous

Management of Nontraumatic Osteonecrosis of the Femoral Head

Evidence-Based Clinical Practice Guideline

Adopted by:

Association Research Circulation Osseous (ARCO), January 20, 2026
American Academy of Orthopaedic Surgeons (AAOS), ***date pending

Disclaimer

This clinical practice guideline (CPG) was developed by the clinical practice guideline development group composed of an international group of volunteer physicians from the Association Research Circulation Osseous (ARCO). The CPG is based on a formal systematic review of the available scientific and clinical information and accepted approaches to treatment and/or diagnosis. This CPG is not intended to be a fixed protocol, as some patients may require more or less treatment or different means of diagnosis. Clinical patients may not necessarily be the same as those found in a clinical trial. Patient care and treatment should always be based on a clinician's independent medical judgment, given the individual patient's specific clinical circumstances. Therefore, these guidelines are not intended to replace clinician judgment, establish a legal standard of care, or serve as insurance benefits coverage criteria.

Disclosure Requirement

In accordance with the Association Research Circulation Osseous and American Academy of Orthopaedic Surgeons (AAOS) policy, all individuals whose names appear as authors or contributors to the clinical practice guideline filed a disclosure statement as part of the submission process. All panel members provided full disclosure of potential conflicts of interest prior to voting on the recommendations contained within this clinical practice guideline.

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FDA Clearance

Some drugs or medical devices referenced or described in this clinical practice guideline may not have been cleared by the Food and Drug Administration (FDA) or may have been cleared for a specific use only. The FDA has stated that it is the responsibility of the physician to determine the FDA clearance status of each drug or device he or she wishes to use in clinical practice.

Contents

SUMMARY OF ACTION STATEMENT 5

1. Diagnosis: Optimal imaging modality for diagnosis of osteonecrosis of the femoral head (ONFH) 5
2. Diagnosis: Optimal imaging modality for detecting subchondral fracture in ONFH 5
3. Diagnosis: Optimal imaging modality for monitoring the effect of any intervention for treating ONFH 6
4. Diagnosis: Imaging studies to correlate and differentiate symptomatic versus asymptomatic ONFH 6
5. Treatment: Core decompression versus core decompression plus bone marrow concentrate for the 6
6. Treatment: Vascularized Fibular Grafting for the treatment of pre-collapse ONFH 6
7. Treatment: Osteotomy for the treatment of pre-collapse ONFH 6
8. Treatment: Core decompression plus non-vascularized autogenous fibula graft for the treatment of 7
9. Treatment: Other joint-preserving treatments for pre-collapse ONFH 7
10. Treatment: Observation versus treatment intervention for patients who have asymptomatic ONFH 7
11. Treatment: Total hip arthroplasty for patients who have symptomatic ONFH without evidence of subchondral... 7
12. Treatment: Surgical treatment for patients who have ONFH and evidence of subchondral fracture or 7

GUIDELINE DEVELOPMENT GROUP ROSTER 8

VOTING MEMBERS 8

NON-VOTING MEMBERS 9

INTRODUCTION 10

OVERVIEW 10

GOALS AND RATIONALE 10

INTENDED USERS 10

PATIENT POPULATION 11

BURDEN OF DISEASE 11

EMOTIONAL AND PHYSICAL IMPACT 11

SCOPE 11

INCIDENCE AND PREVALENCE 11

RISK FACTORS 12

POTENTIAL BENEFITS, HARM, AND CONTRAINDICATIONS 12

DIFFERENCES BETWEEN THE PRESENT AND PREVIOUS GUIDELINES 12

METHODS 13

PICO QUESTIONS & CRITERIA 14

LITERATURE SEARCH 15

DATA EXTRACTION AND RISK OF BIAS ASSESSMENT 16

EVIDENCE SYNTHESIS 16

DEFINING THE QUALITY OF EVIDENCE 16

DEFINING THE STRENGTH OF RECOMMENDATION 17

VOTING ON THE RECOMMENDATIONS 17

UNDERSTANDING THE QUALITY OF EVIDENCE AND STRENGTH OF RECOMMENDATION 18
REVIEW AND APPROVAL PROCESS 19
ARCO APPROVAL PROCESS 19
REVISION PLANS 19
CPG DISSEMINATION PLAN 19
STUDY ATTRITION FLOWCHARTS 20
Figure 1a. PICO 1: Diagnostic Imaging of ONFH 20
Figure 1b. PICO 2: Treatment of ONFH before subchondral fracture (ARCO stages I and II) 21
Figure 1c. PICO 3: Treatment of ONFH after subchondral fracture (ARCO stage III) 22
RECOMMENDATIONS 23
1. Diagnosis: Optimal imaging modality for diagnosis of ONFH 23
2. Diagnosis: Optimal imaging modality for detecting subchondral fracture in ONFH 27
3. Diagnosis: Optimal imaging modality for monitoring the effect of any intervention for treating ONFH 29
4. Diagnosis: Imaging studies to correlate and differentiate symptomatic versus asymptomatic ONFH 31
5. Treatment: Core decompression versus core decompression plus bone marrow concentrate for the 33
6. Treatment: Vascularized Fibular Grafting for the treatment of pre-collapse ONFH 35
7. Treatment: Osteotomy for the treatment of pre-collapse ONFH 37
8. Treatment: Core decompression plus non-vascularized autogenous fibula graft for the treatment of 39
9. Treatment: Other joint-preserving treatments for pre-collapse ONFH 41
10. Treatment: Observation versus treatment intervention for patients who have asymptomatic ONFH before 43
11. Treatment: Total hip arthroplasty for patients who have symptomatic ONFH, without evidence of 45
12. Treatment: Surgical treatment for patients with ONFH and evidence of subchondral fracture or collapse. 47
APPENDICES 49
APPENDIX I: REFERENCES 49
INTRODUCTION & DESCRIPTION REFERENCES 49
APPENDIX II: RECOMMENDATION REFERENCES 51
Appendix III: LITERATURE SEARCH STRATEGY 61
APPENDIX IV: SUPPLEMENTAL MATERIAL SUPPORTING AGREEII REPORTING GUIDELINES 72
APPENDIX V: GUIDELINE DEVELOPMENT GROUP DISCLOSURES 73

SUMMARY OF ACTION STATEMENT

1. Diagnosis: Optimal imaging modality for diagnosis of osteonecrosis of the femoral head (ONFH)

A magnetic resonance image (MRI) is the recommended diagnostic imaging test for ONFH.

Quality of Evidence: Very low
Strength of Recommendation: Strong

2. Diagnosis: Optimal imaging modality for detecting subchondral fracture in ONFH

A computed tomography evaluation (CT) or an MRI is preferred over plain radiography for detecting subchondral fractures. There is variable evidence to justify the benefit of a frog-leg lateral radiograph.

Quality of Evidence: Very low
Strength of Recommendation: Weak

3. Diagnosis: Optimal imaging modality for monitoring the effect of any intervention for treating ONFH

An MRI can quantify the area and extent of osteonecrosis and may be used to monitor the effect of any treatment in ONFH.

Quality of Evidence: Very low
Strength of Recommendation: Weak

4. Diagnosis: Imaging studies to correlate and differentiate symptomatic versus asymptomatic ONFH

In ONFH, before subchondral fracture or collapse, MRI is recommended to determine if hip pain is due to ONFH, as bone marrow edema and joint effusion on MRI correlate with pain. Bone marrow edema, when compared to joint effusion, is a more accurate indicator of hip pain.

Quality of Evidence: Moderate
Strength of Recommendation: Strong

5. Treatment: Core decompression (CD) versus CD plus bone marrow concentrate (BMC) for the treatment of pre-collapse ONFH

For patients who have ONFH without subchondral fracture or collapse (ARCO stages I to II), CD can be considered for treatment. For patients undergoing CD, adding BMC to the

procedure may reduce the risk of femoral head collapse. However, there are no comparative data to clearly state what treatment is best for pre-collapse ONFH to prevent subchondral fracture.

Quality of Evidence: Low
Strength of Recommendation: Weak

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6. Treatment: Vascularized Fibular Grafting (VFG) for the treatment of pre-collapse ONFH

For patients who have ONFH without subchondral fracture or collapse (ARCO stages I to II), VFG may be considered as a femoral head-preserving option, but this must be balanced with the increased morbidity of this procedure as compared to lower-complexity procedures.

Quality of Evidence: Very low
Strength of Recommendation: Weak

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7. Treatment: Osteotomy for the treatment of pre-collapse ONFH

For patients who have ONFH without subchondral fracture or collapse (ARCO stages I to II), proximal femoral osteotomy may occasionally be considered to preserve the femoral head and shift weight-bearing to the non-necrotic bone, but this must be balanced by the deformity created and any impact on subsequent joint arthroplasty procedures.

Quality of Evidence: Very low
Strength of Recommendation: Weak

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8. Treatment: CD plus non-vascularized autogenous fibula graft for the treatment of pre-collapse ONFH

The workgroup recommends against adding a non-vascularized autogenous fibular graft to CD for the purpose of preventing femoral head collapse, as there is no clear benefit, and it incurs the morbidity of obtaining the autogenous bone graft.

Quality of Evidence: Very low
Strength of Recommendation: Weak

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9. Treatment: Other joint-preserving treatments for pre-collapse ONFH

For patients who have ONFH without subchondral fracture or collapse (ARCO stages I to II), there are many other treatments in the literature, beyond those previously outlined in the above guidelines; however, the evidence base consists of fewer than three studies eligible for analysis, per the guideline inclusion criteria. Therefore, we issue no recommendation for the routine use of these other treatments to prevent subchondral fracture in ARCO stages-I to II ONFH.

Quality of Evidence: Insufficient evidence
Strength of Recommendation: None

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10. Treatment: Observation versus treatment intervention for patients who have asymptomatic ONFH before subchondral fracture.

In the absence of sufficient evidence, it is the opinion of the workgroup that for patients who have asymptomatic ONFH, without subchondral fracture or collapse (ARCO stages I to II), treatment may be considered depending on the risk of developing symptoms and subchondral collapse (e.g., ARCO size types 2 or 3), as well as the volume or extent of involvement. Treatments with low morbidity are preferred.

Quality of Evidence: Very low
Strength of Recommendation: Weak

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11. Treatment: Total hip arthroplasty (THA) for patients who have symptomatic ONFH without evidence of subchondral fracture, collapse, or arthritis, i.e., ARCO stages I or II.

For patients who have symptomatic ONFH without subchondral fracture (ARCO stages I to II), alternative treatments/procedures to THA should be considered.

Quality of Evidence: Insufficient evidence
Strength of Recommendation: Strong (consensus-based)

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12. Treatment: Surgical treatment for patients who have ONFH and evidence of subchondral fracture or collapse, i.e., ARCO stage III.

In ARCO stage-III ONFH, femoral head-preserving procedures are associated with a smaller functional improvement compared to THA, and the outcome is less predictable. However, shared decision-making between patients and their physicians is necessary, especially in younger patients, because of the value of joint preservation.

Quality of Evidence: Very low
Strength of Recommendation: Weak

GUIDELINE DEVELOPMENT GROUP ROSTER

VOTING MEMBERS

All voting members voted on all guideline statements, regardless of PICO workgroup assignment.

CPG project executive committee:

Edward Y. Cheng, MD, FAAOS, FAOA; ***CPG project chair,*** *University of Minnesota, Minneapolis, USA*
Quanjun Cui, MD; *University of Virginia, Charlottesville, USA*
Stuart N. Goodman, MD, PhD, FRCSC, FACS, FBSE, FIOR, FORS; *Stanford University, Palo Alto, USA*
Michael A. Mont, MD, FAAOS; *The Rubin Institute, Sinai Hospital, LifeBridge Health, Baltimore, USA*
Lynne C. Jones, PhD; *Johns Hopkins University, Baltimore, USA*

PICO 1 workgroup:

Edward Y. Cheng, MD, FAAOS, FAOA; Workgroup Chair*, University of Minnesota, Minneapolis, USA*
Takashi Sakai, MD; *Yamaguchi University, Yamaguchi, Japan*
Kyung-Hoi Koo, MD; *Seoul National University Bundang Hospital, Seongnam, South Korea*
Lynne Jones, PhD; *Johns Hopkins University, Baltimore, USA*
Young-Kyun Lee, MD; *Seoul National University Bundang Hospital, Seoul National University College of Medicine, Seongnam, South Korea*
Takuaki Yamamoto, MD; *Fukuoka University, Fukuoka City, Japan*
Harry K.W. Kim, MD, MS; *Scottish Rite for Children, University of Texas-Southwestern, Dallas, USA*
Ines Reichert, MD; *King's College Hospital / King's College London, London, United Kingdom*
Nobuhiko Sugano, MD, PhD; *Osaka University, Osaka, Japan*
Philippe Hernigou, MD; *Hôpital Henri-Mondor, Paris, France*

PICO 2 workgroup:

Quanjun Cui, MD; Workgroup Chair*, University of Virginia, Charlottesville, USA*
Michael Mont, MD, FAAOS; *Sinai Hospital, LifeBridge Health, Baltimore, USA*
Wolf Drescher, MD; *RWTH Aachen University, Aachen, Germany*
Dewei Zhao, MD; *Zhongshan Hospital of Dalian University, Dalian, China*
Benjamin M Stronach; *University of Arkansas for Medical Sciences, Little Rock, AR, USA*
Byung-Ho Yoon, MD; *Ewha Womans University, Seoul, South Korea*

PICO 3 workgroup:

Stuart Goodman, MD, PhD, FRCSC, FACS, FBSE, FIOR, FORS; Workgroup Chair, *Stanford University, Palo Alto, USA*
Yong-Chan Ha, MD; *Chung-Ang University, Seoul, South Korea*
Mel S. Lee, MD, PhD; *Pao-Chien Hospital, Pingtung, Taiwan*
Seung-Hoon Baek, MD, PhD; *Kyungpook National University, Daegu, South Korea*
Rafael J. Sierra, MD; *Mayo Clinic, Rochester, USA*
Tae-Young Kim, MD; *Konkuk University, Seoul, South Korea*
Wataru Ando, MD; *Department of Orthopaedic Surgery, Kansai Rosai Hospital, Hyogo, Japan*

NON-VOTING MEMBERS

Alireza Mirzaei, PhD; *Department of Orthopedic Surgery, University of Minnesota, Minneapolis, USA*
Mary E. Butler, PhD, MBA; *Co-Director, Minnesota Evidence-based Practice Center, University of*

Minnesota, Minneapolis, USA
Romil R. Parikh, MBBS, MPH, PhD; *Clinical Epidemiologist, Minnesota Evidence-based Practice Center, University of Minnesota, Minneapolis, USA*
Caitlin Bakker, PhD, MLIS; *Discoveries Tech Librarian, University of Regina, Regina, Canada*
Sergio F. Guarin Perez, MD; *Mayo Clinic, Rochester, USA*
Diego J. Restrepo, MD; *Mayo Clinic, Rochester, USA*
Sallee Brandt, MPH; *Project Manager, Evidence Synthesis Program, University of Minnesota, Minneapolis, USA*
Gabrielle Swartz, MD; *Sinai Hospital, LifeBridge Health, Baltimore, USA*
Reza Katanbaf, MD; *Sinai Hospital, LifeBridge Health, Baltimore, USA*

INTRODUCTION

OVERVIEW

This clinical practice guideline (CPG) is based on a systematic review of published studies reporting the diagnosis and treatment of nontraumatic osteonecrosis of the femoral head (ONFH). It is developed under the auspices of the Association Research Circulation Osseous (ARCO), which is devoted to the study of this disease and other bone circulatory disorders. An international group of experts from ARCO, based on their established scholarly contributions, was convened to develop this CPG. The CPG development group reflected broad international collaboration, encompassing experts from eight countries across three continents — North America, Europe, and Asia. Members represented leading academic and clinical institutions in the United States, Japan, South Korea, China, Taiwan, the United Kingdom, France, and Germany. It provides recommendations to assist practitioners in integrating current evidence into clinical care and highlights gaps in the literature that need to be addressed in future research. This CPG is intended to be used by qualified and appropriately trained physicians and clinicians involved in the diagnosis and treatment of ONFH. It also serves as an information resource for decision makers and all other potential users of the CPG.

GOALS AND RATIONALE

The purpose of this CPG is to evaluate the current best evidence associated with the diagnosis and management of non-traumatic ONFH. The standards of evidence-based medicine emphasize that clinical decision-making should be guided by the highest quality evidence available. To this aim, a systematic review of the literature in publication was started in March 2020. The development of this project coincided with the outbreak of the COVID-19 pandemic, during which reduced clinical activity allowed surgeons more time to contribute to the early phases of the guideline. However, following the resumption of regular clinical duties after the pandemic shutdown, surgeon availability became limited, and the project was delayed. Additional resources, staff, and support were identified, and work resumed in 2023. Methodologists at the Minnesota Evidence-based Practice Center, a University of Minnesota center primarily funded by the U.S. Agency for Healthcare Research and Quality (AHRQ), were engaged and provided staff to work with the physician/clinician work group at the Association Research Circulation Osseous (ARCO) in evaluating the existing literature and formulating the following recommendations based on a rigorous systematic approach.

This guideline was created as an educational tool to guide qualified physicians and clinicians in making diagnostic and therapeutic decisions that improve the quality and consistency of care.

This guideline should not be construed as including all potential methods of care, nor does it preclude other reasonable approaches aimed at achieving positive outcomes. The choice of a specific diagnostic or treatment strategy should ultimately be made jointly by the physician and patient, considering individual circumstances, available resources, and patient preferences.

INTENDED USERS

This guideline is intended to be used by orthopedic surgeons and other healthcare providers involved in the diagnosis and management of ONFH. Primary users include orthopedic surgeons, many of whom will have completed subspecialty training in joint preservation surgery or arthroplasty. Physicians in related specialties—such as rheumatology, radiology, and rehabilitation medicine—as well as adult primary care physicians, geriatricians, hospital-based internal medicine specialists, physical therapists, occupational therapists, nurse practitioners, and physician assistants who routinely encounter these patients in various settings may also benefit from this guideline.

The ONFH management assumes that care decisions are made through shared communication between the treating physician and the patient and/or the patient's qualified healthcare advocate. Patients should be informed of available diagnostic and treatment options, including their potential benefits and risks, and these options should be discussed in the context of individual patient values and preferences. Once informed, the patient and/or their advocate, together with the treating physician, can make a collaborative decision regarding the most appropriate course of management. Clinician input—drawing on experience with nonoperative care, joint-preserving surgery, and arthroplasty—enhances the ability to match patients with interventions that are most likely to improve outcomes. The ARCO guideline development process adopted the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) Evidence-to-Decision Framework [1-3] to enable workgroup members to incorporate multiple factors into recommendation strength and to move beyond the rigidity of earlier guideline language stems.

This guideline is not intended for use as a benefits determination document. It does not address allocation of resources, business or ethical considerations, or other factors required to determine the material value of musculoskeletal care.

PATIENT POPULATION

This guideline addresses the diagnosis and treatment of adult patients (≥ 16 years of age) with nontraumatic ONFH. It is not intended to address the management of pediatric patients with osteonecrosis or other types of osteonecrosis, such as traumatic ONFH.

BURDEN OF DISEASE

Osteonecrosis of the femoral head often results in profound disability, leading to wheelchair dependence or necessitating joint arthroplasty, and imposes the lifelong burden of managing an implant [4,5]. Currently, over 450,000 Total Hip Arthroplasties (THAs) are performed each year in the United States [6], with ONFH accounting for as much as 18% of these procedures [7]. This figure is expected to increase twofold by 2030 [8]. These procedures contribute to nearly $18 billion in annual healthcare expenditures [9]. With an aging population and the growing use of THA in younger patients, the incidence of complications, including aseptic loosening, periprosthetic fractures, and prosthetic joint infection, is anticipated to increase, further intensifying both the economic and health burdens associated with THA [10,11]. Notably, patients who have ONFH have historically experienced poorer outcomes after THA, including higher risks of revision surgery, infection, and hospital readmission, compared with those treated for osteoarthritis [12].

EMOTIONAL AND PHYSICAL IMPACT

Osteonecrosis of the femoral head has profound physical and emotional consequences [13]. Patients often present with progressive hip pain, functional limitations, and reduced mobility that can significantly impair activities of daily living, employment, and participation in recreational pursuits [13]. In advanced cases, disability may result in dependence on walking aids or wheelchairs, thereby diminishing the quality of life [13]. Emotional impacts include anxiety, depression, and social withdrawal [13], particularly among younger patients who face the lifelong burden of joint arthroplasty. The ONFH disproportionately affects patients in their third to fifth decades of life, compounding its social and psychological burden by limiting productivity during peak working years [13,14].

SCOPE

The scope of this guideline includes the diagnosis and management of patients who have nontraumatic ONFH. It does not address traumatic osteonecrosis resulting from fracture or dislocation, pediatric cases, or osteonecrosis affecting other skeletal sites.

INCIDENCE AND PREVALENCE

The number of new cases of ONFH is estimated 2,500–3,000 in Japan [15], 15,000–20,000 in the United States [16], and 100,000–200,000 in China [17]. When adjusted for population size, the overall incidence does not appear markedly different among these countries. However, epidemiological studies indicate substantial variation in the prevalence of ONFH across various ethnic and racial groups, which is influenced by a combination of genetics, lifestyle, and frequency of pre-existing health conditions [18]. Notably, the incidence in Korea is relatively higher, with nearly half of all THAs performed for ONFH[19], compared with approximately 10% in the United States [20]. A high proportion of ONFH among THA cases is not unique to Korea; other Asian countries, such as China, Thailand, and India, also report similarly elevated proportions, whereas Japan reports a much lower proportion, with ONFH accounting for less than 10% of THA cases [21,22]. However, evaluating the frequency of ONFH based solely on its proportion among THAs is not an appropriate approach. A lower prevalence of osteoarthritis in certain populations can lead to a relatively higher proportion of ONFH among THA cases, which may misrepresent the true incidence of ONFH.

RISK FACTORS

Several risk factors have been consistently associated with the development of ONFH. Prolonged or high-dose corticosteroid therapy and chronic alcohol consumption are among the most widely recognized contributors, both of which are linked to impaired microcirculation, fat embolism, and elevated intraosseous pressure [23]. Autoimmune diseases such as SLE, as well as other systemic inflammatory or hematologic disorders, further increase risk through both disease-related mechanisms and corticosteroid exposure[24]. Additional risk factors include metabolic syndrome, hyperlipidemia, coagulopathies, a history of organ transplantation, and smoking [25,26]. Genetic predisposition has also been implicated in ONFH risk, with certain variants increasing individual susceptibility [27]. It is believed that the presence of risk factors does not invariably lead to disease, but they substantially increase the likelihood of ONFH development when coincident with an underlying genetic predisposition [27].

POTENTIAL BENEFITS, HARM, AND CONTRAINDICATIONS

The main benefits of this guideline include streamlining and standardizing the diagnostic evaluation and surgical management of ONFH based on the best available evidence. Unlike prior regional guidelines, this represents the first international, consensus-driven CPG developed under the ARCO. By incorporating perspectives from diverse healthcare systems, it aims to harmonize care globally, reduce regional variability, and improve outcomes across different practice settings. Additional benefits include earlier and more accurate diagnosis, improved selection of stage-appropriate surgical interventions, and greater consistency in treatment planning and patient counseling. Potential harms are primarily related to diagnostic procedures and surgical treatment. Imaging studies may result in radiation exposure or increased healthcare costs. Surgical interventions for ONFH are associated with risks such as infection, thromboembolic events, hardware failure, and the possibility of revision surgery, particularly in younger patients. Contraindications vary by disease stage, treatment modality, and patient characteristics. For example, advanced femoral head collapse may preclude joint-preserving techniques, while severe comorbid conditions or poor bone stock may limit surgical options. Treatment selection should therefore be guided by a shared decision-making process that balances diagnostic accuracy, surgical risks, and patient-specific values, preferences, and goals.

DIFFERENCES BETWEEN THE PRESENT AND PREVIOUS GUIDELINES

This CPG is the first international guideline for ONFH, which was developed under the auspices of the ARCO. Previous guidelines for ONFH were developed at the national or regional level (e.g., Japan, China, Korea, United States) and reflected local practice patterns. In contrast, the present guideline incorporates global perspectives, with the goal of harmonizing care across diverse geographic and clinical settings. In developing this document, the work group considered the literature examined in prior national guidelines as well as empirical evidence published in the intervening years. Importantly, a high level of methodological rigor was used to establish this guideline. It was developed using the GRADE Evidence-to-Decision Framework [1-3] in consultation with the Minnesota Evidence-Based Practice Center. Additional consultations were undertaken with the American Academy of Orthopaedic Surgeons. The GRADE Framework enabled the incorporation of additional contextual factors into the strength of each recommendation. A notable distinction is that this guideline provides disease stage-specific recommendations for the diagnosis and management of ONFH. This guideline uses the ARCO-defined staging system [28] for ONFH while acknowledging that individual published studies may use alternative staging systems. Whereas previous guidelines often emphasized either early-stage or advanced-stage arthroplasty, the present guideline systematically addresses diagnostic strategies and treatment options tailored to each ARCO stage of disease. This approach enables more consistent, evidence-based decision-making and supports clinicians in selecting interventions most appropriate to the patient's disease stage. Furthermore, it establishes a platform for additional CPG development to address many other issues related to both ONFH and osteonecrosis of other disease sites.

METHODS

This CPG evaluates the diagnosis and management of nontraumatic ONFH. The approach adopted by ARCO incorporated practicing physicians (clinical experts) and methodologists who were free of potential conflicts of interest relevant to the topic under study, as recommended by clinical practice guideline development standards [29].

This CPG was prepared by the ARCO ONFH Guideline Development Group (clinical experts) with the guidance and assistance of methodologists from the Minnesota Evidence-based Practice Center. The initial protocol for the development of this clinical CPG was made publicly available in an earlier publication [30]. Any deviations from that protocol are addressed in this section.

To develop this CPG, the work group held an initial meeting in March 2020 to establish the scope of the guideline. As the physician experts, the work group defined the scope by developing PICO questions (population, intervention, comparison, and outcome), which directed the systematic literature search [30]. The workgroup also defined the inclusion and exclusion criteria for articles to be included for data abstraction. After the COVID-19 pandemic, progress was delayed. The project resumed in 2023 with an updated literature review to capture new publications from the intervening years to June 2024. The workgroup was subdivided into 3 smaller workgroups to address the 3 PICO questions, with a chair identified for each PICO question-focused workgroup. Multiple workgroup meetings took place virtually to further refine the PICO questions and to gain consensus on decisions and practices with respect to systematic search, literature review, and rating articles for inclusion in analysis. Experienced medical research librarians created and executed the systematic searches. After the included literature was identified, a core group of physicians and scientists worked with the CPG project chair and the Minnesota Evidence-based Practice Center to complete the steps in risk of bias assessment, data abstraction, evidence synthesis, biostatistical analysis, and assessing the quality of the evidence base. With the exception of the CPG project chair, this review group excluded the voting guideline panel.

The synthesized evidence was reviewed and appraised by the guideline panel according to the GRADE Evidence-to-Decision Framework [31,32], which enabled the panel to incorporate contextual factors into the strength of each recommendation.

PICO QUESTIONS & CRITERIA

PICO 1 – Diagnostic Imaging

In patients undergoing diagnostic evaluation for ONFH, what imaging studies are most sensitive and specific for:

a) Diagnosis

b) Detecting a subchondral fracture
c) Monitoring the effect of any intervention
d) Correlating with symptomatic vs. asymptomatic disease

Inclusion criteria

- The focus of the article is on imaging, not on a treatment outcome
- Humans only
- Adult population only (age >16 years)

Exclusion criteria

- Animal studies
- Foreign language without full-text English translation
- Single case reports
- Articles that do not present original data (e.g., reviews, editorials)

PICO 2 – Early Disease (ARCO stages I and II)

In patients with ONFH, ARCO stages I and II (without femoral head fracture or collapse):

a) What treatment (e.g., bisphosphonates, core decompression, cellular stem cell therapy) is best at preventing a subsequent femoral head subchondral fracture?
b) For asymptomatic patients, does treatment vs. serial observation reduce the risk of a subchondral femoral head fracture?
c) For symptomatic patients, should total hip arthroplasty (THA) be performed to reduce pain?

Inclusion criteria

- Evidence level 1 to 4
- Case series with >15 patients
- Humans only
- Prospective or retrospective studies
- Diagnosis = non-traumatic ONFH
- Age > 16 years
- Advanced imaging (CT or MRI), in addition to X-ray, is used to assess for subchondral collapse
- Treatment intervention is uniform across the entire treatment cohort
- Outcome includes radiographic progression (not only conversion to total hip arthroplasty)
- Follow-up > two years

Exclusion criteria

- Animal studies
- Foreign language without full-text English translation
- Single case reports
- No duplicate papers or patient cohorts
- Articles that do not present original data (e.g., reviews, editorials)

PICO 3 – Advanced Disease (ARCO stage III)

In patients with ONFH, ARCO stage III (with a femoral head fracture, with or without collapse), what surgical treatment (e.g., rotational osteotomy, hemiarthroplasty, surface replacement arthroplasty, total hip arthroplasty) yields the best functional outcome over:

a) < 25-year time frame? (Older patient)
b) ≥ 25-year time frame? (Younger patient)

Inclusion criteria

- Evidence levels 1 to 4
- Case series with >15 patients
- Humans only
- Prospective or retrospective studies
- Diagnosis = non-traumatic ONFH
- Age >16 years
- Staging data provided
- Treatment intervention is uniform across the entire treatment cohort
- Outcome data provided
- Follow-up > two years

Exclusion criteria

- Animal studies
- Foreign language without full-text English translation
- Single case reports
- No duplicate papers or patient cohorts
- Articles that do not present original data (e.g., reviews, editorials)

LITERATURE SEARCH

In consultations with the CPG development group, University of Minnesota medical librarians developed search algorithms for PubMed, EMBASE, and the Cochrane Central Register of Controlled Trials databases using MESH and keyword terms derived from the PICO questions (Appendix III) [30]. Searches were conducted from database inception to June 2024. Database searches were supplemented with hand searches of bibliographies of secondary literature sources, such as systematic reviews, when available. References identified by database searches were imported into Rayyan, an AI-powered systematic review management platform [https://www.rayyan.ai/], and independently screened by two reviewers using predefined study selection criteria [30] at title/abstract and at full text for potentially eligible studies. Disagreements between reviewers were resolved through consultation with a third reviewer. Workgroup sessions were conducted among the different PICO workgroups to train the screeners to ensure calibration. A project webpage [https://sites.google.com/umn.edu/arcocpg/home] was established to allow all participants to be involved asynchronously as required. The project webpage also served as a depository and resource for foundational documents, definitions, training tip sheets, and other documents to keep this large, international group unified and aligned in their work. Additional training sessions were used to train non-voting personnel and staff who joined the project effort after its initiation.

Each article was screened independently and in a blinded fashion at both title/abstract and full text screening by at least 3 experts, for either inclusion or exclusion in the final set of articles. Tie-breaking votes were made by the PICO workgroup chair when required.

A study attrition diagram is provided in Figures 1a, 1b, and 1c, corresponding to PICO 1, PICO 2, and PICO 3 questions. These diagrams demonstrate the detailed numbers of identified abstracts, recalled and selected studies, and excluded studies that were evaluated for the guideline. The complete search strategies used to identify the abstracts are provided in Appendix III.

The number of studies included in the synthesis reflects all eligible articles that met the inclusion criteria for that PICO question. However, only a subset of those studies could be used as evidence to support the recommendation, because not all synthesized studies reported the specific outcomes required for pooled analysis, had comparable study designs, or provided data suitable for quantitative evaluation. Nonetheless, these studies were used to help the consensus-reaching process.

DATA EXTRACTION AND RISK OF BIAS ASSESSMENT

Two reviewers independently extracted study characteristics and outcome data from included studies using standardized extraction forms. QUADAS-2 [33], the Cochrane ROB 2 [34], and the ROBINS-I tools [35] were used to assess the risk of bias of included diagnostic, randomized controlled trials, or observational studies, respectively. Risk of bias was assessed by two independent reviewers, and differences in overall risk of bias assessments were discussed in the team and resolved by consensus.

EVIDENCE SYNTHESIS

The workgroup prespecified thresholds for evidence synthesis. At least three eligible studies reporting on the same intervention and outcome were required for pooled analysis or meta-analysis. When three or more studies with comparable designs and outcomes were available, a meta-analysis was performed. When only single-arm studies or heterogeneous designs were available, results were synthesized as pooled data. Interventions with fewer than three eligible studies were considered below the threshold for evidence synthesis, and no formal recommendation was issued for their routine use. This rule ensured consistency in how recommendations were drawn across interventions and explains why some treatments, despite being reported in the literature, did not receive recommendations in this guideline. We used random-effects regression modeling for meta-analyses. Between-study heterogeneity was assessed using the restricted maximum likelihood estimator. All analyses were conducted using the statistical software R (Version 4.2.2). The systematic review and meta-analysis underpinning the recommendations has been published separately [36].

DEFINING THE QUALITY OF EVIDENCE

The quality of evidence for each outcome was assessed using the modified GRADE approach [31,32], which considers several key domains in defining the quality. In this respect, the initial rating depends on study design: randomized controlled trials (RCTs) begin as “high” quality, while observational studies begin as “low.” The rating is then adjusted based on positive and negative factors. Negative factors (downgrades) include serious risk of bias, unexplained heterogeneity or inconsistency, indirectness of evidence, imprecision of estimates (wide confidence intervals or small sample size), and suspected publication bias. Each serious limitation results in the evidence being rated down by one level, and very serious limitations may result in a two-level downgrade. Conversely, certain conditions allow upgrading of observational evidence. Positive factors (upgrades) include a large magnitude of effect, the presence of a dose-response gradient, or situations where all plausible confounding would reduce an apparent effect or suggest a spurious effect when results show no effect. These upgrades can raise the quality rating by one or two levels, depending on strength. Based on these domains, the quality of evidence for each outcome was categorized into four levels: high, moderate, low, or very low. “High” indicates that further research is very unlikely to change confidence in the estimate of effect, whereas “very low” reflects substantial uncertainty in the evidence base. The intermediate categories (“moderate” and “low”) signify increasing degrees of uncertainty and potential for future studies to influence the effect estimate.

DEFINING THE STRENGTH OF RECOMMENDATION

The strength of each recommendation was determined based on the GRADE results, integrating both the certainty of evidence and additional contextual factors [31,32]. Recommendations were classified as either strong or weak (Table I). Strong recommendations were made when the panel judged that the desirable effects of an intervention clearly outweighed the undesirable effects (or vice versa), supported by high- or moderate-certainty evidence, consistent findings, and broad applicability. Weak recommendations were issued when there was greater uncertainty, often due to low or very low certainty evidence, variability in patient preferences, or concerns regarding feasibility or resource use. In formulating recommendations, the panel carefully considered the certainty of the supporting evidence, the balance between benefits and harms, patient values and preferences as informed by patient stakeholders, resource implications and feasibility across diverse healthcare systems, and additional aspects such as equity, acceptability, and implementation challenges. Final recommendations were derived through structured consensus discussions within each PICO group and were subsequently ratified by the full guideline development panel.

VOTING ON THE RECOMMENDATIONS

The recommendations and their strength were developed through a structured consensus process involving the multidisciplinary guideline development panel. After evidence summaries and GRADE appraisals were prepared for each PICO domain, draft recommendations were generated within the corresponding working groups. These draft recommendations were first circulated to the ARCO executive members for initial evaluation of clarity, clinical applicability, and strength.

During scheduled consensus meetings, recommendations were presented to the full guideline development group for discussion and voting. A modified Delphi approach [37] was employed to achieve consensus. Consensus was defined as ≥ 80% agreement. If consensus was not achieved in the first round, recommendations were revised and re-voted in subsequent meetings. Final recommendations were endorsed during a full-panel meeting, where unresolved disagreements were resolved through majority vote after open discussion. Nearly all recommendations achieved unanimous (100%) consensus; in the few instances where unanimity was not reached, consensus was achieved with a single dissenting vote. More detailed information supporting compliance with the AGREE II reporting guideline can be found in Appendix V.

http://dx.doi.org/10.2106/JBJS.25.01616

Understanding the Quality of Evidence and Strength of Recommendation

Table Ia. Strength and Quality Descriptions (used with permission from Joannidis et al., as modified from Guyatt et al.)[31,32]

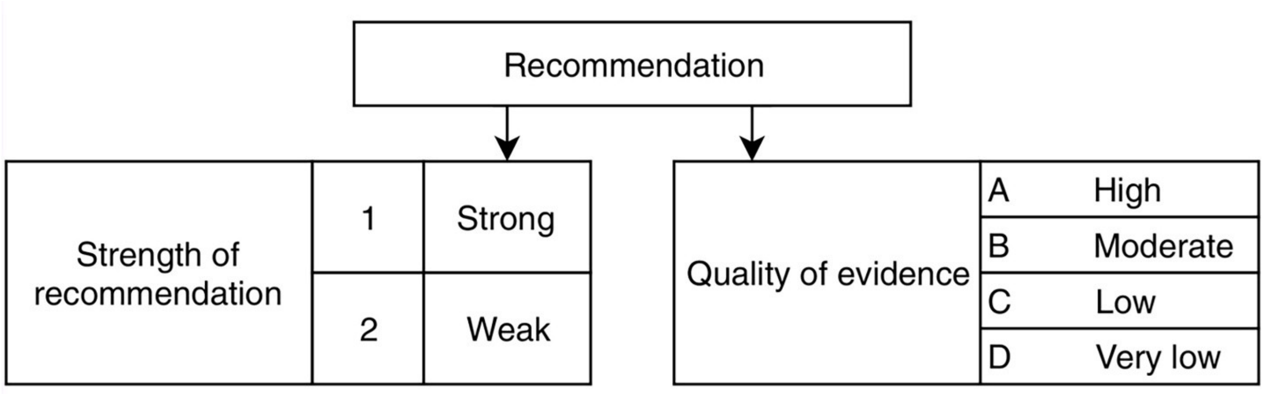

Table Ib.

Quality of evidence and definitions (Guyatt et al.)	
High quality	Further research is very unlikely to change our confidence in the estimate of effect
Moderate quality	Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate
Low quality	Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate
Very low quality	Any estimate of effect is very uncertain

Table II. Interpreting the Strength of a Recommendation

Strength of Recommendation	Patient Counseling (Time)	Decision Aids	Impact of Future Research
Strong	Less	Less Important	Not likely to change
Weak	More	More Important	Change possible/anticipated

REVIEW AND APPROVAL PROCESS

Following the final meeting, the primary draft of the guideline underwent a structured external review period of three weeks to obtain additional input from content experts outside the work group. Written comments were collected using a standardized review form, and all reviewers were required to disclose potential conflicts of interest (COI).

External reviewers—orthopaedic and non-orthopaedic—were encouraged to coordinate review through their evidence-based practice (EBP) or guideline committees, consolidate feedback into a single document, and ensure disclosure of any COI by the chair or designated representative. This process allowed broad stakeholder engagement while maintaining a structured and transparent system of feedback.

The review stage provided an opportunity for external stakeholders to identify overlooked evidence or highlight areas needing clarification. As the draft remained subject to revision until its final approval by the ARCO Executive Committee, confidentiality of all working drafts was emphasized throughout the review process. The draft guideline was also circulated to ARCO members, affiliated societies, and relevant external organizations to maximize opportunities for input.

All comments received during the review period were collated and initially addressed by the chairs of each PICO question and the methodologists. Methodological issues were handled by the methodological team. Clinical questions were addressed by the physician co-chairs. Draft responses were then reviewed by all CPG members, and any proposed modifications to recommendation language were required to be evidence-based and formally approved by the ARCO CPG development group. Final revisions were summarized in a review report that accompanied the guideline through subsequent approval stages.

ARCO APPROVAL PROCESS

This final CPG draft was approved by the ARCO Board. Their responsibility was to approve or reject the document for publication by majority vote; they did not suggest modifications to the scientific content of the guideline.

REVISION PLANS

This guideline is intended to be a living document that will be revised as new evidence becomes available. The guideline development group has committed to a formal review of the literature at least every five years, or sooner if pivotal studies are published that could alter current recommendations. The update process will follow the same rigorous methodology used for the initial guideline. Feedback from clinicians, patients, and other stakeholders will also be solicited to ensure that revisions remain clinically relevant and patient-centered.

CPG DISSEMINATION PLAN

This CPG will be disseminated internationally to support harmonization of ONFH care across diverse practice settings. Publication of this CPG will be announced jointly by ARCO and the American Academy of Orthopaedic Surgeons (AAOS). The final guideline and supporting rationales will be hosted on the AAOS Clinical Practice Guideline website (www.OrthoGuidelines.org) with AAOS endorsement, ensuring wide visibility and accessibility. In addition, ARCO will disseminate the guideline through its website, www.arco-intl.org, newsletters, and affiliated society networks. Further dissemination will include peer-reviewed publications authored by members of the guideline development group, educational articles, and presentations at ARCO and AAOS annual meetings. Shorter versions, including summary recommendation tables and implementation tools, will be prepared for broader circulation.

By leveraging both ARCO's international reach and AAOS endorsement, this CPG will be broadly distributed to orthopaedic surgeons, allied specialists, and healthcare stakeholders worldwide.

STUDY ATTRITION FLOWCHARTS

Figure 1a. PICO 1: Diagnostic Imaging of ONFH

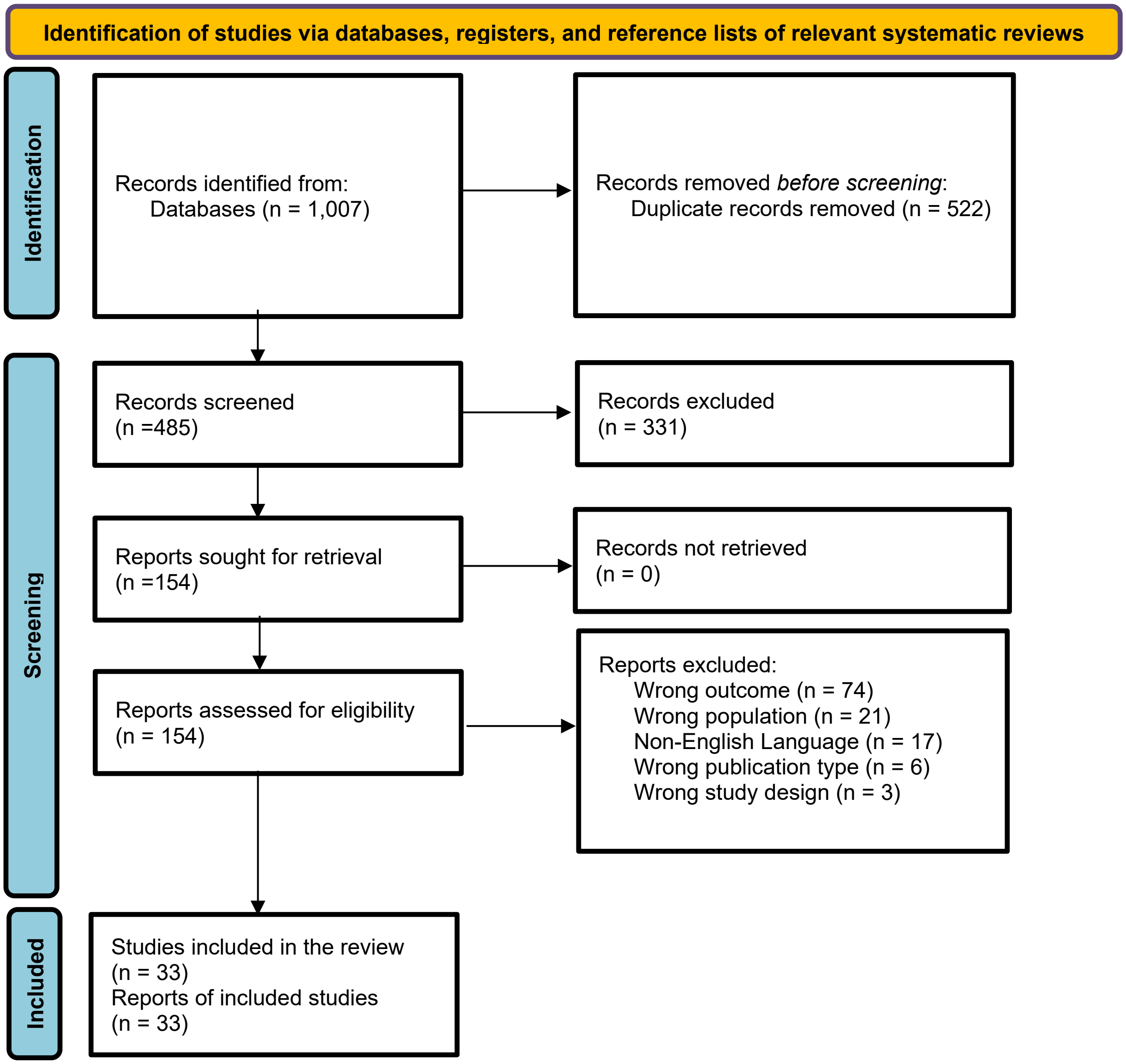

Figure 1b. PICO 2: Treatment of ONFH before subchondral fracture (ARCO stages I and II)

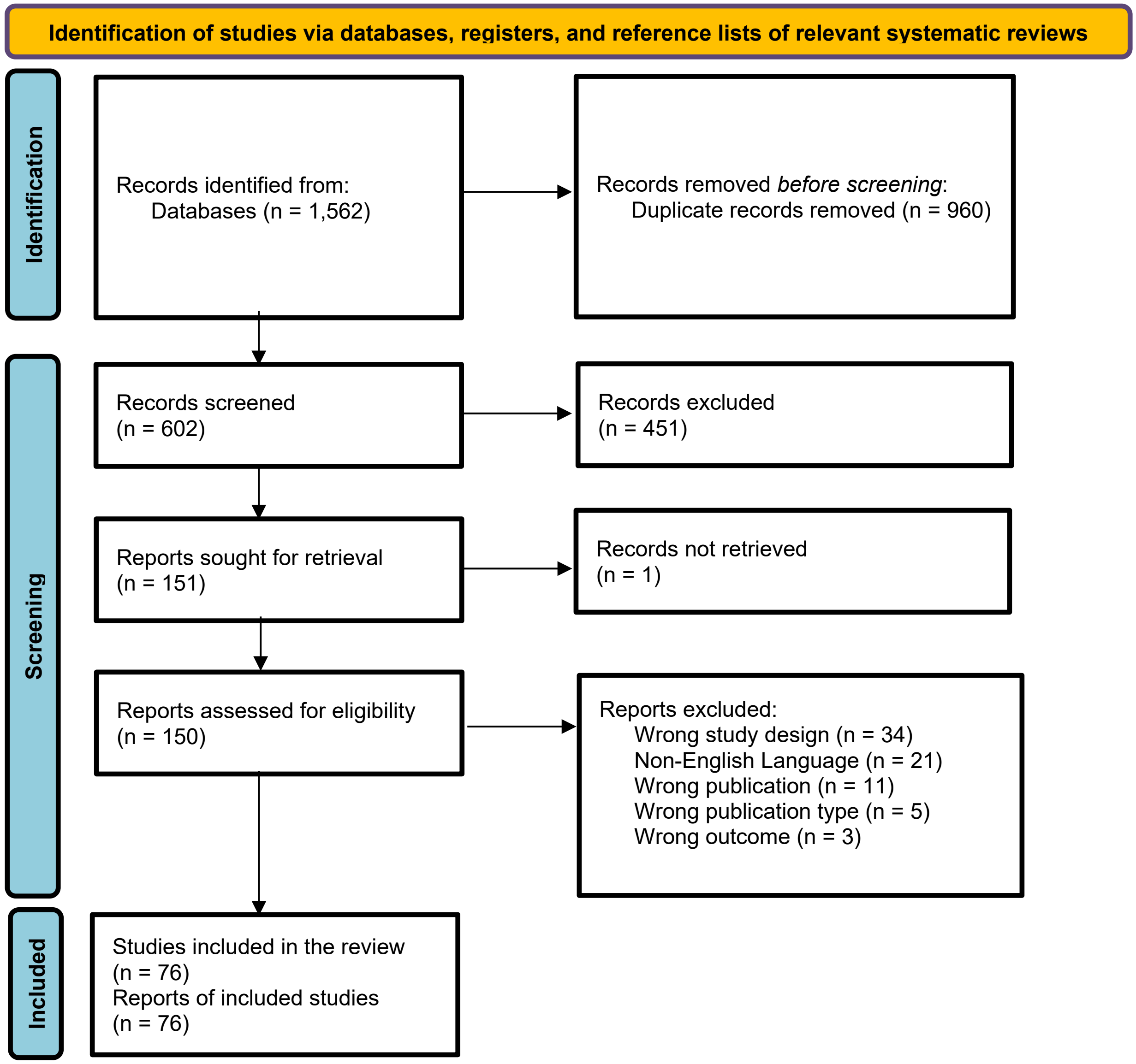

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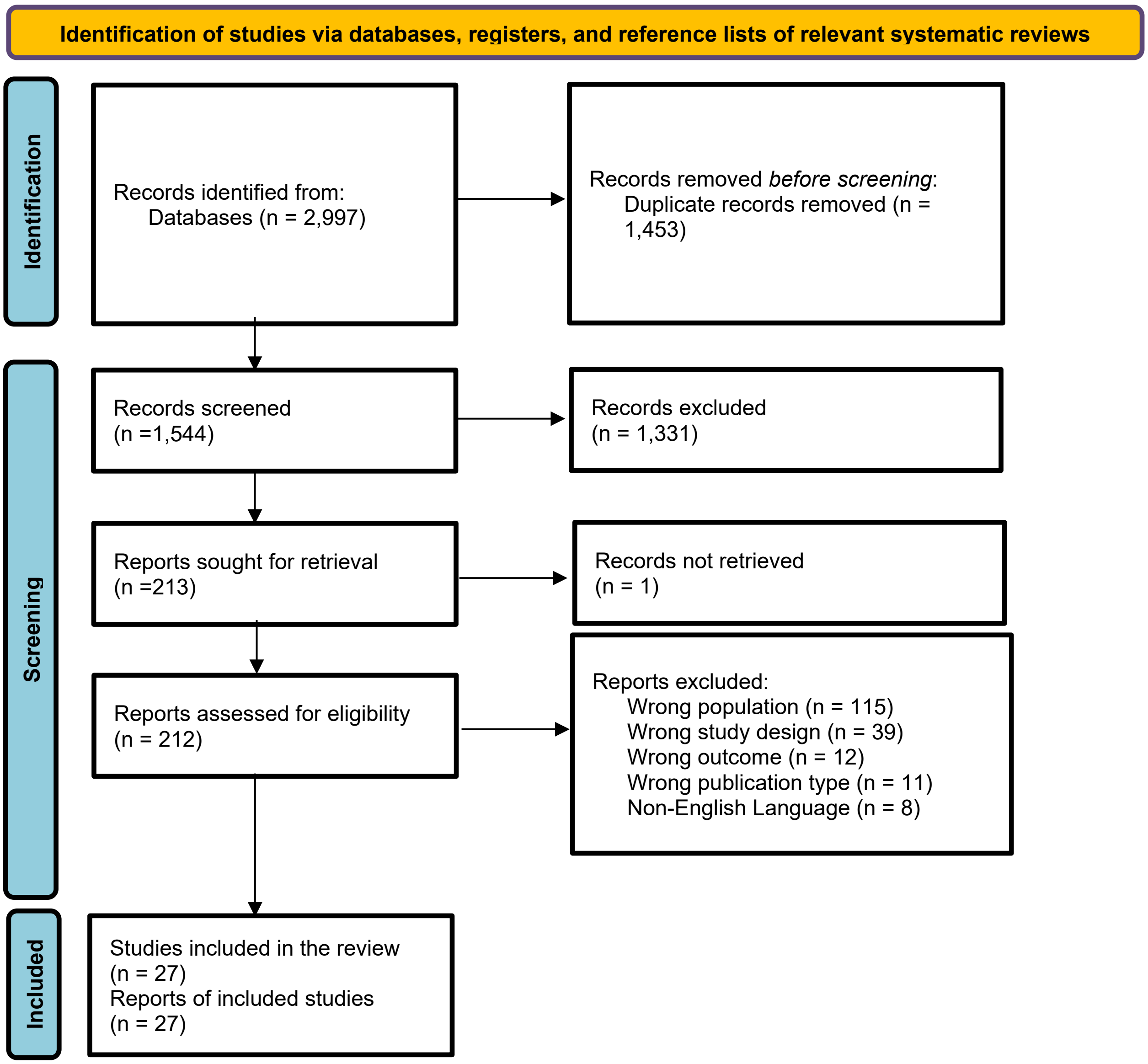
Figure 1c. PICO 3: Treatment of ONFH after subchondral fracture (ARCO stage III)



RECOMMENDATIONS

Recommendations are made when sufficient evidence (at least three studies reporting the same intervention) supports a clear directional statement. Strong recommendations are based on high- or moderate-certainty evidence or when the Evidence-to-Decision (EtD) Framework shows a compelling balance of benefits and harms. Weak recommendations are issued when evidence is low or very low, inconsistent, or when patient preferences, feasibility, or resource concerns limit confidence. In the absence of sufficient evidence, explicitly labeled consensus-based recommendations may be provided.

1. Diagnosis: Optimal imaging modality for diagnosis of ONFH

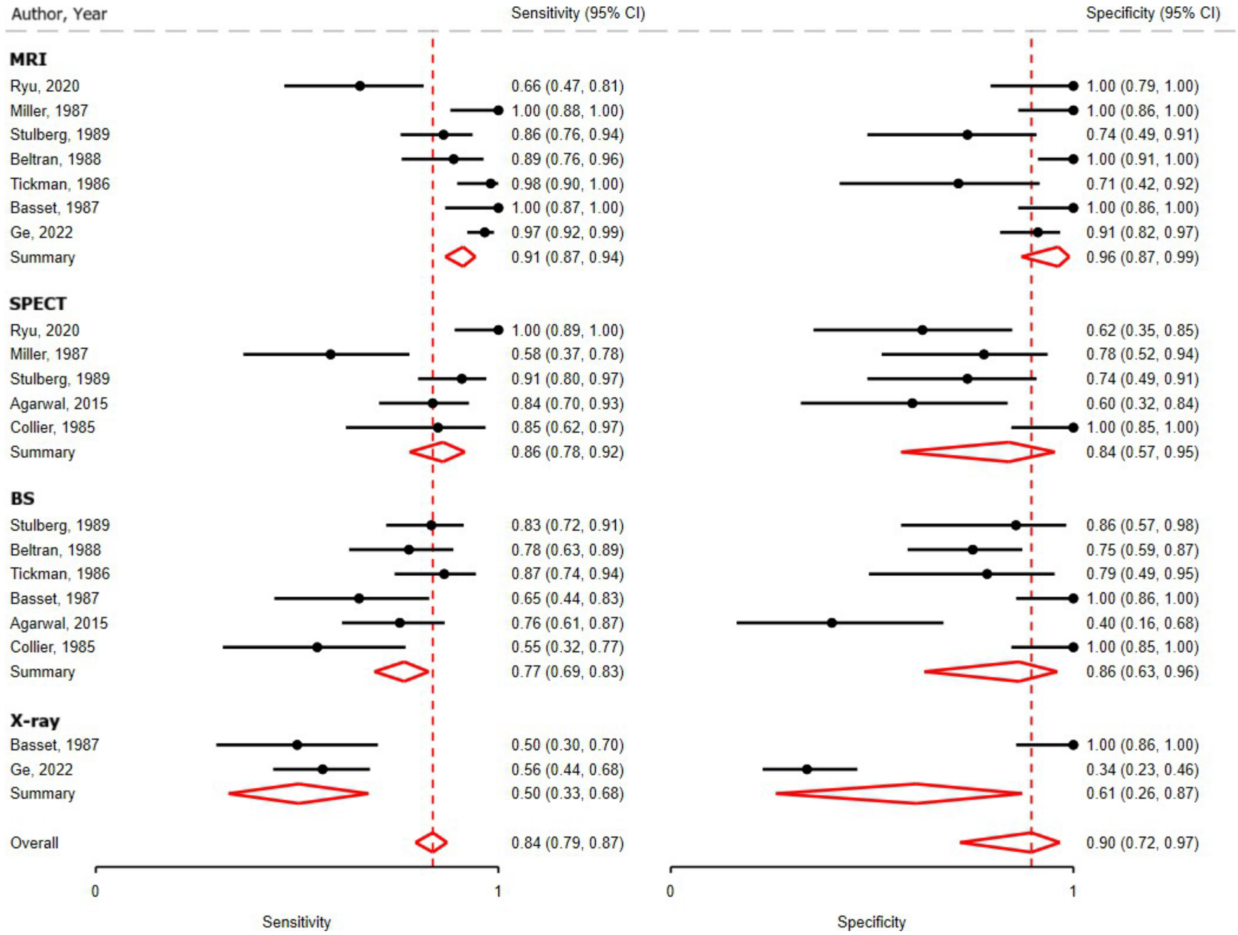
An MRI is the recommended diagnostic imaging test for ONFH.

Quality of Evidence: Very low
Strength of Recommendation: Strong

Description: Limited-level evidence was downgraded due to major concerns addressed in the EtD framework, including substantial imprecision and inconsistency across studies. In the absence of sufficient evidence, the guideline work group is making a recommendation based on its clinical observation and opinion. While plain radiographs often are performed as an initial imaging test, often for cost considerations, it is less sensitive than MRI and the guideline work group strongly supports MRI as the ONFH diagnostic imaging test of choice, given that MRI will detect ONFH before plain radiography and that ONFH has unique features on MRI, in particular the double line sign[37], that help distinguish ONFH from other disease entities or neoplasms. This recommendation achieved unanimous (100%) agreement among all voting members.

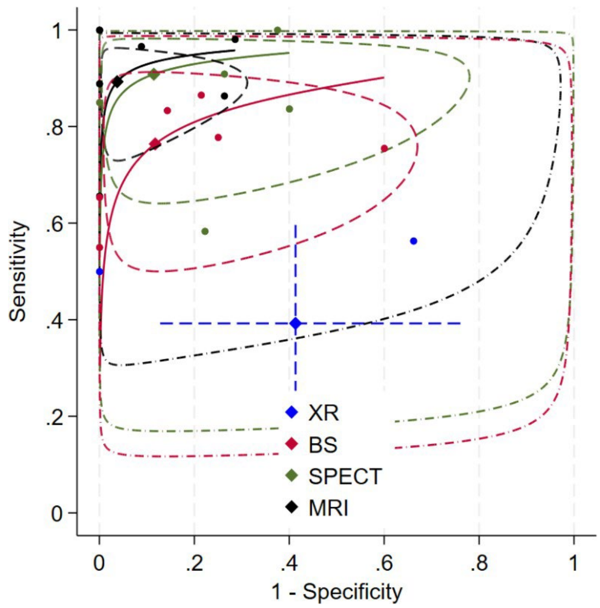
Rationale
By applying a bivariate random effects model, forest plots and summary Receiver Operating Characteristic (sROC) curves were constructed using histology as the reference standard. Among different modalities, MRI had the highest pooled specificity (estimate, 0.96; 95% CI, 0.87, 0.99) and very high pooled sensitivity (estimate, 0.91; 95% CI, 0.87, 0.94) (Figure 2a). The sROC plot (Figure 2b) demonstrated substantial imprecision due to a wide 95% prediction interval, and forest plots (Figure 2a) showed inconsistency across studies, suggesting a very low quality of evidence.

Figure 2a. Forest Plot for Pooled Specificity and Sensitivity Estimates.



Imaging modalities: BS – bone scintigraphy; MRI – magnetic resonance imaging; SPECT - single-photon emission computed tomography; XR – X-ray.

Figure 2b. Graphical Plot of Summary Receiver Operating Characteristic (sROC) Curves



Note: Diamonds represent the pooled summary estimate. Dashed line contours represent 95% confidence interval for the summary estimate. Dash-Dot-Dash line contours represent the 95% prediction interval for the summary estimate.

Benefits/Harms of Implementation

An MRI offers high diagnostic accuracy, avoids radiation, and aligns with patient preference for non-invasive testing, supporting an earlier and more effective management of ONFH. However, higher cost, limited availability, contraindications (e.g., implants, claustrophobia), and variability in diagnostic quality may restrict its use, while overutilization could increase healthcare costs.

Outcome Importance

Accurate identification of ONFH, particularly in early stages, is critical for guiding appropriate treatment, preventing disease progression, and optimizing long-term joint preservation.

Cost Effectiveness/Resource Utilization

The cost of an MRI has become more reasonable with increasing availability, making it a feasible option in many healthcare settings. However, plain radiographs remain less expensive and may be used as an initial assessment. The CT scans or other advanced imaging, such as bone scan, and Single Photon Emission Computed Tomography (SPECT), may be considered in settings when MRI is not accessible.

Acceptability

An MRI is widely accepted among clinicians and patients as the preferred diagnostic imaging modality for ONFH due to its accuracy and noninvasive nature.

Feasibility

An MRI is feasible in most modern medical settings, but may be limited by cost, accessibility, or patient-specific contraindications (e.g., implants, claustrophobia). In such cases, other modalities can be employed, although their diagnostic performance is lower.

Future Research

Future research should primarily focus on high-quality comparative studies evaluating the diagnostic accuracy of different imaging modalities for ONFH, particularly in early disease stages when the disease may be clinically occult but potentially reversible. Additional priorities include evaluating cost-effective diagnostic algorithms incorporating staged imaging and further validating emerging modalities to enhance early and accurate detection of ONFH.

2. Diagnosis: Optimal imaging modality for detecting subchondral fracture in ONFH

A CT or an MRI is preferred over plain radiography for detecting subchondral fractures. There is variable evidence to justify the benefit of a frog-leg lateral radiograph.

Quality of Evidence: Very low
Strength of Recommendation: Weak

Description: The evidence base for imaging subchondral fractures in ONFH is limited, with only three of the 33 included studies directly addressing this outcome. Evidence was downgraded due to inconsistency and limited comparative data. Despite these limitations, the workgroup supports CT and MRI as the diagnostic tests of choice based on available evidence, expert observation, and consensus. Subchondral fractures of the femoral head related to osteonecrosis frequently occur in the superior, anterior segment and are often more readily visualized on the frog-leg lateral view radiograph as opposed to the anterior-posterior view projection. Nevertheless, subtle fractures that have not yet resulted in subchondral collapse are more readily visualized on cross-sectional imaging such as CT or MRI. Therefore, as a subchondral fracture is the major distinction between ARCO stages II and III, CT or MRI is critical to perform for accurate staging of ONFH. This recommendation achieved unanimous (100%) agreement among all voting members.

Rationale
Among the three studies, results were inconsistent regarding the utility of frog-leg lateral versus anteroposterior X-ray views. CT and MRI were more frequently used as reference standards, with CT demonstrating superior ability to identify subchondral fractures that were not visualized by MRI or conventional radiography in several cases. SPECT and SPECT/CT may provide additional diagnostic value, but comparative data are lacking. A CT appears more sensitive and specific than MRI although confidence in this conclusion is tempered by the limited and heterogeneous evidence base.

Benefits/Harms of Implementation
The use of CT allows for more accurate identification of subchondral fractures, which is crucial for staging ONFH and guiding surgical decision-making. A CT is generally less costly and faster to perform than MRI, but it carries the risk of radiation exposure. MRI, while advantageous for evaluating bone marrow and soft tissue changes, may fail to detect some fractures identifiable by CT, especially in the absence of a joint effusion. Ultimately, the choice between CT and MRI represents a trade-off between diagnostic accuracy and radiation risk and should be guided by clinical judgment.

Outcome Importance
Detection of subchondral fracture is critical. Clinically, it strongly influences ONFH prognosis and treatment, particularly in determining the selection of joint-preserving versus reconstructive surgical strategies. Research-wise, because it helps ensure that the treatment across an entire patient cohort is for a uniform cadre of patients who have similar prognoses and outcomes. As such, CT or MRI are critical to perform for accurate staging of ONFH.

Cost Effectiveness/Resource Utilization
A CT is more costly than plain radiography but generally less expensive than an MRI. Its increasing availability has improved feasibility over the past years. Resource considerations may vary depending on local access and the need for repeat imaging. In settings where CT is unavailable, MRI may serve as a secondary option, though with lower sensitivity for subchondral

fractures.

Acceptability
Both CT and MRI are widely accepted in clinical practice for bone imaging and are often favored by surgeons for detecting fractures. Patient acceptability is high, although concerns exist about CT radiation exposure, particularly for younger patients requiring repeat studies.

Feasibility
A CT is feasible in most modern healthcare systems, offering rapid acquisition and high diagnostic yield. However, its availability may be limited in rural or resource-constrained settings. MRI is feasible in many institutions, but less accessible globally, and requires longer scan times.

Future Research
Future research should prioritize high-quality comparative studies evaluating the diagnostic performance of CT versus MRI, as well as other advanced modalities such as SPECT, SPECT/CT, for detecting subchondral fractures in ONFH. Standardized protocols and outcome measures are imperative to reduce heterogeneity and strengthen confidence in imaging-based diagnostic procedures.

3. Diagnosis: Optimal imaging modality for monitoring the effect of any intervention for treating ONFH

An MRI can quantify the area and extent of osteonecrosis and may be used to monitor the effect of any treatment in ONFH.

Quality of Evidence: Very low
Strength of Recommendation: Weak

Description: The evidence base for imaging modalities to monitor ONFH progression or response to treatment is limited. Only three studies addressed this outcome, with just one providing a direct comparison between MRI and bone scintigraphy. Evidence was downgraded due to the limited number of studies and the lack of standardized outcome thresholds. Despite these limitations, the workgroup supports MRI as the preferred modality for monitoring treatment response, based on its ability to visualize lesion extent by demonstrating the lesion border and response to intervention. This recommendation achieved 94% agreement among all voting members.

Rationale

Across the three identified studies, two non-comparative studies reported that MRI consistently demonstrated the capacity to measure lesion size and extent over time. A study compared MRI with bone scintigraphy and reported that MRI was superior to bone scintigraphy for detecting changes in necrotic involvement after intervention. However, the threshold for defining clinically meaningful MRI-detected changes remains undefined, limiting its ability to directly guide treatment modification. While CT, radiographs, and bone scintigraphy can provide supportive information, they lack the sensitivity of MRI in detecting subtle changes in bone and marrow tissue.

Benefits/Harms of Implementation

An MRI provides a non-invasive method to evaluate disease progression and treatment response, which can aid in clinical decision-making. Potential harms include high cost, variability in access, and the absence of standardized benchmarks for interpreting imaging changes. Overuse of MRI for routine follow-up may increase healthcare utilization without clear evidence that serial imaging improves patient outcomes.

Outcome Importance

Monitoring disease progression and treatment response is critical for tailoring management strategies in ONFH. The ability to assess changes in lesion size or extent can influence whether joint-preserving measures are continued or whether more invasive procedures, such as arthroplasty, are indicated.

Cost Effectiveness/Resource Utilization

An MRI is more costly than radiography and CT and may be limited in availability in some healthcare settings. Repeat imaging can further increase costs. Bone scintigraphy and CT may be more accessible alternatives, while less sensitive for monitoring subtle disease changes.

Acceptability

An MRI is widely accepted by clinicians as the imaging modality of choice for ONFH diagnosis and follow-up. However, patient acceptability may be reduced by MRI cost, longer acquisition times, and contraindications such as claustrophobia or implanted devices.

Feasibility
An MRI is feasible in most tertiary care and academic centers but may be less accessible in resource-limited settings. Its role in routine monitoring of ONFH is constrained by availability, cost, and lack of clear interpretive thresholds for clinically meaningful change.

Future Research
Future studies should establish standardized definitions of clinically meaningful MRI changes and determine whether serial imaging leads to improved patient outcomes. Comparative studies evaluating MRI against CT, bone scintigraphy, or advanced hybrid modalities (e.g., SPECT/CT) for ONFH monitoring are needed.

http://dx.doi.org/10.2106/JBJS.25.01616

4. Diagnosis: Imaging studies to correlate and differentiate symptomatic versus asymptomatic ONFH

In ONFH before subchondral fracture or collapse, MRI is recommended to determine if hip pain is due to ONFH, as bone marrow edema (BME) and joint effusion on MRI correlate with pain. BME, when compared to joint effusion, is a more accurate indicator of hip pain.

Quality of Evidence: Moderate
Strength of Recommendation: Strong

Description: There are three studies that met the inclusion criteria. A meta-analysis showed that BME was strongly associated with pain, with a positive likelihood ratio of 16.2. Joint effusion was less specific, with a likelihood ratio of 3.3. Evidence quality was downgraded due to small sample sizes and limited study numbers, but upgraded for large effect sizes. Overall certainty was judged as moderate. This recommendation achieved 83% agreement among all voting members.

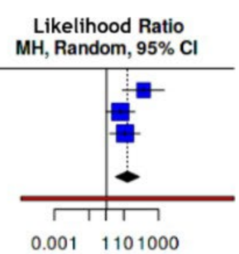
Rationale

Osteonecrosis of the femoral head may or may not cause hip or groin pain. In patients who did not have any hip pain, ONFH may be diagnosed incidentally on imaging performed for reasons unrelated to the hip. When ONFH is identified in patients who have symptoms, it is difficult to know whether or not the pain generator is the ONFH or a different pathology. An MRI provides some insight into this issue.

An MRI offers non-invasive detection of BME and joint effusion without radiation exposure. The BME has demonstrated high specificity for symptomatic ONFH, whereas joint effusion was less reliable. Based on a meta-analysis of three studies, symptomatic patients were 16.2 times more likely to have a positive sign for BME on MRI compared to asymptomatic patients (62.7% with BME among symptomatic patients versus 1.8% with BME among asymptomatic patients; Figure 3a). In contrast, symptomatic patients were 3.3 times more likely to have a positive sign for joint effusion (grade 2 or higher; 77.2% with effusion among symptomatic patients versus 23.8% with BME among asymptomatic patients; Figure 3b). Therefore, BME appears to be more specific to symptomatic ONFH, compared to joint effusion (grade 2 or higher). Despite the limited number of studies, the strong association between BME and pain, along with clinical consensus, supports MRI as the preferred modality to correlate imaging findings with symptoms.

Figure 3a. Forest Plot of Positive Likelihood Ratio for Bone Marrow Edema in Symptomatic Versus Asymptomatic Patients.

Study	Symptomatic Events	Symptomatic Total	Asymptomatic Events	Asymptomatic Total	Weight	Likelihood Ratio MH, Random, 95% CI
Hatanaka 2019	40	46	0	77	23.4%	135.00 [8.50; 2143.81]
Huang 2003	52	98	1	12	39.5%	6.37 [0.97; 41.97]
Koo 1999	7	14	1	23	37.1%	11.50 [1.58; 83.89]
Total (95% CI)		**158**		**112**	**100.0%**	**16.21 [3.50; 75.13]**
Prediction interval						**[0.00; 22135621.62]**

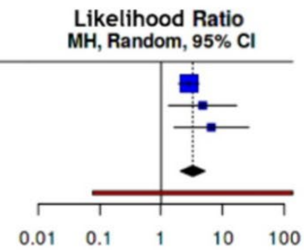


Heterogeneity: $Tau^2 = 0.6239$; $Chi^2 = 3.29$, df = 2 ($P = 0.19$); $I^2 = 39\%$
Test for overall effect: $Z = 3.56$ ($P < 0.01$)
MH, Random - Mantel-Haenszel random effect regression model.

Figure 3b. Forest Plot of Positive Likelihood Ratio for Joint Effusion (Grade 2 or Higher) in Symptomatic Versus Asymptomatic Patients.

Study	Symptomatic Events	Symptomatic Total	Asymptomatic Events	Asymptomatic Total	Weight	Likelihood Ratio MH, Random, 95% CI
Hatanaka 2019	37	46	22	77	77.9%	2.82 [1.92; 4.12]
Huang 2003	77	98	2	12	12.1%	4.71 [1.32; 16.78]
Koo 1999	8	14	2	23	10.1%	6.57 [1.62; 26.64]
Total (95% CI)		**158**		**112**	**100.0%**	**3.26 [2.06; 5.16]**
Prediction interval						**[0.08; 137.99]**

Heterogeneity: $Tau^2 = 0.0323$; $Chi^2 = 1.77$, df = 2 (P = 0.41); $I^2 = 0\%$
Test for overall effect: Z = 5.06 (P < 0.01)



MH, Random - Mantel-Haenszel random effect regression model.

Benefits/Harms of Implementation
An MRI assessment of BME provides clinicians with a reliable marker for symptom correlation in ONFH, improving diagnostic confidence and guiding treatment. Benefits include high accuracy, non-invasiveness, and avoidance of radiation. Potential harms include higher cost, limited access in some settings, and patient-specific contraindications such as claustrophobia or metallic implants.

Outcome Importance
Identifying whether symptoms are attributable to ONFH is clinically important, as the presence of pain unrelated to ONFH may impact a patient's management and decision-making regarding other potential or existing pathologies that may be confounding a patient's clinical presentation.

Cost Effectiveness/Resource Utilization
An MRI is more expensive than CT and radiography, but provides unique diagnostic value by distinguishing symptomatic from asymptomatic hips, which may help avoid unnecessary interventions. CT and radiographs are less expensive, but not reliable for this purpose.

Acceptability
An MRI is widely accepted by clinicians and patients for assessing symptom correlation in ONFH owing to its high accuracy and favorable safety profile.

Feasibility
An MRI is feasible in most clinical settings, but can be limited by access, cost, and patient contraindications. In resource-limited settings, feasibility may be restricted. In these conditions, clinical judgment may guide correlation of pain to ONFH.

Future Research
Future research should focus on larger, high-quality comparative studies to validate the accuracy of BME and joint effusion in distinguishing symptomatic from asymptomatic ONFH. Standardized imaging protocols are needed to strengthen diagnostic procedures.

5. Treatment: Core decompression (CD) versus CD plus bone marrow concentrate (BMC) for the treatment of pre-collapse ONFH

For patients who have ONFH without subchondral fracture or collapse (ARCO stages I to II), CD can be considered for treatment. For patients undergoing CD, adding BMC to the procedure may reduce the risk of femoral head collapse. However, there are no comparative data to clearly state what treatment is best for pre-collapse ONFH to prevent subchondral fracture.

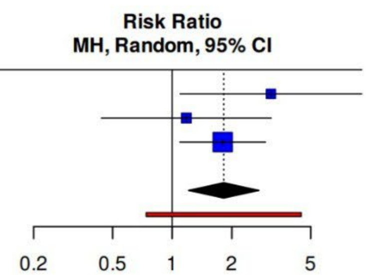
Quality of Evidence: Low
Strength of Recommendation: Weak

Description: A meta-analysis of three comparative studies (Figure 4) showed that CD alone was associated with a higher risk of femoral head collapse than CD plus BMC (relative risk 1.82; 95% CI 1.21 to 2.74; *P* = 0.0042). Adding BMC reduced the absolute risk of collapse by approximately 26% (95% CI 10 to 43). Heterogeneity was low (I² = 0%), but confidence was downgraded due to small sample sizes and inconsistency in the magnitude of effect estimate between studies (Figure 4). This recommendation achieved unanimous (100%) agreement among all voting members.

Figure 4. Forest Plot for Relative Risk of Collapse After CD Alone Versus CD Enhanced with BMC

Study	CD Events	CD Total	CD+BMC Events	CD+BMC Total	Weight	Risk Ratio MH, Random, 95% CI
Gangji (RCT) 2011	8	11	3	13	15.1%	3.15 [1.10; 9.06]
Pepke (RCT) 2016	6	14	4	11	17.2%	1.18 [0.44; 3.17]
Boontanapibul (non-RCT) 2021	19	33	16	50	67.7%	1.80 [1.09; 2.96]
Total (95% CI)		**58**		**74**	**100.0%**	**1.82 [1.21; 2.74]**
Prediction interval						**[0.74; 4.48]**

Heterogeneity: $Tau^2 < 0.0001$; $Chi^2 = 1.78$, df = 2 (P = 0.4102); $I^2 = 0.0\%$
Test for overall effect: Z = 2.86 (P = 0.0042)



BMC – bone marrow concentrate; CD – core decompression; MH, Random - Mantel-Haenszel random effect regression model.

Rationale

A CD remains one of the most widely used interventions for early ONFH, and most studies suggest it can be effective in preventing or delaying femoral head collapse. However, outcomes remain inconsistent. The addition of BMC may enhance biological repair and further improve femoral head preservation. Despite these promising findings, the strength of evidence is limited by the small number of studies, variability in BMC preparation protocols, and lack of standardized long-term outcome reporting.

Benefits/Harms of Implementation

Potential benefits of CD+BMC include reduced collapse rates, delayed need for arthroplasty, and the opportunity to preserve the native hip joint. Harms include the added operative time, cost, and need for specialized cell-processing facilities, along with donor site morbidity.

Outcome Importance

Preventing femoral head collapse is a critical goal in pre-collapse ONFH, as it strongly influences long-term native joint survival, the success of joint-preserving strategies, and the timing of possible hip arthroplasty. As ONFH often occurs in young adults and middle-aged patients who have an expected lifespan of many decades, it is in their best interest to prevent a subchondral fracture from developing, as the subsequent secondary arthritis that routinely occurs after a subchondral fracture is often treated by hip arthroplasty, which has a limited durability and known failure rate requiring revision arthroplasty procedures. For this reason, joint-preserving procedures that have low morbidity and do not alter or complicate subsequent hip arthroplasty are favored.

Cost Effectiveness/Resource Utilization

A CD is less resource-intensive and widely available, but its efficacy may be lower than CD plus BMC. A CD plus BMC may provide improved outcomes, but requires cell-processing expertise, infrastructure, and additional costs, which may limit its applicability in some settings.

Acceptability

A CD is well established and generally accepted by both patients and clinicians. The addition of BMC is increasingly accepted in specialized centers, though variability in preparation methods and limited evidence may influence adoption.

Feasibility

A CD can be performed in most orthopaedic settings, while CD plus BMC requires additional resources and technical expertise, which may adversely affect its feasibility in centers with limited resources.

Future Research

Future research should focus on adequately powered randomized controlled trials comparing CD versus CD plus BMC, using standardized BMC preparation methods. Studies should also explore cost-effectiveness and patient-reported measures to guide broader adoption.

6. Treatment: Vascularized Fibular Grafting (VFG) for the treatment of pre-collapse ONFH

For patients who have ONFH without subchondral fracture or collapse (ARCO stages I to II), VFG may be considered as a femoral head-preserving option, but this must be balanced with the increased morbidity of this procedure as compared to lower-complexity procedures.

Quality of Evidence: Very low
Strength of Recommendation: Weak

Description: Observational series suggest that VFG is associated with relatively low 5-year collapse rates (pooled risk approximately 13%, k = four studies). However, evidence is limited to single-arm studies without high-quality comparative trials, and outcomes are highly dependent on surgical expertise and case selection. This recommendation achieved unanimous (100%) agreement among all voting members.

Rationale

A VFG has been used as a biological and mechanical support to preserve femoral head integrity in early ONFH. While results from select centers are encouraging, the procedure is technically demanding, resource-intensive, and carries donor site morbidity. The absence of adequately powered comparative studies and heterogeneous outcome reporting limits confidence in its superiority over less invasive techniques.

Benefits/Harms of Implementation

Potential benefits of VFG include improved femoral head preservation, reduced collapse rates, and possible delay or avoidance of arthroplasty. Harms include significant surgical complexity, longer operative time, and donor site morbidity.

Outcome Importance

Preserving the femoral head is particularly important in younger patients who have ONFH. As ONFH often occurs in young adults and middle-aged patients who have an expected lifespan of many decades, it is in their best interest to prevent a subchondral fracture from developing, as the subsequent secondary arthritis that routinely occurs after a subchondral fracture is often treated by hip arthroplasty, which has a limited durability and known failure rate requiring revision arthroplasty procedures. For this reason, joint-preserving procedures that have low morbidity and do not alter or complicate subsequent hip arthroplasty are favored. Nevertheless, VFG may provide durable outcomes in carefully selected cases; however, the high surgical burden necessitates weighing the benefits against the risks that include not only the impact on the subsequent hip arthroplasty but also the donor site morbidity of harvesting the autogenous vascularized fibula.

Cost Effectiveness/Resource Utilization

A VFG is a resource-intensive technique, requiring microsurgical expertise, specialized equipment, and longer hospital stays. These factors increase cost and may limit widespread applicability, especially in resource-limited healthcare systems.

Acceptability

A VFG is generally acceptable among experienced surgeons and patients seeking joint preservation, but its invasiveness and potential morbidity may make it less appealing compared with less complex alternatives.

Feasibility
Feasibility is limited to high-volume centers with microsurgical expertise and appropriate infrastructure. The technical demands make VFG impractical in many settings.

Future Research
Future studies should include adequately powered comparative trials evaluating VFG against other femoral head–preserving procedures, with standardized outcome measures and long-term follow-up.

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7. Treatment: Osteotomy for the treatment of pre-collapse ONFH

For patients who have ONFH without subchondral fracture or collapse (ARCO stages I to II), proximal femoral osteotomy may occasionally be considered to preserve the femoral head and shift weight-bearing to the non-necrotic bone, but this must be balanced by the deformity created and any impact on subsequent joint arthroplasty procedures.

Quality of Evidence: Very low
Strength of Recommendation: Weak

Description: Very limited, single-institutional, observational data suggest low long-term collapse rates after osteotomy (pooled risk approximately 11% at 20 years; k = three studies) but techniques vary (varus and valgus repositioning, rotational repositioning), and studies are comparable, with heterogeneous reporting and small sample sizes. This recommendation achieved unanimous (100%) agreement among all voting members.

Rationale
Osteotomy, most commonly in the coronal plane or rotationally along the femoral neck longitudinal axis, can biomechanically offload the necrotic segment and may preserve the native hip in select early-stage cases. However, technical demands, variability across varus/valgus and rotational techniques, and the potential to complicate future arthroplasty by distorting anatomy and compromising future implant fit, limit enthusiasm in the absence of robust comparative trials. Selection criteria should involve assessment of lesion position, size, age, and weight as defined by body mass index (BMI).

Benefits/Harms of Implementation
Osteotomy may preserve the femoral head and delay or avoid the need for arthroplasty by shifting weight-bearing away from necrotic bone, offering durable outcomes in select patients. However, the procedure carries significant drawbacks, including technical complexity and longer recovery. Also, it may complicate future arthroplasty due to altered proximal femoral anatomy. These trade-offs limit its routine use despite potential long-term benefit in carefully chosen cases.

Outcome Importance
Preventing/delaying collapse and maintaining joint function are critical to delay or avoid arthroplasty, particularly relevant for younger patients. Osteotomy may achieve these aims in select cases but with a higher surgical morbidity, including the risk of nonunion/malunion, issues related to internal fixation placement, and the altered anatomy create challenges for subsequent hip arthroplasty procedures.

Cost Effectiveness/Resource Utilization
Compared with lower-complexity options (e.g., CD), osteotomy generally requires longer operative time, specialized expertise, and more intensive postoperative care with longer recuperative time, factors that increase costs and limit scalability.

Acceptability
Acceptable to experienced surgeons and motivated patients pursuing joint preservation; acceptance may be lower where less invasive options exist or when the possibility of more difficult future THA is a major concern.

Feasibility

Osteotomy is best suited for centers with expertise in hip preservation and the capacity for careful preoperative planning, including lesion mapping and precise surgical execution. Feasibility may be limited in settings without sufficient surgical experience and preplanning resources.

Future Research

Adequately powered comparative studies that evaluate specific osteotomy types (varus, valgus, anterior/posterior rotational) against other head-preserving procedures are needed, with standardized staging, lesion stratification, and long-term survivorship.

8. Treatment: CD plus non-vascularized autogenous fibula graft for the treatment of pre-collapse ONFH (ARCO stages I and II)

The workgroup recommends against adding a non-vascularized autogenous fibular graft to CD for the purpose of preventing femoral head collapse, as there is no clear benefit, and it incurs the morbidity of obtaining the autogenous bone graft.

Quality of Evidence: Very low
Strength of Recommendation: Weak

Description: Pooled data showed high 10-year collapse rates (pooled risk approximately 64%, k = three studies), which were worse than outcomes reported with other femoral head-preserving options. Additionally, the available evidence is limited to small, non-comparative, and heterogeneous observational studies. This recommendation achieved unanimous (100%) agreement among all voting members.

Rationale

Although intended to provide structural support following CD, non-vascularized fibular grafting has not been shown to improve outcomes, while it introduces the added morbidity of graft harvest. Inconsistent reporting, small sample sizes, and the lack of high-quality comparative studies further limit confidence in its utility. There was consensus agreement among the workgroup that the increased morbidity of obtaining the non-vascularized, autogenous fibula graft is not justified, given the lack of evidence demonstrating any benefit.

Benefits/Harms of Implementation

While theoretically providing mechanical support to the femoral head, non-vascularized fibular grafting after CD has not demonstrated improved collapse prevention rates. Harms include increased operative time, donor site morbidity, and lack of evidence supporting added benefit, making routine use unjustified.

Outcome Importance

Preventing femoral head collapse is central in pre-collapse ONFH; however, CD plus non-vascularized fibula grafting does not achieve this aim and may expose patients to unnecessary risks without clear benefit.

Cost Effectiveness/Resource Utilization

In comparison with CD alone or CD plus BMC, the addition of a non-vascularized fibula graft to CD incurs increased costs, surgical complexity, donor site morbidity, and hospital resource utilization without proven benefit, thereby rendering it a low-value intervention.

Acceptability

Acceptability is limited given the lack of demonstrated efficacy and the added morbidity of fibula harvest. Patients and clinicians generally prefer alternatives with stronger supporting evidence.

Feasibility

This procedure is technically feasible in most orthopaedic centers, but the absence of evidence for improved outcomes reduces justification for its use. The added morbidity and lack of clear benefit limit practical adoption.

Future Research

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Future research should clarify whether any subgroup benefits from this approach. However, current evidence suggests prioritizing comparative trials of other femoral head–preserving techniques with greater biological plausibility and stronger preliminary data.

9. Treatment: Other joint-preserving treatments for pre-collapse ONFH

For patients who have ONFH without subchondral fracture or collapse (ARCO stages I to II), there are many other treatments in the literature, beyond those previously outlined in the above guidelines; however, the evidence base consists of fewer than three studies eligible for analysis, per the guideline inclusion criteria. Therefore, we issue no recommendation for the routine use of these other treatments to prevent subchondral fracture in ARCO stage-I to II ONFH.

Quality of Evidence: Insufficient evidence
Strength of Recommendation: None

Description: Isolated studies have evaluated a variety of interventions, including pharmacologic agents (e.g., alendronate, zoledronate), biologics (e.g., autologous mesenchymal stem cells [MSCs], platelet-rich plasma [PRP], bone morphogenetic proteins [BMPs]), mechanical implants (e.g., porous tantalum rods), and adjunctive therapies (e.g., extracorporeal shockwave therapy [ESWT], pulsed electromagnetic field [PEMF] stimulation, hyperbaric oxygen therapy). Each is represented by one or two small, heterogeneous studies without replication or comparative data. This recommendation achieved 94% agreement among all voting members.

Rationale

Although some approaches appear promising, the current body of evidence is insufficient to make a conclusion regarding their effectiveness. The heterogeneity of interventions and lack of reproducible, high-quality studies prevent either evidence-based or consensus-driven recommendations.

Benefits/Harms of Implementation

Potential benefits are theoretical, based on small single-center reports. Harms include procedural morbidity, additional cost, and uncertain efficacy, with no demonstrated advantage over established options.

Outcome Importance

Preventing femoral head collapse is a key clinical outcome; however, available data are too limited to determine whether these interventions achieve this goal.

Cost Effectiveness/Resource Utilization

Given the lack of sufficient evidence of efficacy, these treatments cannot be considered cost-effective for routine practice.

Acceptability

Some of these interventions, such as ESWT, are generally considered acceptable by both clinicians and patients. However, in the absence of sufficient supporting evidence, their routine use in standard clinical practice is not currently recommended.

Feasibility

Feasibility varies substantially across these interventions. Some, such as ESWT, are already in routine clinical use in many centers and are relatively easy to implement. Others, such as pulsed electromagnetic field (PEMF) stimulation, or platelet-rich plasma (PRP), may be available in select institutions but not universally adopted. More resource-intensive or infrastructure-dependent approaches, such as hyperbaric oxygen therapy, bone morphogenetic proteins (BMPs), or porous

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tantalum rod implantation, remain limited to specialized centers.

Future Research
Adequately powered and reproducible comparative trials with standardized staging and outcome measures are needed to determine whether any of these interventions provide clinically meaningful benefit.

10. Treatment: Observation versus treatment intervention for patients who have asymptomatic ONFH before subchondral fracture.

In the absence of sufficient evidence, it is the opinion of the workgroup that for patients with asymptomatic ONFH, without subchondral fracture or collapse (ARCO stages I to II), treatment may be considered depending on the risk of developing symptoms and subchondral collapse (e.g., ARCO size types 2 or 3), as well as the volume or extent of involvement. Treatments with low morbidity are preferred.

Quality of Evidence: Very low
Strength of Recommendation: Weak

Description: There are no RCTs or controlled prospective trials that have addressed this PICO question. Observational studies show that a substantial proportion of asymptomatic hips progress to pain or collapse over time; pooling was not done due to the variable length of follow-up across studies. In Kang et al.[62], 56% of initially asymptomatic patients developed symptoms within 2.3 years. Min et al.[80] reported 38% developed symptoms and 32% collapsed within four years. Nam et al.[90] found 59% became symptomatic within approximately two years. In sickle cell disease, nearly all stages I to II lesions became symptomatic within two to three years [45]. A larger lesion size and laterally based femoral head location consistently predicted worse outcomes. The systematic review by Mont et al.[86] concluded that large lesions have an approximately 84% risk of progression, medium lesions approximately 25%, while small/medial lesions carry less than 10% risk. This recommendation achieved 94% agreement among all voting members.

Rationale
Asymptomatic ONFH often progresses to symptomatic disease. However, the progression rate varies by lesion characteristics. Larger and more lateral lesions are at particularly high risk of becoming symptomatic and collapsing, while small- and medially-located lesions may remain stable. Evidence for treatment effectiveness in asymptomatic patients is lacking, and clinical practice must balance the risks of unnecessary intervention against the likelihood of progression.

Benefits/Harms of Implementation
Potential benefits of early treatment in high-risk, asymptomatic patients include preventing collapse and reducing the need for future arthroplasty. Harms include subjecting patients who may never become symptomatic to invasive procedures with associated morbidity, cost, and recovery burden.

Outcome Importance
Preventing progression from asymptomatic to symptomatic disease and avoiding collapse is clinically important but must be weighed against overtreatment of low-risk lesions. In older patients, for whom a hip arthroplasty procedure may offer a lifelong, durable reconstruction, the benefit of preventing subchondral fracture and hip arthrosis is lower than in younger patients. Therefore, the risk-benefit ratio for surgically intervening in older patients is higher than in younger patients, and non-surgical observation becomes a more attractive treatment strategy.

Cost Effectiveness/Resource Utilization

Routine treatment of all asymptomatic ONFH would increase healthcare utilization without clear benefit, particularly for small or medial lesions at low risk of progression. Targeting higher-risk lesions may improve cost-effectiveness.

Acceptability

Observation is acceptable to many patients, especially those with low-risk lesions, as well as older patients. Treatment may be more acceptable in younger patients with larger or lateral lesions, or those highly motivated to pursue joint-preserving strategies.

Feasibility

Both observation and treatment are feasible, but treatment decisions should be individualized using a shared decision-making process. The availability of specific procedures (e.g., CD, CD plus BMC, osteotomy) may also vary across centers.

Future Research

Adequately powered prospective studies over a long-time horizon are needed to compare early intervention with observation in asymptomatic ONFH, stratified by lesion size, location, and ARCO stage. Future work should also evaluate the cost-effectiveness of the intervention vs. observation.

11. Treatment: Total hip arthroplasty (THA) for patients who have symptomatic ONFH, without evidence of subchondral fracture, collapse, or arthritis, i.e, ARCO stages I or II.

For patients who have symptomatic ONFH who do not have subchondral fracture (ARCO stages I to II), alternative treatments/procedures to THA should be considered.

Quality of Evidence: Insufficient evidence
Strength of Recommendation: Strong (consensus-based)

Description: There was no study addressing the role of THA in symptomatic ONFH who did not have subchondral fracture or collapse. The evidence base is absent; therefore, this recommendation is based solely on consensus expert opinion, which was aligned and strong for this recommendation. This recommendation achieved 94% agreement among all voting members.

Rationale

Although THA is effective for pain relief, performing it in pre-collapse ONFH may not be appropriate because the femoral head is still potentially salvageable, and degenerative joint disease (DJD) arthritis is not present. Furthermore, THA is typically reserved for treating DJD, and in this ARCO stage, DJD is not only absent, but may not occur if collapse never develops. Joint-preserving procedures offer the possibility of delaying arthroplasty, or foregoing it completely, which is especially important in younger patients. A THA would be considered premature in these patients and risks unnecessary prosthesis implantation, an increased likelihood of revision surgeries over a lifetime, and loss of native joint preservation options.

Benefits/Harms of Implementation

Avoiding THA in symptomatic, pre-collapse disease prevents and/or delays undergoing premature surgical interventions and the need for future revisions. Alternative joint-preserving strategies may maintain hip function and postpone or avoid THA. The harm of not performing THA in this stage is the possibility of persistent pain, but consensus opinion by the workgroup suggests that this risk is outweighed by the benefits of joint preservation and avoiding prosthetic implant-related complications in both the near and long term.

Outcome Importance

Preserving the native joint and femoral head for as long as possible is a critical outcome in young and middle-aged patients, as it reduces the risk of multiple future revision surgeries.

Cost Effectiveness/Resource Utilization

Avoiding THA in early-stage ONFH is cost-effective, as it prevents the expense of prosthesis implantation and potential revision procedures, while also reducing unnecessary healthcare resource utilization.

Acceptability

Avoidance of THA in early-stage ONFH is widely accepted among both clinicians and patients, especially in young patients with a longer life expectancy, where preserving the native hip reduces the risk of multiple future revisions.

Feasibility

Joint-preserving procedures are feasible in most orthopaedic settings, though availability may vary depending on surgical expertise and institutional resources. THA remains feasible, but should be reserved for later stages or cases where preservation strategies are no longer viable.

Future Research

Future studies should investigate long-term outcomes of early-stage symptomatic ONFH treated with joint-preserving strategies compared to THA, with a focus on pain relief, revision rates, and quality of life.

12. Treatment: Surgical treatment for patients with ONFH and evidence of subchondral fracture or collapse, i.e., ARCO stage III.

In ARCO stage-III ONFH, femoral head-preserving procedures are associated with a smaller functional improvement compared to THA, and the outcome is less predictable. However, shared decision-making between patients and their physicians is necessary, especially in younger patients, because of the value of joint preservation.

Quality of Evidence: Very low
Strength of Recommendation: Weak

Description: There is no treatment modality had a sufficient number of eligible studies to allow for pooled or meta-analysis. Most available studies included both ARCO stages III and IV patients, and outcomes were rarely reported separately for stage III. In addition, studies fail to report outcomes according to age and generally only report a mean age for the cohort studied. Reported interventions mainly included CD, bone grafting, osteotomy, vascularized grafts, resurfacing, hemiarthroplasty, and THA. Functional outcome data were highly heterogeneous, and long-term survivorship was inconsistently reported. This recommendation achieved unanimous (100%) agreement among all voting members.

Rationale
The lack of specific evidence data for different age groups precluded the workgroup from making a stronger evidence-based recommendation for specific age groups. However, there was strong consensus among the workgroup members regarding the principles of surgical treatment for patients with ARCO stage III ONFH. These principles are: (1) hip arthroplasty is associated with better functional outcomes compared to hip preservation surgeries, (2) extrapolating from reported outcomes of total hip arthroplasty compared to bipolar hemiarthroplasty in prospective trials for non-ONFH conditions, THA is associated with better functional outcomes than hemiarthroplasty and, (3) as the patient’s age rises, and the anticipated lifespan of the patient approaches the expected lifespan of the hip arthroplasty, the risk/benefit ratio shifts in the direction of lower risk and higher benefit, thereby favoring hip arthroplasty as the optimal treatment.
Stage III ONFH is defined by the presence of a subchondral fracture with or without collapse, representing a transitional stage where joint-preserving strategies are less effective. While hip-preserving procedures (e.g., osteotomy, bone grafting) have shown some improvement in select reports, THA and hemiarthroplasty consistently provide more predictable pain relief and functional recovery. However, in younger patients, delaying arthroplasty remains desirable to reduce the risk of multiple future revisions. In patients with an expected future lifespan of < 25 years, THA offers an excellent treatment option as it has a high likelihood of improving function, eliminating pain, and being durable and functional for the patient’s expected future lifespan. However, in patients with an expected future lifespan of greater than 25 years, the risk of multiple future revision hip arthroplasty procedures changes the risk-benefit ratio due to a higher risk associated with a lifelong time period of being at risk for future arthroplasty complications. The benefit of delaying future subsequent surgeries will be valued differently by each individual patient, and therefore, this variation in benefit, along with the minimal data available to address this question, precludes the workgroup from making any recommendation in younger patients that could be broadly applicable. Hence, a shared decision-making process, or collaborative approach involving both patient and physician, which incorporates a patient’s goals, preferences, and values, is required to arrive at treatment decisions.
Benefits/Harms of Implementation
The benefit of hip arthroplasty in stage III ONFH is more reliable symptom relief and functional

improvement. Harms include loss of the native hip and risk of revision surgeries, especially in younger patients. Joint-preserving procedures may preserve the femoral head in select cases but carry higher variability in outcomes, and the potential to complicate the future implantation of a hip implant due to an altered proximal femoral anatomy.

Outcome Importance
Achieving long-lasting pain relief and functional restoration is the primary goal in ARCO stage III disease. While preservation of the femoral head may be valuable in younger patients, durability of outcomes is a critical consideration in treatment choice.

Cost Effectiveness/Resource Utilization
A THA is a resource-intensive procedure, but it provides consistent outcomes and may be more cost-effective than repeated, less effective preservation attempts. However, in younger patients, multiple future revisions increase long-term costs, urging careful selection of preservation procedures when feasible.

Acceptability
A THA and hemiarthroplasty are generally acceptable among clinicians and patients due to their reliability. Preservation procedures are less acceptable due to unreliable outcomes, although younger patients and their providers may prefer them to delay arthroplasty.

Feasibility
All major treatment modalities are technically feasible, but feasibility depends on surgical expertise and institutional resources. Preservation techniques may be limited to high-volume centers with hip reconstruction expertise, whereas THA is widely available in most developed countries.

Future Research
Adequately powered comparative trials are needed to clarify the relative value of hip-preserving versus arthroplasty procedures in ARCO stage III ONFH. Research should stratify outcomes by lesion size, patient age, and follow-up duration, and use standardized functional and quality-of-life measures.

APPENDICES

APPENDIX I: REFERENCES

INTRODUCTION & DESCRIPTION REFERENCES

1. Schünemann H, Brożek J, Guyatt G, Oxman A. The GRADE handbook. Cochrane Collaboration London, UK; 2013.
2. Schünemann HJ, Oxman AD, Brozek J, et al. Grading quality of evidence and strength of recommendations for diagnostic tests and strategies. *Bmj*. May 17 2008;336(7653):1106-10. doi:10.1136/bmj.39500.677199.AE
3. Prasad M. Introduction to the GRADE tool for rating certainty in evidence and recommendations. *Clinical Epidemiology and Global Health*. 2024/01/01/ 2024;25:101484. doi:https://doi.org/10.1016/j.cegh.2023.101484
4. Uesugi Y, Sakai T, Seki T, et al. Quality of life of patients with osteonecrosis of the femoral head: a multicentre study. *Int Orthop*. Jul 2018;42(7):1517-1525. doi:10.1007/s00264-018-3897-8
5. Wang C, Peng J, Lu S. Summary of the various treatments for osteonecrosis of the femoral head by mechanism: A review. *Exp Ther Med*. Sep 2014;8(3):700-706. doi:10.3892/etm.2014.1811
6. American Academy of Orthopaedic Surgeons. *"Total Hip Replacement."* OrthoInfo, https://orthoinfo.aaos.org/en/treatment/total-hip-replacement/. Accessed 20 Jan. 2026.
7. Atilla B, Bakırcıoğlu S, Shope AJ, Parvızı J. Joint-preserving procedures for osteonecrosis of the femoral head. *EFORT Open Rev*. Dec 2019;4(12):647-658. doi:10.1302/2058-5241.4.180073
8. Higgins BT, Barlow DR, Heagerty NE, Lin TJ. Anterior vs. posterior approach for total hip arthroplasty, a systematic review and meta-analysis. *J Arthroplasty*. Mar 2015;30(3):419-34. doi:10.1016/j.arth.2014.10.020
9. Sloan M, Premkumar A, Sheth NP. Projected Volume of Primary Total Joint Arthroplasty in the U.S., 2014 to 2030. *J Bone Joint Surg Am*. Sep 5 2018;100(17):1455-1460. doi:10.2106/jbjs.17.01617
10. Zhao AY, Chiu A, Agarwal AR, et al. The growing burden of periprosthetic fractures after total hip arthroplasty: identifying overall trends and at-risk groups. *Osteoporos Int*. Aug 2025;36(8):1371-1377. doi:10.1007/s00198-025-07583-1
11. Park J-W, Won S-H, Moon S-Y, Lee Y-K, Ha Y-C, Koo K-H. Burden and future projection of revision Total hip Arthroplasty in South Korea. *BMC Musculoskeletal Disorders*. 2021/04/22 2021;22(1):375. doi:10.1186/s12891-021-04235-3
12. Salman LA, Hantouly AT, Khatkar H, et al. The outcomes of total hip replacement in osteonecrosis versus osteoarthritis: a systematic review and meta-analysis. *Int Orthop*. Dec 2023;47(12):3043-3052. doi:10.1007/s00264-023-05761-6
13. Mouzas OD, Zibis AH, Bonotis KS, et al. Psychological distress, personality traits and functional disability in patients with osteonecrosis of the femoral head. *J Clin Med Res*. Oct 2014;6(5):336-44. doi:10.14740/jocmr1851w
14. Cheng EY, Mirzaei A, Sugano N, et al. Osteonecrosis: A More Appropriate Term than Avascular Necrosis–Pathophysiologic Rationale. *The Journal of Arthroplasty*. 2025/05/26/ 2025;doi:https://doi.org/10.1016/j.arth.2025.05.064
15. Fukushima W, Fujioka M, Kubo T, Tamakoshi A, Nagai M, Hirota Y. Nationwide epidemiologic survey of idiopathic osteonecrosis of the femoral head. *Clin Orthop Relat Res*. Oct 2010;468(10):2715-24. doi:10.1007/s11999-010-1292-x

16. Mont MA, Zywiel MG, Marker DR, McGrath MS, Delanois RE. The natural history of untreated asymptomatic osteonecrosis of the femoral head: a systematic literature review. *J Bone Joint Surg Am*. Sep 15 2010;92(12):2165-70. doi:10.2106/jbjs.I.00575

17. Liu LY. Analysis of osteonecrosis of the femoral head. China J Convalescent Med. 2007;16:447.

18. Chang JD, Hur M, Lee SS, Yoo JH, Lee KM. Genetic background of nontraumatic osteonecrosis of the femoral head in the Korean population. *Clin Orthop Relat Res*. May 2008;466(5):1041-6. doi:10.1007/s11999-008-0147-1

19. Chang JD, Lee SH, Oh SY, Wi YH, Lee JS. The risk factors associated with alcohol-induced osteonecrosis of the femoral head. *Journal of the Korean Orthopaedic Association*. 2004;39(6):692-699.

20. Moya-Angeler J, Gianakos AL, Villa JC, Ni A, Lane JM. Current concepts on osteonecrosis of the femoral head. *World J Orthop*. Sep 18 2015;6(8):590-601. doi:10.5312/wjo.v6.i8.590

21. Zhao DW, Yu M, Hu K, 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)*. Nov 5 2015;128(21):2843-50. doi:10.4103/0366-6999.168017

22. Goyal T, Singh A, Sharma R, Choudhury AK, Arora SS. Osteo-necrosis of femoral head in North Indian population: Risk factors and clinico-radiological correlation. *Clinical Epidemiology and Global Health*. 2019/09/01/ 2019;7(3):446-449. doi:https://doi.org/10.1016/j.cegh.2019.01.012

23. Cheng EY, Mirzaei A. Exploring the feasibility of pharmacologic management in non-traumatic osteonecrosis: An etiology-based hypothesis. *Medical Hypotheses*. 2024/12/01/ 2024;193:111497. doi:https://doi.org/10.1016/j.mehy.2024.111497

24. Cheng EY, Mirzaei A. Differential risk of autoimmune disorders in non-traumatic osteonecrosis: clue to pathogenesis. *Expert Rev Clin Immunol*. Apr 2025;21(4):413-424. doi:10.1080/1744666x.2025.2475982

25. Cheng EY, Mirzaei A. Potential molecular targets for the pharmacologic management of non-traumatic osteonecrosis. *Expert Opin Ther Targets*. Nov 2024;28(11):991-1000. doi:10.1080/14728222.2024.2421755

26. Tani T, Ando W, Fukushima W, et al. Geographic distribution of the incidence of osteonecrosis of the femoral head in Japan and its relation to smoking prevalence. *Mod Rheumatol*. Jan 5 2022;32(1):186-192. doi:10.1080/14397595.2021.1899452

27. Wang T, Azeddine B, Mah W, Harvey EJ, Rosenblatt D, Séguin C. Osteonecrosis of the femoral head: genetic basis. *Int Orthop*. Mar 2019;43(3):519-530. doi:10.1007/s00264-018-4172-8

28. Yoon BH, Mont MA, Koo KH, et al. The 2019 Revised Version of Association Research Circulation Osseous Staging System of Osteonecrosis of the Femoral Head. *J Arthroplasty*. Apr 2020;35(4):933-940. doi:10.1016/j.arth.2019.11.029

29. Steinberg E, Greenfield S, Wolman DM, Mancher M, Graham R. *Clinical practice guidelines we can trust*. national academies press; 2011.

30. Cheng EY, Cui Q, Goodman SB, et al. Diagnosis and Treatment of Femoral Head Osteonecrosis: A Protocol for Development of Evidence-Based Clinical Practice Guidelines. *Surg Technol Int*. May 20 2021;38:371-378. doi:10.52198/21.Sti.38.Os1437

31. Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *Bmj*. Apr 26 2008;336(7650):924-6. doi:10.1136/bmj.39489.470347.AD

32. Joannidis M, Forni LG, Klein SJ, et al. Lung-kidney interactions in critically ill patients:

consensus report of the Acute Disease Quality Initiative (ADQI) 21 Workgroup. *Intensive Care Med*. Apr 2020;46(4):654-672. doi:10.1007/s00134-019-05869-7
33. Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Ann Intern Med*. Oct 18 2011;155(8):529-36. doi:10.7326/0003-4819-155-8-201110180-00009
34. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *Bmj*. Aug 28 2019;366:l4898. doi:10.1136/bmj.l4898
35. Sterne JA, Hernán MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *Bmj*. Oct 12 2016;355:i4919. doi:10.1136/bmj.i4919
36. Parikh RR, Mirzaei A, Butler ME, et al. Diagnosis and Treatment of Nontraumatic Osteonecrosis of the Femoral Head: A Systematic Review and Meta-Analyses for the ARCO Clinical Practice Guideline Development Workgroup. Med Sci. 2026 Feb; 14(1):107. https://doi.org/10.3390/medsci14010107
37. Heil EL, Bork JT, Abbo LM, et al. Optimizing the Management of Uncomplicated Gram-Negative Bloodstream Infections: Consensus Guidance Using a Modified Delphi Process. *Open Forum Infect Dis*. Oct 2021;8(10):ofab434. doi:10.1093/ofid/ofab434

APPENDIX II: Recommendation Included References

1. Agarwal KK, Mukherjee A, Sharma P, Bal C, Kumar R. Incremental value of 99mTc-MDP hybrid SPECT/CT over planar scintigraphy and SPECT in avascular necrosis of the femoral head. Nucl Med Commun. Oct 2015;36(10):1055-62. doi:10.1097/mnm.0000000000000357
2. Barille MF, Wu JS, McMahon CJ. Femoral head avascular necrosis: a frequently missed incidental finding on multidetector CT. Clin Radiol. Mar 2014;69(3):280-5. doi:10.1016/j.crad.2013.10.012
3. Bassett LW, Gold RH, Reicher M, Bennett LR, Tooke SM. Magnetic resonance imaging in the early diagnosis of ischemic necrosis of the femoral head. Preliminary results. Clin Orthop Relat Res. Jan 1987;(214):237-48.
4. Bassounas AE, Karantanas AH, Fotiadis DI, Malizos KN. Femoral head osteonecrosis: volumetric MRI assessment and outcome. Eur J Radiol. Jul 2007;63(1):10-5. doi:10.1016/j.ejrad.2007.03.028
5. Beltran J, Herman LJ, Burk JM, et al. Femoral head avascular necrosis: MR imaging with clinical-pathologic and radionuclide correlation. Radiology. Jan 1988;166(1 Pt 1):215-20. doi:10.1148/radiology.166.1.3336682
6. Belmar CJ, Steinberg ME, Hartman-Sloan KM. Does pain predict outcome in hips with osteonecrosis? Clin Orthop Relat Res. Aug 2004;(425):158-62. doi:10.1097/00003086-200408000-00021
7. Biswal S, Hazra S, Yun HH, Hur CY, Shon WY. Transtrochanteric rotational osteotomy for nontraumatic osteonecrosis of the femoral head in young adults. Clin Orthop Relat Res. Jun 2009;467(6):1529-37. doi:10.1007/s11999-008-0696-3
8. Boontanapibul K, Huddleston JI, 3rd, Amanatullah DF, Maloney WJ, Goodman SB. Modified Kerboul Angle Predicts Outcome of Core Decompression With or Without Additional Cell Therapy. J Arthroplasty. Jun 2021;36(6):1879-1886. doi:10.1016/j.arth.2021.01.075
9. Chen CH, Chang JK, Lai KA, Hou SM, Chang CH, Wang GJ. Alendronate in the prevention of collapse of the femoral head in nontraumatic osteonecrosis: a two-year multicenter, prospective, randomized, double-blind, placebo-controlled study. Arthritis Rheum. May 2012;64(5):1572-8. doi:10.1002/art.33498
10. Cruz-Pardos A, Garcia-Rey E, Ortega-Chamarro JA, Duran-Manrique D, Gomez-Barrena
11. E. Mid-term comparative outcomes of autologous bone-marrow concentration to treat osteonecrosis of the femoral head in standard practice. Hip Int. Sep 29 2016;26(5):432-437.

doi:10.5301/hipint.5000366
12. Chee CG, Cho J, Kang Y, et al. Diagnostic accuracy of digital radiography for the diagnosis of osteonecrosis of the femoral head, revisited. Acta Radiol. Aug 2019;60(8):969-976. doi:10.1177/0284185118808083
13. Chee CG, Kim Y, Kang Y, et al. Performance of a Deep Learning Algorithm in Detecting Osteonecrosis of the Femoral Head on Digital Radiography: A Comparison With Assessments by Radiologists. American Journal of Roentgenology. 2019/07/01 2019;213(1):155-162. doi:10.2214/AJR.18.20817
14. Collier BD, Carrera GF, Johnson RP, et al. Detection of femoral head avascular necrosis in adults by SPECT. J Nucl Med. Sep 1985;26(9):979-87.
15. Capone A, Bienati F, Torchia S, Podda D, Marongiu G. Short stem total hip arthroplasty for osteonecrosis of the femoral head in patients 60 years or younger: a 3- to 10-year follow-up study. BMC Musculoskelet Disord. Jul 17 2017;18(1):301. doi:10.1186/s12891-017-1662-6
16. Chan YS, Shih CH. Bipolar versus total hip arthroplasty for hip osteonecrosis in the same patient. Clin Orthop Relat Res. Oct 2000;(379):169-77. doi:10.1097/00003086-200010000-00020
17. Chen L, Hong G, Hong Z, et al. Optimizing indications of impacting bone allograft transplantation in osteonecrosis of the femoral head. Bone Joint J. Jul 2020;102-b(7):838-844. doi:10.1302/0301-620x.102b7.Bjj-2019-1101.R2
18. Chen JM, Hsu SL, Wong T, Chou WY, Wang CJ, Wang FS. Functional outcomes of bilateral hip necrosis: total hip arthroplasty versus extracorporeal shockwave. Arch Orthop Trauma Surg. Jun 2009;129(6):837-41. doi:10.1007/s00402-008-0812-6
19. Cheng Q, Zhao FC, Xu SZ, Zheng L, Zheng X. Modified trapdoor procedures using autogenous tricortical iliac graft without preserving the broken cartilage for treatment of osteonecrosis of the femoral head: a prospective cohort study with historical controls. J Orthop Surg Res. May 24 2020;15(1):183. doi:10.1186/s13018-020-01691-w
20. Cuckler JM, Moore KD, Estrada L. Outcome of hemiresurfacing in osteonecrosis of the femoral head. Clin Orthop Relat Res. Dec 2004;(429):146-50. doi:10.1097/01.blo.0000150121.88033.50
21. Dudani B, Shyam AK, Arora P, Veigus A. Bipolar hip arthroplasty for avascular necrosis of femoral head in young adults. Indian J Orthop. May-Jun 2015;49(3):329-35. doi:10.4103/0019-5413.156207
22. Daltro GC, Fortuna V, de Souza ES, et al. Efficacy of autologous stem cell-based therapy for osteonecrosis of the femoral head in sickle cell disease: a five-year follow-up study. Stem Cell Res Ther. May 29 2015;6(1):110. doi:10.1186/s13287-015-0105-2
23. Demirel M, Ersin M, Ekinci M, Mert L, Koyuncu D, Kılıçoğlu Ö I. Long-term outcomes of conventional core decompression for osteonecrosis of the femoral head in systemic lupus erythematosus: a single-center retrospective study. Eur Rev Med Pharmacol Sci. Mar 2023;27(5):1837-1843. doi:10.26355/eurrev_202303_31546
24. Ding H, Wang S, Feng H, et al. Clinical efficacy of individual extracorporeal shockwave treatment. Orthopade. Jul 2019;48(7):610-617. Klinische Wirksamkeit der individuellen extrakorporalen Stoßwellentherapie. doi:10.1007/s00132-018-03682-6
25. Erivan R, Caputo T, Riouach H, et al. Primary total hip replacement in Ficat-Arlet stage 3 and 4 osteonecrosis: a retrospective study at a minimum 12-year follow-up. Eur J Orthop Surg Traumatol. Jul 2020;30(5):845-850. doi:10.1007/s00590-020-02644-z
26. Fairbank AC, Bhatia D, Jinnah RH, Hungerford DS. Long-term results of core decompression for ischaemic necrosis of the femoral head. J Bone Joint Surg Br. Jan 1995;77(1):42-9.
27. Fang Y, Ding C, Wang Y, Zhang H. Comparison of core decompression and porous tantalum rod implantation with conservative treatment for avascular necrosis of the femoral head: A minimum 18 month follow-up study. Exp Ther Med. Jul 2020;20(1):472-478.

doi:10.3892/etm.2020.8669
28. Farahmandi M, Abbasian M, Safdari F, Emami Moghaddam Tehrani M. Midterm results of treating femoral head osteonecrosis with autogenous corticocancellous bone grafting. Trauma Mon. Nov 2014;19(4):e17092. doi:10.5812/traumamon.17092
29. Gangji V, Toungouz M, Lechanteur C, et al. THU0540 Autologous Osteoblastic Cells versus Concentrated Bone Marrow Implantation in Osteonecrosis of The Femoral Head: A Randomized Controlled Single Blind Study. Annals of the Rheumatic Diseases. 2016/06/01/ 2016;75:387. doi:https://doi.org/10.1136/annrheumdis-2016-eular.1502
30. Glueck CJ, Freiberg RA, Sieve L, Wang P. Enoxaparin prevents progression of stages I and II osteonecrosis of the hip. Clin Orthop Relat Res. Jun 2005;(435):164-70. doi:10.1097/01.blo.0000157539.67567.03
31. Gómez-Barrena E, Padilla-Eguiluz NG, Rosset P, et al. Osteonecrosis of the Femoral Head Safely Healed with Autologous, Expanded, Bone Marrow-Derived Mesenchymal Stromal Cells in a Multicentric Trial with Minimum 5 Years Follow-Up. J Clin Med. Feb 1 2021;10(3)doi:10.3390/jcm10030508
32. Gayana S, Bhattacharya A, Sen RK, Singh P, Prakash M, Mittal BR. F-18 fluoride positron emission tomography/computed tomography in the diagnosis of avascular necrosis of the femoral head: Comparison with magnetic resonance imaging. Indian J Nucl Med. Jan-Mar 2016;31(1):3-8. doi:10.4103/0972-3919.172337
33. Ge H, Wang Z, Zhang J. X-ray, digital tomographic fusion, CT, and MRI in early ischemic necrosis of the femoral head. Medicine (Baltimore). Jan 12 2024;103(2):e36281. doi:10.1097/md.0000000000036281
34. Genez BM, Wilson MR, Houk RW, et al. Early osteonecrosis of the femoral head: detection in high-risk patients with MR imaging. Radiology. Aug 1988;168(2):521-4. doi:10.1148/radiology.168.2.3393675
35. Gupta PK, Mittal M, Gupta A, Swaika S. Advantage of Magnetic Resonance Imaging Over X Ray In Detection of Avascular Necrosis of Femoral Head. Journal of Cardiovascular Disease Research. 2022;13(1):1664-1670
36. Gągała J, Tarczyńska M, Gaweda K. A seven- to 14-year follow-up study of bipolar hip arthroplasty in the treatment of osteonecrosis of the femoral head. Hip Int. Jan-Feb 2014;24(1):14-
37. 9. doi:10.5301/hipint.5000084
38. Hwang KT, Kim YH, Kim YS, Choi IY. Is bipolar hemiarthroplasty a reliable option for Ficat stage III osteonecrosis of the femoral head? 15- to 24-year follow-up study. Arch Orthop Trauma Surg. Dec 2012;132(12):1789-96. doi:10.1007/s00402-012-1613-5
39. Hungerford MW, Mont MA, Scott R, Fiore C, Hungerford DS, Krackow KA. Surface replacement hemiarthroplasty for the treatment of osteonecrosis of the femoral head. J Bone Joint Surg Am. Nov 1998;80(11):1656-64. doi:10.2106/00004623-199811000-00013
40. Huang GS, Chan WP, Chang YC, Chang CY, Chen CY, Yu JS. MR imaging of bone marrow edema and joint effusion in patients with osteonecrosis of the femoral head: relationship to pain. AJR Am J Roentgenol. Aug 2003;181(2):545-9. doi:10.2214/ajr.181.2.1810545
41. Hatanaka H, Motomura G, Ikemura S, et al. Differences in magnetic resonance findings between symptomatic and asymptomatic pre-collapse osteonecrosis of the femoral head. Eur J Radiol. Mar 2019;112:1-6. doi:10.1016/j.ejrad.2019.01.002
42. Han X, Hong G, Chen L, et al. T(1) ρ and T(2) mapping for the determination of articular cartilage denaturalization with osteonecrosis of the femoral head: A prospective controlled trial. J Magn Reson Imaging. Mar 2019;49(3):760-767. doi:10.1002/jmri.26267
43. Hauzeur JP, Lechanteur C, Baudoux E, et al. Did Osteoblastic Cell Therapy Improve the Prognosis of Pre-fracture Osteonecrosis of the Femoral Head? A Randomized, Controlled Trial. Clin Orthop Relat Res. Jun 2020;478(6):1307-1315. doi:10.1097/corr.0000000000001107
44. Hernigou P, Dubory A, Homma Y, et al. Cell therapy versus simultaneous contralateral

decompression in symptomatic corticosteroid osteonecrosis: a thirty year follow-up prospective randomized study of one hundred and twenty five adult patients. Int Orthop. Jul 2018;42(7):1639-1649. doi:10.1007/s00264-018-3941-8
45. Hernigou P, Habibi A, Bachir D, Galacteros F. The natural history of asymptomatic osteonecrosis of the femoral head in adults with sickle cell disease. J Bone Joint Surg Am. Dec 2006;88(12):2565-72. doi:10.2106/jbjs.E.01455
46. Hernigou P, Poignard A, Zilber S, Rouard H. Cell therapy of hip osteonecrosis with autologous bone marrow grafting. Indian J Orthop. Jan 2009;43(1):40-5. doi:10.4103/0019-5413.45322
47. Hernigou P, Homma Y, Hernigou J, Flouzat Lachaniette CH, Rouard H, Verrier S. Mesenchymal Stem Cell Therapy for Bone Repair of Human Hip Osteonecrosis with Bilateral Match-Control Evaluation: Impact of Tissue Source, Cell Count, Disease Stage, and Volume Size on 908 Hips. Cells. May 1 2024;13(9)doi:10.3390/cells13090776
48. Hernigou P, Beaujean F. Treatment of osteonecrosis with autologous bone marrow grafting. Clin Orthop Relat Res. Dec 2002;(405):14-23. doi:10.1097/00003086-200212000-00003
49. Houdek MT, Wyles CC, Collins MS, et al. Stem Cells Combined With Platelet-rich Plasma Effectively Treat Corticosteroid-induced Osteonecrosis of the Hip: A Prospective Study. Clin Orthop Relat Res. Feb 2018;476(2):388-397. doi:10.1007/s11999.0000000000000033
50. Houdek MT, Wyles CC, Smith JH, Terzic A, Behfar A, Sierra RJ. Hip decompression combined with bone marrow concentrate and platelet-rich plasma for corticosteroid-induced osteonecrosis of the femoral head : mid-term update from a prospective study. Bone Jt Open. Nov 2021;2(11):926-931. doi:10.1302/2633-1462.211.Bjo-2021-0132.R1
51. Huang Z, Fu F, Ye H, et al. Chinese herbal Huo-Gu formula for the treatment of steroid-associated osteonecrosis of femoral head: A 14-year follow-up of convalescent SARS patients. J Orthop Translat. Jul 2020;23:122-131. doi:10.1016/j.jot.2020.03.014
52. Huang K, Zeng Y, Zhang Q, et al. Less Acetabular Coverage Predicts the Failure of Core Decompression for Osteonecrosis of the Femoral Head: A Retrospective Cohort Study. Orthop Surg. Jul 2024;16(7):1614-1621. doi:10.1111/os.14094
53. Jayankura M, Thomas T, Seefried L, et al. Does Adjunction of Autologous Osteoblastic Cells Improve the Results of Core Decompression in Early-stage Femoral Head Osteonecrosis? A Double-blind, Randomized Trial. Clin Orthop Relat Res. Aug 1 2023;481(8):1527-1540. doi:10.1097/corr.0000000000002610
54. Jiang HJ, Huang XJ, Tan YC, Liu DZ, Wang L. Core decompression and implantation of calcium phosphate cement/Danshen drug delivery system for treating ischemic necrosis of femoral head at Stages I, II and III of antigen reactive cell opsonization. Chin J Traumatol. Oct 2009;12(5):285-90.
55. Jordan E, Varady NH, Hosseinzadeh S, et al. Femoral Head Osteonecrosis: Computed Tomography Not Needed to Identify Collapse When Using the Association Research Circulation Osseous Staging System. Arthroplast Today. Dec 2023;24:101244. doi:10.1016/j.artd.2023.101244
56. Koo KH, Ahn IO, Kim R, et al. Bone marrow edema and associated pain in early stage osteonecrosis of the femoral head: prospective study with serial MR images. Radiology. Dec 1999;213(3):715-22. doi:10.1148/radiology.213.3.r99dc06715
57. Khanna AJ, Yoon TR, Mont MA, Hungerford DS, Bluemke DA. Femoral head osteonecrosis: detection and grading by using a rapid MR imaging protocol. Radiology. Oct 2000;217(1):188-92. doi:10.1148/radiology.217.1.r00oc26188
58. Kim KY, Lee SH, Moon DH, Nah HY. The diagnostic value of triple head single photon emission computed tomography (3H-SPECT) in avascular necrosis of the femoral head. Int Orthop. 1993;17(3):132-8. doi:10.1007/bf00186372
59. Kang JS, Suh YJ, Moon KH, et al. Clinical efficiency of bone marrow mesenchymal stem

cell implantation for osteonecrosis of the femoral head: a matched pair control study with simple core decompression. Stem Cell Res Ther. Oct 25 2018;9(1):274. doi:10.1186/s13287-018-1030-y

60. Karimi M, Moharrami A, Vahedian Aedakani M, Mirghaderi SP, Ghadimi E, Mortazavi SJ. Predictors of Core Decompression Success in Patients with Femoral Head Avascular Necrosis. Arch Bone Jt Surg. 2023;11(8):517-523. doi:10.22038/abjs.2022.61327.3011

61. Kawate K, Ohmura T, Hiyoshi N, et al. Limitations of Joint-Preserving Treatment for Osteonecrosis of the Femoral Head: Limitation of Free Vascularized Fibular Grafting. Treatment of Osteoarthritic Change in the Hip: Joint Preservation or Joint Replacement? Springer; 2007:97-104.

62. Kang JS, Moon KH, Kwon DG, Shin BK, Woo MS. The natural history of asymptomatic osteonecrosis of the femoral head. Int Orthop. Mar 2013;37(3):379-84. doi:10.1007/s00264-013-1775-y

63. Kim SY, Kim YG, Kim PT, Ihn JC, Cho BC, Koo KH. Vascularized compared with nonvascularized fibular grafts for large osteonecrotic lesions of the femoral head. J Bone Joint Surg Am. Sep 2005;87(9):2012-8. doi:10.2106/jbjs.D.02593

64. Koren L, Ginesin E, Melamed Y, Norman D, Levin D, Peled E. Hyperbaric oxygen for stage I and II femoral head osteonecrosis. Orthopedics. Mar 2015;38(3):e200-5. doi:10.3928/01477447-20150305-57

65. Kuroda Y, Tanaka T, Miyagawa T, et al. Classification of osteonecrosis of the femoral head: Who should have surgery? Bone Joint Res. Oct 2019;8(10):451-458. doi:10.1302/2046-3758.810.Bjr-2019-0022.R1

66. Karasuyama K, Motomura G, Ikemura S, et al. Risk factor analysis for postoperative complications requiring revision surgery after transtrochanteric rotational osteotomy for osteonecrosis of the femoral head. J Orthop Surg Res. Jan 10 2018;13(1):6. doi:10.1186/s13018-018-0714-4

67. Kubo Y, Motomura G, Ikemura S, Sonoda K, Yamamoto T, Nakashima Y. Factors influencing progressive collapse of the transposed necrotic lesion after transtrochanteric anterior rotational osteotomy for osteonecrosis of the femoral head. Orthop Traumatol Surg Res. Apr 2017;103(2):217-222. doi:10.1016/j.otsr.2016.10.019

68. Kuroda Y, Nankaku M, Okuzu Y, Kawai T, Goto K, Matsuda S. Percutaneous autologous impaction bone graft for advanced femoral head osteonecrosis: a retrospective observational study of unsatisfactory short-term outcomes. J Orthop Surg Res. Feb 17 2021;16(1):141. doi:10.1186/s13018-021-02288-7

69. Lee SB, Sugano N, Nakata K, Matsui M, Ohzono K. Comparison between bipolar hemiarthroplasty and THA for osteonecrosis of the femoral head. Clin Orthop Relat Res. Jul 2004;(424):161-5. doi:10.1097/01.blo.0000128217.18356.87

70. Learmonth ID, Maloon S, Dall G. Core decompression for early atraumatic osteonecrosis of the femoral head. J Bone Joint Surg Br. May 1990;72(3):387-90. doi:10.1302/0301-620x.72b3.2341433

71. Lee YK, Ha YC, Cho YJ, et al. Does Zoledronate Prevent Femoral Head Collapse from Osteonecrosis? A Prospective, Randomized, Open-Label, Multicenter Study. J Bone Joint Surg Am. Jul 15 2015;97(14):1142-8. doi:10.2106/jbjs.N.01157

72. Li D, Sun S, Yang Z, Luo Y, Kang P. Efficacy of Modified Lightbulb Technique by Percutaneous Femoral Neck-Head Fenestration Combined With Compacted Artificial Bone Graft for Treating Precollapse Osteonecrosis of the Femoral Head. J Arthroplasty. Sep 2023;38(9):1760-1766. doi:10.1016/j.arth.2023.03.012

73. Lu Y, Lu X, Li M, et al. Minimally invasive treatment for osteonecrosis of the femoral head with angioconductive bioceramic rod. Int Orthop. Jul 2018;42(7):1567-1573. doi:10.1007/s00264-018-3919-6

74. Lee EJ, Lee KH, Huh WS, et al. Incidence and radio-uptake patterns of femoral head avascular osteonecrosis at 1 year after renal transplantation: a prospective study with planar bone scintigraphy. Nucl Med Commun. Nov 2006;27(11):919-24. doi:10.1097/01.mnm.0000239479.46157.2d
75. Maillefert JF, Toubeau M, Piroth C, Piroth L, Brunotte F, Tavernier C. Bone scintigraphy equipped with a pinhole collimator for diagnosis of avascular necrosis of the femoral head. Clin Rheumatol. Jun 1997;16(4):372-7. doi:10.1007/bf02242454
76. Miller IL, Savory CG, Polly DW, Jr., Graham GD, McCabe JM, Callaghan JJ. Femoral head osteonecrosis. Detection by magnetic resonance imaging versus single-photon emission computed tomography. Clin Orthop Relat Res. Oct 1989;(247):152-62.
77. Ma Y, Wang T, Liao J, et al. Efficacy of autologous bone marrow buffy coat grafting combined with core decompression in patients with avascular necrosis of femoral head: a prospective, double-blinded, randomized, controlled study. Stem Cell Res Ther. Oct 14 2014;5(5):115. doi:10.1186/scrt505
78. Mao Q, Jin H, Liao F, Xiao L, Chen D, Tong P. The efficacy of targeted intraarterial delivery of concentrated autologous bone marrow containing mononuclear cells in the treatment of osteonecrosis of the femoral head: a five year follow-up study. Bone. Dec 2013;57(2):509-16. doi:10.1016/j.bone.2013.08.022
79. Markel DC, Miskovsky C, Sculco TP, Pellicci PM, Salvati EA. Core decompression for osteonecrosis of the femoral head. Clin Orthop Relat Res. Feb 1996;(323):226-33. doi:10.1097/00003086-199602000-00031
80. Min BW, Song KS, Cho CH, Lee SM, Lee KJ. Untreated asymptomatic hips in patients with osteonecrosis of the femoral head. Clin Orthop Relat Res. May 2008;466(5):1087-92. doi:10.1007/s11999-008-0191-x
81. Martinot P, Dartus J, Justo A, et al. Does augmented core decompression decrease the rate of collapse and improve survival of femoral head avascular necrosis? Case-control study comparing 184 augmented core decompressions to 79 standard core decompressions with a minimum 2 years' follow-up. Orthop Traumatol Surg Res. Dec 2020;106(8):1561-1568. doi:10.1016/j.otsr.2020.03.040
82. Massari L, Fini M, Cadossi R, Setti S, Traina GC. Biophysical stimulation with pulsed electromagnetic fields in osteonecrosis of the femoral head. J Bone Joint Surg Am. Nov 2006;88 Suppl 3:56-60. doi:10.2106/jbjs.F.00536
83. Mohanty SP, Singh KA, Kundangar R, Shankar V. Management of non-traumatic avascular necrosis of the femoral head-a comparative analysis of the outcome of multiple small diameter drilling and core decompression with fibular grafting. Musculoskelet Surg. Apr 2017;101(1):59-66. doi:10.1007/s12306-016-0431-2
84. Mont MA, Etienne G, Ragland PS. Outcome of nonvascularized bone grafting for osteonecrosis of the femoral head. Clin Orthop Relat Res. Dec 2003;(417):84-92. doi:10.1097/01.blo.0000096826.67494.38
85. Mont MA, Ragland PS, Etienne G. Core decompression of the femoral head for osteonecrosis using percutaneous multiple small-diameter drilling. Clin Orthop Relat Res. Dec 2004;(429):131-8. doi:10.1097/01.blo.0000150128.57777.8e
86. Mont MA, Zywiel MG, Marker DR, McGrath MS, Delanois RE. The natural history of untreated asymptomatic osteonecrosis of the femoral head: a systematic literature review. J Bone Joint Surg Am. Sep 15 2010;92(12):2165-70. doi:10.2106/jbjs.I.00575
87. Mont MA, Jones LC, Pacheco I, Hungerford DS. Radiographic predictors of outcome of core decompression for hips with osteonecrosis stage III. Clin Orthop Relat Res. Sep 1998;(354):159-68. doi:10.1097/00003086-199809000-00019
88. Moon JK, Yoon JY, Kim CH, et al. Multiple drilling and multiple matchstick-like bone allografts for large osteonecrotic lesions in the femoral head: an average 3-year follow-up study.

Arch Orthop Trauma Surg. Nov 2020;140(11):1655-1663. doi:10.1007/s00402-020-03364-z
89. Matsusaki H, Noguchi M, Kawakami T, Tani T. Use of vascularized pedicle iliac bone graft combined with transtrochanteric rotational osteotomy in the treatment of avascular necrosis of the femoral head. Arch Orthop Trauma Surg. Mar 2005;125(2):95-101. doi:10.1007/s00402-004-0777-z
90. 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. Mar 2008;90(3):477-84. doi:10.2106/jbjs.F.01582
91. Öztürk K, Baydar M, Alpay Y, Şencan A, Orman O, Aykut S. Clinical results of free vascularized fibula graft in the management of precollapse osteonecrosis of the femoral head: A retrospective clinical study. Acta Orthop Traumatol Turc. Mar 2022;56(2):105-110. doi:10.5152/j.aott.2022.21012
92. Plenk H, Jr., Gstettner M, Grossschmidt K, Breitenseher M, Urban M, Hofmann S. Magnetic resonance imaging and histology of repair in femoral head osteonecrosis. Clin Orthop Relat Res. May 2001;(386):42-53. doi:10.1097/00003086-200105000-00006
93. Pan J, Ding Q, Lv S, et al. Prognosis after autologous peripheral blood stem cell transplantation for osteonecrosis of the femoral head in the pre-collapse stage: a retrospective cohort study. Stem Cell Res Ther. Feb 26 2020;11(1):83. doi:10.1186/s13287-020-01595-w
94. Park JY, Cho BW, Kwon HM, Lee WS, Park KK. Multiple Drilling with Recombinant Human Bone Morphogenetic Protein-2 in Korean Patients with Non-Traumatic Osteonecrosis of the Femoral Head: A Prospective Randomized Pilot Study with a Minimum Two-Year Follow-Up. J Clin Med. Sep 20 2022;11(19)doi:10.3390/jcm11195499
95. Pepke W, Kasten P, Beckmann NA, Janicki P, Egermann M. Core Decompression and Autologous Bone Marrow Concentrate for Treatment of Femoral Head Osteonecrosis: A Randomized Prospective Study. Orthop Rev (Pavia). Mar 21 2016;8(1):6162. doi:10.4081/or.2016.6162
96. Pilge H, Bittersohl B, Schneppendahl J, et al. Bone Marrow Aspirate Concentrate in Combination With Intravenous Iloprost Increases Bone Healing in Patients With Avascular Necrosis of the Femoral Head: A Matched Pair Analysis. Orthop Rev (Pavia). Nov 17 2016;8(4):6902. doi:10.4081/or.2016.6902
97. Plakseychuk AY, Kim SY, Park BC, Varitimidis SE, Rubash HE, Sotereanos DG. Vascularized compared with nonvascularized fibular grafting for the treatment of osteonecrosis of the femoral head. J Bone Joint Surg Am. Apr 2003;85(4):589-96. doi:10.2106/00004623-200304000-00001
98. Rijnen WH, Gardeniers JW, Buma P, Yamano K, Slooff TJ, Schreurs BW. Treatment of femoral head osteonecrosis using bone impaction grafting. Clin Orthop Relat Res. Dec 2003;(417):74-83. doi:10.1097/01.blo.0000096823.67494.64
99. Rocchi M, Del Piccolo N, Mazzotta A, et al. Core decompression with bone chips allograft in combination with fibrin platelet-rich plasma and concentrated autologous mesenchymal stromal cells, isolated from bone marrow: results for the treatment of avascular necrosis of the femoral head after 2 years minimum follow-up. Hip Int. Dec 2020;30(2_suppl):3-12. doi:10.1177/1120700020964996
100. Ryu JS, Kim JS, Moon DH, et al. Bone SPECT is more sensitive than MRI in the detection of early osteonecrosis of the femoral head after renal transplantation. J Nucl Med. Aug 2002;43(8):1006-11.
101. Scher MA, Jakim I. Intertrochanteric osteotomy and autogenous bone-grafting for avascular necrosis of the femoral head. J Bone Joint Surg Am. Aug 1993;75(8):1119-33. doi:10.2106/00004623-199308000-00001
102. Siguier T, Siguier M, Judet T, Charnley G, Brumpt B. Partial resurfacing arthroplasty of the femoral head in avascular necrosis. Methods, indications, and results. Clin Orthop Relat Res.

May 2001;(386):85-92. doi:10.1097/00003086-200105000-00011
103. Samy AM. Management of osteonecrosis of the femoral head: A novel technique. Indian J Orthop. Jul-Aug 2016;50(4):359-65. doi:10.4103/0019-5413.185590
104. Stevens K, Tao C, Lee SU, et al. Subchondral fractures in osteonecrosis of the femoral head: comparison of radiography, CT, and MR imaging. AJR Am J Roentgenol. Feb 2003;180(2):363-8. doi:10.2214/ajr.180.2.1800363
105. Stulberg BN, Levine M, Bauer TW, et al. Multimodality approach to osteonecrosis of the femoral head. Clin Orthop Relat Res. Mar 1989;(240):181-93.
106. Sen RK, Tripathy SK, Aggarwal S, Marwaha N, Sharma RR, Khandelwal N. Early results of core decompression and autologous bone marrow mononuclear cells instillation in femoral head osteonecrosis: a randomized control study. J Arthroplasty. May 2012;27(5):679-86. doi:10.1016/j.arth.2011.08.008
107. Seyler TM, Marker DR, Ulrich SD, Fatscher T, Mont MA. Nonvascularized bone grafting defers joint arthroplasty in hip osteonecrosis. Clin Orthop Relat Res. May 2008;466(5):1125-32. doi:10.1007/s11999-008-0211-x
108. Simank HG, Brocai DR, Brill C, Lukoschek M. Comparison of results of core decompression and intertrochanteric osteotomy for nontraumatic osteonecrosis of the femoral head using Cox regression and survivorship analysis. J Arthroplasty. Sep 2001;16(6):790-4. doi:10.1054/arth.2001.23580
109. Soucacos PN, Beris AE, Malizos K, Koropilias A, Zalavras H, Dailiana Z. Treatment of avascular necrosis of the femoral head with vascularized fibular transplant. Clin Orthop Relat Res. May 2001;(386):120-30. doi:10.1097/00003086-200105000-00016
110. Steinberg ME, Larcom PG, Strafford B, et al. Core decompression with bone grafting for osteonecrosis of the femoral head. Clin Orthop Relat Res. May 2001;(386):71-8. doi:10.1097/00003086-200105000-00009
111. Tokunaga K, Sofue M, Dohmae Y, et al. Vascularized Iliac Bone Graft Using Deep Circumflex Iliac Vessels for Idiopathic Osteonecrosis of the Femoral Head. Treatment of Osteoarthritic Change in the Hip: Joint Preservation or Joint Replacement? Springer; 2007:125-134.
112. Tomaru Y, Yoshioka T, Sugaya H, et al. Ten-year results of concentrated autologous bone marrow aspirate transplantation for osteonecrosis of the femoral head: a retrospective study. BMC Musculoskelet Disord. Sep 5 2019;20(1):410. doi:10.1186/s12891-019-2797-4
113. Tomaru Y, Yoshioka T, Sugaya H, et al. Comparison Between Concentrated Autologous Bone Marrow Aspirate Transplantation as a Hip Preserving Surgery and Natural Course in Idiopathic Osteonecrosis of the Femoral Head. Cureus. May 2022;14(5):e24658. doi:10.7759/cureus.24658
114. Theodorou DJ, Malizos KN, Beris AE, Theodorou SJ, Soucacos PN. Multimodal imaging quantitation of the lesion size in osteonecrosis of the femoral head. Clin Orthop Relat Res. May 2001;(386):54-63. doi:10.1097/00003086-200105000-00007
115. Theysohn JM, Kraff O, Theysohn N, et al. Hip imaging of avascular necrosis at 7 Tesla compared with 3 Tesla. Skeletal Radiol. May 2014;43(5):623-32. doi:10.1007/s00256-014-1818-5
116. Thickman D, Axel L, Kressel HY, et al. Magnetic resonance imaging of avascular necrosis of the femoral head. Skeletal radiology. 1986;15(2):133-140.
117. Ünal MB, Cansu E, Parmaksızoğlu F, Cift H, Gürcan S. Treatment of osteonecrosis of the femoral head with free vascularized fibular grafting: Results of 7.6-year follow-up. Acta Orthop Traumatol Turc. Oct 2016;50(5):501-506. doi:10.1016/j.aott.2016.01.001
118. Wan J, Hu Y, Li J, Zeng Y, Ren H. Comparison of the outcome of different bone grafts combined with modified core decompression for the treatment of ARCO II stage femoral head necrosis. Int Orthop. Sep 2022;46(9):1955-1962. doi:10.1007/s00264-022-05418-w

119. Wang CJ, Wang FS, Yang KD, et al. Treatment of osteonecrosis of the hip: comparison of extracorporeal shockwave with shockwave and alendronate. Arch Orthop Trauma Surg. Sep 2008;128(9):901-8. doi:10.1007/s00402-007-0530-5
120. Wang BL, Sun W, Shi ZC, et al. Treatment of nontraumatic osteonecrosis of the femoral head with the implantation of core decompression and concentrated autologous bone marrow containing mononuclear cells. Arch Orthop Trauma Surg. Jul 2010;130(7):859-65. doi:10.1007/s00402-009-0939-0
121. Wang B, Zhao D, Liu B, Wang W. Treatment of osteonecrosis of the femoral head by using the greater trochanteric bone flap with double vascular pedicles. Microsurgery. Nov 2013;33(8):593-9. doi:10.1002/micr.22114
122. Wei BF, Ge XH. Treatment of osteonecrosis of the femoral head with core decompression and bone grafting. Hip Int. Mar-Apr 2011;21(2):206-10. doi:10.5301/hip.2011.6525
123. Xie K, Mao Y, Qu X, et al. High-energy extracorporeal shock wave therapy for nontraumatic osteonecrosis of the femoral head. J Orthop Surg Res. Feb 2 2018;13(1):25. doi:10.1186/s13018-017-0705-x
124. Xie H, Wang B, Tian S, Liu B, Qin K, Zhao D. Retrospective Long-Term Follow-Up Survival Analysis of the Management of Osteonecrosis of the Femoral Head With Pedicled Vascularized Iliac Bone Graft Transfer. J Arthroplasty. Aug 2019;34(8):1585-1592. doi:10.1016/j.arth.2019.03.069
125. Yang F, Deng X, Xin P, et al. The Value of the Frog Lateral View Radiograph for Detecting Collapse of Femur Head Necrosis: A Retrospective Study of 1001 Cases. Front Med (Lausanne). 2022;9:811644. doi:10.3389/fmed.2022.811644
126. Yuan P, Liu X, Du B, Sun GQ, Wang X, Lin XY. Mid- to long-term results of modified avascular fibular grafting for ONFH. J Hip Preserv Surg. Aug 2021;8(3):274-281. doi:10.1093/jhps/hnab046
127. Yeh LR, Chen CK, Huang YL, Pan HB, Yang CF. Diagnostic performance of MR imaging in the assessment of subchondral fractures in avascular necrosis of the femoral head. Skeletal Radiol. Jun 2009;38(6):559-64. doi:10.1007/s00256-009-0659-0
128. Yoon JY, Lee SJ, Yoon KS, Yoon PW. The diagnostic value of SPECT/CT in predicting the occurrence of osteonecrosis following femoral neck fracture: a prospective cohort study. BMC Musculoskelet Disord. Aug 3 2020;21(1):517. doi:10.1186/s12891-020-03538-1
129. Zhao G, Liu Y, Zheng Y, Wang M, Li Z, Li C. Hip Arthroscopy Debridement Combined with Multiple Small-Diameter Fan-Shaped Low-Speed Drilling Decompression in the Treatment of Early and Middle Stage Osteonecrosis of the Femoral Head: 14 Years Follow-Up. Orthop Surg. Mar 2024;16(3):604-612. doi:10.1111/os.13985
130. Zhao G, Yamamoto T, Ikemura S, et al. Radiological outcome analysis of transtrochanteric curved varus osteotomy for osteonecrosis of the femoral head at a mean follow-up of 12.4 years. J Bone Joint Surg Br. Jun 2010;92(6):781-6. doi:10
131. Zhang J, Wang Z, Hong G. Clinical value of digital tomographic fusion imaging in the diagnosis of avascular necrosis of the femoral head in adults. Ir J Med Sci. Nov 2021;190(4):1585-1589. doi:10.1007/s11845-020-02451-9
132. Zhang L, Fan Y, Zhang Y, Chen X, Liu Y. Comparison of sartorius muscle-pedicle and circumflex iliac deep bone flap grafts in the treatment of early non-traumatic osteonecrosis of femoral head in young adults. Acta Orthop Traumatol Turc. Jul 2019;53(4):255-259. doi:10.1016/j.aott.2019.04.005
133. Zhao D, Cui D, Wang B, et al. Treatment of early stage osteonecrosis of the femoral head with autologous implantation of bone marrow-derived and cultured mesenchymal stem cells. Bone. Jan 2012;50(1):325-30. doi:10.1016/j.bone.2011.11.002
134. Zhao D, Xie H, Xu Y, et al. Management of osteonecrosis of the femoral head with pedicled iliac bone flap transfer: A multicenter study of 2190 patients. Microsurgery. Nov 2017;37(8):896-

901. doi:10.1002/micr.30195
135. Zhao Y, Zhang G, Song Q, Fan L, Shi Z. Intramedullary core decompression combined with endoscopic intracapsular decompression and debridement for pre-collapse non-traumatic osteonecrosis of the femoral head. J Orthop Surg Res. Jan 2 2023;18(1):6. doi:10.1186/s13018-022-03477-8
136. Zeng-ming Xiao, Xin-li Zhan , Shi-de Li, Q○ Cui, GJ Wang. Biomechanical changes of the prostheses for the sur face hemi-ar throplasty of the hip in the treatment of femor al head avascularnecrosis by using computer -assisted Einzel-Bild-Rontgen-Analyse-femor al component analysis. Chinese Journal of Clinical Rehabilitation. 2006;10:216-219.
137. Zhao D, Fan D, Liu B, Tian S. Clinical Follow-up Study of the Reconstruction of the Femoral Head With Transferred Vascularized Greater Trochanter Bone Graft for Association Research Circulation Osseous III-IV Osteonecrosis of the Femoral Head. Ann Plast Surg. May 2020;84(5S Suppl 3):S215-s221. doi:10.1097/sap.0000000000002363

Appendix III: LITERATURE SEARCH STRATEGY

PICO 1: Diagnostic Imaging

Ovid MEDLINE(R) ALL	
1	osteonecrosis/
2	exp Osteoradionecrosis/
3	1 or 2
4	exp Femur Head/
5	3 and 4
6	exp Femur Head Necrosis/
7	((femur or femoral) adj2 head).tw,kw.
8	((avascular or aseptic or ischemic) adj2 (necrosis or necroses)).tw,kw.
9	(osteonecrosis or osteonecroses or osteoradionecrosis or osteoradionecroses).tw,kw.
10	8 or 9
11	7 and 10
12	onfh.tw,kw.
13	5 or 6 or 11 or 12
14	exp Diagnostic Imaging/
15	((diagnostic or "magnetic resonance" or medical) adj2 imag*).tw,kw.
16	"diagnostic imaging".fs. 1479543
17	(mri* or tomograph* or radiograph* or ultrasonograph* or x-ray).tw,kw.
18	((ct or cat) adj2 scan*).tw,kw.
19	14 or 15 or 16 or 17 or 18
20	exp "Sensitivity and Specificity"/
21	sensitivity.tw,kw.
22	specificity.tw,kw.
23	((pre-test or pretest) adj probability).tw,kw.
24	post-test probability.tw,kw.
25	predictive value*.tw,kw.
26	likelihood ratio*.tw,kw.
27	diagnostic accuracy.tw,kw.
28	20 or 21 or 22 or 23 or 24 or 25 or 26 or 27
29	13 and 19 and 28
30	exp Animals/ not exp Humans/
31	29 not 30
32	exp adult/
33	exp child/ or exp infant/ or exp adolescent/
34	33 not 32
35	31 not 34
36	"case report".ti.
37	(letter or commentary or editorial).pt.
38	36 or 37
39	35 not 38
PubMed	

(((((((("Osteonecrosis"[Mesh:NoExp]) OR "Osteoradionecrosis"[Mesh]) AND ("Femur Head"[Mesh])) OR ("Femur Head Necrosis"[Mesh])) OR (("femur head"[tiab] OR "femoral head"[tiab]) AND (("avascular necrosis"[tiab] OR "avascular necrosis"[tiab] OR "ischemic necrosis"[tiab] OR "avascular necroses"[tiab] OR "avascular necroses"[tiab] OR "ischemic necroses"[tiab]) OR (osteonecrosis[tiab] OR osteonecroses[tiab] OR osteoradionecrosis[tiab] OR osteoradionecroses[tiab])))) OR (onfh[tiab])) AND ((((("Diagnostic Imaging"[Mesh]) OR ("diagnostic imag*"[tiab] OR "magnetic resonance imag*"[tiab] OR "medical imag*"[tiab])) OR ("diagnostic imaging" [Subheading])) OR (mri[tiab] OR tomograph*[tiab] OR radiograph*[tiab] OR ultrasonograph*[tiab] OR x-ray[tiab])) OR ("ct scan"[tiab] OR "cat scan"[tiab]))) AND (((((((("Sensitivity and Specificity"[Mesh]) OR (sensitivity[tiab])) OR (specificity[tiab])) OR ("pre-test probability"[tiab] OR "pretest probability"[tiab])) OR ("post-test probability"[tiab])) OR ("predictive value*"[tiab])) OR ("likelihood ratio*"[tiab])) OR ("diagnostic accuracy"[tiab]))) NOT ("animals"[Mesh] NOT "humans"[Mesh])) NOT (("child"[Mesh] OR "infant"[Mesh] OR "adolescent"[Mesh]) NOT ("adult"[Mesh]))	
Embase Classic+Embase (via Ovid)	
1	bone necrosis/
2	exp osteoradionecrosis/
3	1 or 2
4	exp femoral head/
5	3 and 4
6	exp femur head necrosis/
7	((femur or femoral) adj2 head).tw,kw.
8	((avascular or aseptic or ischemic) adj2 (necrosis or necroses)).tw,kw.
9	(osteonecrosis or osteonecroses or osteoradionecrosis or osteoradionecroses).tw,kw.
10	8 or 9
11	7 and 10
12	onfh.tw,kw.
13	5 or 6 or 11 or 12
14	exp diagnostic imaging/
15	((diagnostic or "magnetic resonance" or medical) adj2 imag*).tw,kw.
16	(mri* or tomograph* or radiograph* or ultrasonograph* or x-ray).tw,kw.
17	((ct or cat) adj2 scan*).tw,kw.
18	14 or 15 or 16 or 17
19	exp "sensitivity and specificity"/
20	sensitivity.tw,kw.
21	specificity.tw,kw.
22	((pre-test or pretest) adj probability).tw,kw.
23	post-test probability.tw,kw.
24	predictive value*.tw,kw.
25	likelihood ratio*.tw,kw.
26	diagnostic accuracy.tw,kw.
27	19 or 20 or 21 or 22 or 23 or 24 or 25 or 26
28	13 and 18 and 27
29	exp Animal/ not exp Human/
30	28 not 29
31	exp adult/
32	exp child/ or exp infant/ or exp adolescent/

33 32 not 31 34 30 not 33 35 (letter or commentary or editorial).pt. 36 34 not 35
Web of Science (Core Collection: SCI-EXPANDED, SSCI, AHCI, CPCI-S, CPCI-SSH, BKCI-SSH, ESCI, CCR-EXPANDED, IC)
TS=(((("femur head" OR "femoral head") NEAR/3 (osteonecrosis OR osteonecroses OR necrosis or necroses) OR osteoradionecrosis OR osteoradionecroses) OR ONFH) AND (((diagnostic OR "magnetic resonance" OR medical) NEAR/2 image) OR MRI OR tomograph* OR radiograph* OR ultrasonograph* OR x-ray OR "CT scan" OR "CAT scan") AND (sensitivity OR specificity OR (pretest NEAR/2 probability) OR "post test probability" OR "predictive value" OR "likelihood ratio" OR "diagnostic accuracy"))
Scopus
((((INDEXTERMS("femur head necrosis")) OR (INDEXTERMS("Osteoradionecrosis" OR "Bone Necrosis" OR "Osteonecrosis") AND INDEXTERMS("Femur Head" OR "Femoral Head")) OR ((TITLE-ABS-KEY(((femur OR femoral) W/2 head))) AND (TITLE-ABS-KEY(((avascular OR aseptic OR ischemic) W/2 (necrosis OR necroses)) OR osteonecrosis OR osteonecroses OR osteoradionecrosis OR osteoradionecroses)) OR TITLE-ABS (ONFH))) AND ((INDEXTERMS("Diagnostic Imaging")) OR (TITLE-ABS((diagnostic NEAR/2 imag*) OR ("magnetic resonance" NEAR/2 imag*) OR (medical NEAR/2 imag*) OR mri* OR tomograph* OR radiograph* OR ultrasonograph* OR x-ray OR (ct NEAR/2 scan*) OR (cat NEAR/2 scan*)))) AND ((INDEXTERMS("Sensitivity and Specificity")) OR (TITLE-ABS(sensitivity OR specificity OR "pre-test probability" OR "pretest probability" OR "post-test probability" OR "predictive value" OR "likelihood ratio" OR "diagnostic accuracy")))) AND NOT ((INDEXTERMS(animal OR animals)) AND NOT (INDEXTERMS(human or humans)))) AND NOT ((INDEXTERMS(Child OR infant OR adolescent)) AND NOT (INDEXTERMS(adult)))
Global Index Medicus
This search 3 results (lacks the sensitivity/diagnostic piece) ((((mh:(Osteoradionecrosis)) or mh:(Osteonecrosis)) OR (mh:(Femur Head Necrosis))) OR (tw:(osteonecrosis OR osteonecroses OR osteoradionecrosis OR osteoradionecroses)) AND (tw:(imaging OR magnetic resonance OR MRI OR tomograph* OR radiograph* OR ultrasonograph* OR x-ray OR CT scan OR CAT scan))) AND (mh:(Sensitivity and Specificity) OR (tw:(sensitivity OR specificity OR pretest OR post-test OR predictive value* OR likelihood ratio* OR diagnostic))) **Zero results (includes sensitivity/diagnostic piece)** (((mh:(Osteoradionecrosis)) OR (mh:(Femur Head Necrosis)) AND (tw:(osteonecrosis OR osteonecroses OR osteoradionecrosis OR osteoradionecroses)) AND (tw:(imaging OR magnetic resonance OR MRI OR tomograph* OR radiograph* OR ultrasonograph* OR x-ray

OR CT scan OR CAT scan))) AND (mh:(Sensitivity and Specificity) OR (tw:(sensitivity OR specificity OR pretest OR post-test OR predictive value* OR likelihood ratio* OR diagnostic)))
Cochrane Library (via Wiley)
#1 MeSH descriptor: [Osteonecrosis] this term only #2 MeSH descriptor: [Osteoradionecrosis] explode all trees #3 #1 OR #2 #4 MeSH descriptor: [Femur Head] explode all trees #5 #3 AND #4 #6 MeSH descriptor: [Femur Head Necrosis] explode all trees #7 (((femur OR femoral) NEXT head)):ti,ab,kw #8 (((avascular OR aseptic OR ischemic) NEXT (necrosis OR necroses))):ti,ab,kw #9 (osteonecrosis OR osteonecroses OR osteoradionecrosis OR osteoradionecroses):ti,ab,kw #10 #8 OR #9 #11 #7 AND #10 #12 ("ONFH"):ti,ab,kw #13 #5 OR #6 OR #11 OR #12 #14 MeSH descriptor: [Diagnostic Imaging] explode all trees #15 (((diagnostic OR "magnetic resonance" OR medical) NEXT imag*)):ti,ab,kw #16 (mri* OR tomograph* OR radiograph* OR ultrasonograph* OR x-ray):ti,ab,kw #17 (((CT OR CAT) NEXT scan*)):ti,ab,kw #18 #14 OR #15 OR #16 OR #17 #19 MeSH descriptor: [Sensitivity and Specificity] explode all trees #20 (sensitivity OR specificity):ti,ab,kw #21 (pretest NEXT probability):ti,ab,kw #22 ("post-test" NEXT probability):ti,ab,kw #23 (predictive NEXT value*):ti,ab,kw #24 (likelihood NEXT ratio*):ti,ab,kw #25 ("diagnostic accuracy"):ti,ab,kw #26 #19 OR #20 OR #21 OR #22 OR #23 OR #24 OR #25 #27 #13 AND #18 AND #26

PICO 2: Optimal management of ARCO Stage I-II

Ovid MEDLINE(R) ALL
1 osteonecrosis/ 2 exp Osteoradionecrosis/ 3 1 or 2 4 exp Femur Head/ 5 3 and 4 6 exp Femur Head Necrosis/ 7 ((femur or femoral) adj2 head).tw,kw. 8 ((avascular or aseptic or ischemic) adj2 (necrosis or necroses)).tw,kw.

9	(osteonecrosis or osteonecroses or osteoradionecrosis or osteoradionecroses).tw,kw.
10	8 or 9
11	7 and 10
12	onfh.tw,kw.
13	5 or 6 or 11 or 12
14	((fracture* or collapse*) adj2 (femur or femoral) adj2 head*).tw,kw.
15	exp Femur Head/
16	exp Hip Fractures/
17	15 and 16
18	14 or 17
19	without.mp.
20	18 and 19
21	(ARCO adj5 ("1" or "2" or One or Two)).tw,kw.
22	("pre-collapse" or precollapse or (before adj2 collaps*)).tw,kw.
23	20 or 21 or 22
24	13 and 23
25	exp Animals/ not exp Humans/
26	24 not 25
27	exp Adult/
28	exp Child/ or exp Infant/ or exp Adolescent/
29	28 not 27
30	26 not 29
31	"case report".ti.
32	(editorial or letter or commentary or note).pt.
33	31 or 32
34	30 not 33

PubMed

((((("Osteonecrosis"[Mesh:NoExp]) OR "Osteoradionecrosis"[Mesh]) AND ("Femur Head"[Mesh])) OR ("Femur Head Necrosis"[Mesh])) OR (("femur head"[tw] OR "femoral head"[tw]) AND (("avascular necrosis"[tw] OR "avascular necrosis"[tw] OR "ischemic necrosis"[tw] OR "avascular necroses"[tw] OR "avascular necroses"[tw] OR "ischemic necroses"[tw]) OR (osteonecrosis[tw] OR osteonecroses[tw] OR osteoradionecrosis[tw] OR osteoradionecroses[tw])))) OR (onfh[tw])) AND ((("femur head fracture"[tw] OR "femoral head fracture"[tw] OR "femur head fracture"[tw] OR "femoral head collapse"[tw]) OR (("Femur Head"[Mesh]) AND "Hip Fractures"[Mesh]) AND "without"[tiab]) OR "ARCO 1"[tw] OR "ARCO 2"[tw] OR "ARCO One"[tw] OR "ARCO Two"[tw] "pre-collapse"[tiab] OR "precollapse"[tiab] OR "before collapse"[Title/Abstract:~2]) NOT ("Animals"[MeSH] NOT "Humans"[MeSH])

Embase Classic+Embase (via Ovid)

1	bone necrosis/
2	exp osteoradionecrosis/
3	1 or 2
4	exp femoral head/
5	3 and 4

6	exp femur head necrosis/
7	((femur or femoral) adj2 head).tw,kw.
8	((avascular or aseptic or ischemic) adj2 (necrosis or necroses)).tw,kw.
9	(osteonecrosis or osteonecroses or osteoradionecrosis or osteoradionecroses).tw,kw.
10	8 or 9
11	7 and 10
12	onfh.tw,kw.
13	5 or 6 or 11 or 12
14	((fracture* or collapse*) adj2 (femur or femoral) adj2 head*).tw,kw.
15	exp femoral head/
16	exp hip fracture/
17	15 and 16
18	14 or 17
19	without.mp.
20	18 and 19
21	(ARCO adj5 ("1" or "2" or One or Two)).tw,kw.
22	("pre-collapse" or precollapse or (before adj2 collaps*)).tw,kw.
23	20 or 21 or 22
24	13 and 23
25	exp animal/ not exp human/
26	24 not 25
27	exp adult/
28	exp child/ or exp infant/ or exp adolescent/
29	28 not 27
30	26 not 29
31	(letter or commentary or editorial).pt.
32	30 not 31
Web of Science (Core Collection: SCI-EXPANDED, SSCI, AHCI, CPCI-S, CPCI-SSH, BKCI-SSH, ESCI, CCR-EXPANDED, IC)	
TS=(((("femur head" OR "femoral head") NEAR/3 necrosis) OR osteoradionecrosis OR osteoradionecroses OR ONFH) AND ((("femur head" OR "femur collapse" OR "femoral collapse") AND without) OR (ARCO NEAR/5(1 OR 2 OR One OR Two)) OR "pre-collapse" OR "before collapse"))	
Scopus	
((((INDEXTERMS("femur head necrosis")) OR (INDEXTERMS("Osteoradionecrosis" OR "Bone Necrosis" OR "Osteonecrosis") AND INDEXTERMS("Femur Head" OR "Femoral Head")) OR ((TITLE-ABS-KEY(((femur OR femoral) W/2 head))) AND (TITLE-ABS-KEY(((avascular OR aseptic OR ischemic) W/2 (necrosis OR necroses)) OR osteonecrosis OR osteonecroses OR osteoradionecrosis OR osteoradionecroses)) OR TITLE-ABS (ONFH))) AND ((((INDEXTERMS("femur head" AND ("hip fractures" OR "hip fracture"))) OR (TITLE-ABS-KEY(((fracture OR collapse) W/2(femur OR femoral)) w/2 head))) AND (TITLE-ABS(without))) OR (TITLE-ABS-KEY(ARCO w/5 (1 OR 2 OR one OR two))) OR (TITLE-ABS-KEY("pre-collapse" OR precollapse)))) AND NOT (INDEXTERMS(animal OR animals) AND NOT	

INDEXTERMS(human OR humans))) AND NOT ((INDEXTERMS(Child OR infant OR adolescent)) AND NOT (INDEXTERMS(adult)))
Global Index Medicus
((((mh:(Osteoradionecrosis)) OR mh:(Osteonecrosis)) AND (mh:(Femur Head))) OR (mh:(Femur Head Necrosis)) OR ((tw:(osteonecrosis OR osteonecroses OR osteoradionecrosis OR osteoradionecroses OR necrosis OR necroses)) AND (tw:(femur OR femoral))) OR (tw:(onfh))) AND ((tw:("ARCO 1" OR "ARCO One" OR "ARCO 2" OR "ARCO Two")) OR (((tw:(fracture* AND (femur OR femoral) AND head)) OR ((mh:(Femur Head)) AND (mh:(Hip Fractures)))) AND (tw:(without))) OR (tw:("pre-collapse" OR precollapse OR "before collapse"))) AND NOT ((mh:(Adult)) AND NOT ((mh:(Child)) OR (mh:(Infant)) OR (mh:(Adolescent)))) AND NOT ((mh:(Animals)) AND NOT (mh:(Humans)))
Cochrane Library (via Wiley)
#1 MeSH descriptor: [Osteonecrosis] this term only #2 MeSH descriptor: [Osteoradionecrosis] explode all trees #3 #1 OR #2 #4 MeSH descriptor: [Femur Head] explode all trees #5 #3 AND #4 #6 MeSH descriptor: [Femur Head Necrosis] explode all trees #7 (((femur OR femoral) NEXT head)):ti,ab,kw #8 (((avascular OR aseptic OR ischemic) NEXT (necrosis OR necroses))):ti,ab,kw #9 (osteonecrosis OR osteonecroses OR osteoradionecrosis OR osteoradionecroses):ti,ab,kw #10 #8 OR #9 #11 #7 AND #10 #12 ("ONFH"):ti,ab,kw #13 #5 OR #6 OR #11 OR #12 #14 (((fracture* OR collapse*) NEXT (femur headOR femoral head))):ti,ab,kw #15 MeSH descriptor: [Femur Head] explode all trees #16 MeSH descriptor: [Hip Fractures] explode all trees #17 #15 AND #16 #18 #14 OR #17 #19 (without):ti,ab,kw #20 #18 AND #19 #21 (ARCO 1 OR ARCO 2 OR ARCO One OR ARCO Two):ti,ab,kw #22 ("pre-collapse" OR precollapse OR (before NEXT collaps*)):ti,ab,kw #23 #20 OR #21 OR #22 #24 #13 AND #23 #25 MeSH descriptor: [Adult] explode all trees #26 MeSH descriptor: [Child] explode all trees #27 MeSH descriptor: [Infant] explode all trees #28 MeSH descriptor: [Adolescent] explode all trees #29 #26 OR #27 OR #28 #30 #29 NOT #25

#31	#24 NOT #30

PICO 3: Surgical Treatment of ARCO stage III

Ovid MEDLINE(R) ALL	
1	osteonecrosis/
2	exp Osteoradionecrosis/
3	1 or 2
4	exp Femur Head/
5	3 and 4
6	exp Femur Head Necrosis/
7	((femur or femoral) adj2 head).tw,kw.
8	((avascular or aseptic or ischemic) adj2 (necrosis or necroses)).tw,kw.
9	(osteonecrosis or osteonecroses or osteoradionecrosis or osteoradionecroses).tw,kw.
10	8 or 9
11	7 and 10
12	onfh.tw,kw.
13	5 or 6 or 11 or 12
14	(ARCO adj5 ("3" or three or "4" or four)).tw,kw.
15	(fracture* adj2 (femur or femoral) adj2 head*).tw,kw.
16	exp Femur Head/
17	exp Hip Fractures/
18	16 and 17
19	14 or 15 or 18
20	exp Orthopedics/
21	exp Orthopedic Procedures/
22	(osteotom* or hemiarthroplast* or arthroplast*).tw,kw.
23	(surger* or surgical).tw,kw.
24	surgery.fs.
25	20 or 21 or 22 or 23 or 24
26	13 and 19 and 25
27	exp animals/ not exp humans/
28	26 not 27
29	exp adult/
30	exp child/ or exp infant/ or exp adolescent/
31	30 not 29
32	28 not 31
33	"case report".ti.
34	(editorial or commentary or comment or letter or review).pt.
35	33 or 34
36	32 not 35

PubMed
(((((((((("Osteonecrosis"[Mesh:NoExp]) OR "Osteoradionecrosis"[Mesh]) AND ("Femur Head"[Mesh])) OR ("Femur Head Necrosis"[Mesh])) OR (("femur head"[tiab] OR "femoral

head"[tiab]) AND (("avascular necrosis"[tiab] OR "avascular necrosis"[tiab] OR "ischemic necrosis"[tiab] OR "avascular necroses"[tiab] OR "avascular necroses"[tiab] OR "ischemic necroses"[tiab]) OR (osteonecrosis[tiab] OR osteonecroses[tiab] OR osteoradionecrosis[tiab] OR osteoradionecroses[tiab])))) OR (onfh[tiab])) AND ((("femur head fracture"[tiab] OR "femoral head fracture"[tiab] OR "femur head collapse"[tiab] OR "femoral head collapse"[tiab]) OR (("Femur Head"[Mesh]) AND "Hip Fractures"[Mesh])) OR ((ARCO[tiab] AND 3[tiab]) OR(ARCO[tiab] AND 4[tiab])))) AND (((("Orthopedics"[Mesh] OR "Orthopedic Procedures"[Mesh]) OR (osteotom*[tiab] OR hemiarthroplast*[tiab] OR arthroplast*[tiab])) OR (surger*[tiab] OR surgical[tiab])) OR ("surgery" [Subheading]))) NOT ("animals"[Mesh] NOT "humans"[Mesh])) NOT (("child"[Mesh] OR "infant"[Mesh] OR "adolescent"[Mesh]) NOT ("adult"[MeSH]))) NOT (editorial[pt] OR letter[pt])	
Embase Classic+Embase (via Ovid)	
1	bone necrosis/
2	exp osteoradionecrosis/
3	1 or 2
4	exp femoral head/
5	3 and 4
6	exp femur head necrosis/
7	((femur or femoral) adj2 head).tw,kw.
8	((avascular or aseptic or ischemic) adj2 (necrosis or necroses)).tw,kw.
9	(osteonecrosis or osteonecroses or osteoradionecrosis or osteoradionecroses).tw,kw.
10	8 or 9
11	7 and 10
12	onfh.tw,kw.
13	5 or 6 or 11 or 12
14	(ARCO adj5 ("3" or three or "4" or four)).tw,kw.
15	(fracture* adj2 (femur or femoral) adj2 head*).tw,kw.
16	exp femoral head/
17	exp hip fracture/
18	16 and 17
19	14 or 15 or 18
20	exp orthopedics/
21	exp orthopedic surgery/
22	(osteotom* or hemiarthroplast* or arthroplast*).tw,kw.
23	(surger* or surgical).tw,kw.
24	surgery.fs.
25	20 or 21 or 22 or 23 or 24
26	13 and 19 and 25
27	exp animal/ not exp human/
28	26 not 27
29	exp adult/
30	exp child/ or exp infant/ or exp adolescent/
31	30 not 29
32	28 not 31
33	(letter or commentary or editorial).pt.
34	32 not 33

Web of Science (Core Collection: SCI-EXPANDED, SSCI, AHCI, CPCI-S, CPCI-SSH, BKCI-SSH, ESCI, CCR-EXPANDED, IC)
TS=(((("femur head" OR "femoral head") NEAR/3 (necrosis OR necroses) OR osteoradionecrosis OR osteoradionecroses OR osteonecrosis OR osteonecroses) OR (ONFH)) AND ((femur head fracture) OR (ARCO NEAR/5 (3 OR three OR 4 OR four))) AND (orthopedic* OR surgery OR surgical OR "orthopedic procedure" OR osteotom* OR hemiarthroplast* OR arthroplast*))
Scopus
((((INDEXTERMS("femur head necrosis")) OR (INDEXTERMS("Osteoradionecrosis" OR "Bone Necrosis" OR "Osteonecrosis") AND INDEXTERMS("Femur Head" OR "Femoral Head")) OR ((TITLE-ABS-KEY(((femur OR femoral) W/2 head))) AND (TITLE-ABS-KEY(((avascular OR aseptic OR ischemic) W/2 (necrosis OR necroses)) OR osteonecrosis OR osteonecroses OR osteoradionecrosis OR osteoradionecroses)) OR TITLE-ABS (ONFH))) AND ((TITLE-ABS-KEY(ARCO w/5 (3 OR three OR 4 OR four))) OR (TITLE-ABS-KEY(((fracture OR collapse) W/2(femur OR femoral)) w/2 head)) OR (INDEXTERMS("femoral head" AND ("hip fracture" OR "hip fractures")))) AND ((INDEXTERMS(orthopedics OR "orthopedic procedures" OR "orthopedic surgery")) OR (TITLE-ABS-KEY(osteotom* OR hemiarthroplast* OR arthroplast OR surgery OR surgical)))) AND NOT ((INDEXTERMS(animal OR animals)) AND NOT (INDEXTERMS(human OR humans)))) AND NOT ((INDEXTERMS(Child OR infant OR adolescent)) AND NOT (INDEXTERMS(adult)))
Global Index Medicus
(((mh:(Osteoradionecrosis)) AND (mh:(Femur Head))) OR (mh:(Femur Head Necrosis)) OR ((tw:(osteonecrosis OR osteonecroses OR osteoradionecrosis OR osteoradionecroses OR necrosis OR necroses)) AND (tw:(femur OR femoral))) OR (tw:(onfh))) AND ((tw:("ARCO 3" OR "ARCO Three" OR "ARCO 4" OR "ARCO Four")) OR (tw:(fracture* AND (femur OR femoral) AND head)) OR ((mh:(Femur Head)) AND (mh:(Hip Fractures)))) AND ((mh:(Orthopedics)) OR (mh:(Orthopedic Procedures)) OR (mh:(Surgery)) OR (tw:(osteotom* OR hemiarthroplast* OR arthroplast* OR surger* OR surgical))) AND NOT ((mh:(Adult)) AND NOT ((mh:(Child)) OR (mh:(Infant)) OR (mh:(Adolescent)))) AND NOT ((mh:(Animals)) AND NOT (mh:(Humans)))
Cochrane Library (via Wiley)
#1 MeSH descriptor: [Osteonecrosis] this term only #2 MeSH descriptor: [Osteoradionecrosis] explode all trees #3 #1 OR #2 #4 MeSH descriptor: [Femur Head] explode all trees #5 #3 AND #4 #6 MeSH descriptor: [Femur Head Necrosis] explode all trees #7 (((femur OR femoral) NEXT head)):ti,ab,kw

http://dx.doi.org/10.2106/JBJS.25.01616

#8 (((avascular OR aseptic OR ischemic) NEXT (necrosis OR necroses))):ti,ab,kw
#9 (osteonecrosis OR osteonecroses OR osteoradionecrosis OR osteoradionecroses):ti,ab,kw
#10 #8 OR #9
#11 #7 AND #10
#12 ("ONFH"):ti,ab,kw
#13 #5 OR #6 OR #11 OR #12
#14 (ARCO 3 OR ARCO three OR ARCO 4 OR ARCO four):ti,ab,kw
#15 ((((femur OR femoral) NEXT head))):ti,ab,kw
#16 MeSH descriptor: [Femur Head] explode all trees
#17 MeSH descriptor: [Hip Fractures] explode all trees
#18 #16 AND #17
#19 #14 OR #15 OR #18
#20 MeSH descriptor: [Orthopedics] explode all trees
#21 MeSH descriptor: [Orthopedic Procedures] explode all trees
#22 (osteotom* OR hemiarthroplast* OR arthroplast*):ti,ab,kw
#23 (surger* OR surgical):ti,ab,kw
#24 MeSH descriptor: [] explode all trees and with qualifier(s): [surgery - SU]
#25 #20 OR #21 OR #22 OR #23 OR #24
#26 #13 AND #19 AND #25
#27 MeSH descriptor: [Adult] explode all trees
#28 MeSH descriptor: [Child] explode all trees
#29 MeSH descriptor: [Infant] explode all trees
#30 MeSH descriptor: [Adolescent] explode all trees
#31 #28 OR #29 OR #30

APPENDIX IV: SUPPLEMENTAL MATERIAL SUPPORTING AGREEII REPORTING GUIDELINE

Stakeholder Involvement	The guideline was developed by an international, multidisciplinary panel convened under the Association Research Circulation Osseous (ARCO), comprising orthopedic surgeons, osteonecrosis researchers, methodologists, and medical librarians. To ensure broad representation, members were drawn from multiple geographic regions and healthcare systems. Stakeholder participation included clinicians, researchers, and policy advisors, who contributed to defining PICO questions, reviewing evidence, and achieving consensus through structured discussions. The patients' views and preferences have also been sought.
External Review	The guideline underwent external peer review by an independent group of four reviewers, including two orthopedic surgeons (Dr. Antonia Chen, Dr. Nicholas Piuzzi, one patient with osteonecrosis (BK), and one healthcare policy/Insurance stakeholder (PG), prior to publication. Their feedback focused on the clarity, applicability, and feasibility of the recommendations, as well as the methodological rigor of the development process. All comments were systematically documented, discussed by the guideline development group, and incorporated into the final document where appropriate.
CPG updating procedure	This guideline is intended to be a living document that will be revised as new evidence becomes available. The guideline development group has committed to a formal review of the literature at least every five years, or sooner if pivotal studies are published that could alter current recommendations. The update process will follow the same rigorous methodology used for the initial guideline. Feedback from clinicians, patients, and other stakeholders will also be solicited to ensure that revisions remain clinically relevant and patient-centered. Updated versions of the guideline will be disseminated through peer-reviewed publications and professional society networks.
Key review criteria for monitoring and/ or audit purposes	Although specific audit measures were not formally defined during guideline development, institutions may evaluate implementation by tracking key process indicators—such as the proportion of patients receiving MRI as the initial diagnostic test, the use of CT or MRI for accurate staging when subchondral fracture is suspected, and appropriate application of joint-preserving versus reconstructive procedures based on ARCO stage. Outcome measures may include rates of femoral head collapse, progression to total hip arthroplasty, complication rates, and patient-reported outcomes related to pain and function. These criteria may be assessed annually or at intervals appropriate to local practice, with operational definitions adapted to regional resources and infrastructure, recognizing that variability in imaging availability, surgical expertise, and healthcare systems may influence how monitoring is implemented.

APPENDIX V: GUIDELINE DEVELOPMENT GROUP DISCLOSURES

Name	Disclosure Summary
Edward Y. Cheng	• **Royalties**: Receives royalties from *Innomed, Inc.* • **Expert Testimony**: Has provided paid expert testimony for various plaintiff and defense attorney firms • **Leadership Roles**: Serves on the *Musculoskeletal Transplant Foundation Biologics, Inc.* Medical Board of Trustees • **Editorial Role**: Editor for the *Journal of Bone and Joint Surgery*
Quanjun Cui	• **Grants:** Department of Defense (DOD), Depuy, Zimmer, Exactech — awarded to the University of Virginia while serving as PI of research projects • **Royalties:** Elsevier; Springer • **Leadership roles:** AAOS-BOC; Virginia Orthopaedic Society (VOS)
Stuart N. Goodman	• **Grants:** NIH – NIAMS and NCATS • **Royalties:** Hyalex • **Consulting fees:** Wishbone Medical Inc. • **Honoraria:** Merck • **Patents:** Confidential (per Stanford University policy) • **Leadership roles:** ARCO • **Stock/Options:** Hyalex; Marine Biomedica • **Editorial roles:** *J Bone and Joint Surgery*, *Bone and Joint Research*, *Clinical Orthopaedics and Related Research*, *Arthroplasty*, *J Biomed Mater Res*, *Journal of Orthopaedic Translation*, *Orthopedics*, *PLOS ONE*, *Regenerative Engineering and Translational Medicine*, *J Inflammation Research*
Michael A. Mont	**Grants:** NIH Grant on Osteonecrosis of the Femoral Head
Lynne C. Jones	• **Grants:** NIH Grant 5U01AR080993 • **Leadership roles:** Executive Director of ARCO; Executive Director of the National Osteonecrosis Foundation; Member of the Presidents Advisory Committee for the Society for Biomaterials; Committee member for the World Biomaterials Congress 2028 • **Editorial roles:** Associate Editor, *Journal of Arthroplasty*
Takashi Sakai	No conflicts to disclose
Kyung-Hoi Koo	No conflicts to disclose
Young-Kyun Lee	No conflicts to disclose
Takuaki Yamamoto	No conflicts to disclose
Harry Kim	No conflicts to disclose
Ines Reichert	• **Leadership roles:** British Orthopaedic Research Society
Nobuhiko Sugano	No conflicts to disclose
Philippe Hernigou	No conflicts to disclose

Wolf Drescher	No conflicts to disclose
Dewei Zhao	No conflicts to disclose
Benjamin M. Stronach	• **Leadership Role**: Chair, *Patient Education Committee* of the *American Association of Hip and Knee Surgeons* • **Scope of Work**: Authored content for patient education on osteonecrosis of the femoral head
Byung-Ho Yoon	No conflicts to disclose
Yong-Chan Ha	No conflicts to disclose
Mel S. Lee	No conflicts to disclose
Seung-Hoon Baek	No conflicts to disclose
Rafael J. Sierra	• **Royalties:** Zimmer Biomet • **Consulting fees:** Zimmer Biomet • **Honoraria:** Zimmer Biomet • **Travel support:** Zimmer Biomet • **Leadership roles:** Hip Society; Müller Foundation ARCOS; American Association of Hip and Knee Surgeons (AAHKS)
Tae-Young Kim	No conflicts to disclose
Wataru Ando	No conflicts to disclose
Alireza Mirzaei	No conflicts to disclose
Mary Butler	No conflicts to disclose
Romil Parikh	No conflicts to disclose
Caitlin Bakker	No conflicts to disclose
Sergio F. Guarin Perez	No conflicts to disclose
Diego J. Restrepo	No conflicts to disclose
Sallee Brandt	No conflicts to disclose
Gabrielle Swartz	No conflicts to disclose
Reza Katanbaf	No conflicts to disclose

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