



A Comprehensive Review of Avascular Necrosis of the Femoral Head

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Abstract

Avascular necrosis (AVN) of the femoral head, also referred to as osteonecrosis of the femoral head (ONFH), is a progressive musculoskeletal disorder resulting from compromised blood supply to the femoral head. Interruption of the vascular supply initiates a cascade of cellular death, structural weakening, and progressive deformation of the femoral head. If the condition is not recognized and managed during its early stages, subchondral fracture and collapse may develop, ultimately resulting in secondary degenerative changes of the hip joint. AVN may arise following traumatic events such as femoral neck fractures and hip dislocation, or from non-traumatic factors including prolonged corticosteroid exposure, excessive alcohol consumption, hematological disorders, autoimmune diseases, metabolic abnormalities and other systemic conditions. Early diagnosis is therefore essential because treatment options are strongly influenced by the structural condition of the femoral head. Conventional radiography remains useful for identifying established structural abnormalities, whereas magnetic resonance imaging (MRI) is particularly valuable for detecting early disease that may not be apparent on plain radiographs. Several classification systems have been developed, with the revised Association Research Circulation Osseous (ARCO) system providing a practical framework for staging disease according to imaging findings and femoral head collapse. Management ranges from observation, modification of risk factors and symptomatic measures to joint-preserving procedures such as core decompression in appropriately selected precollapse disease. Advanced disease with structural collapse and degenerative joint changes may require total hip arthroplasty. This review summarizes the major etiological factors, underlying mechanisms, clinical presentation, diagnostic approaches, staging systems and current treatment strategies for femoral head AVN, emphasizing the importance of early recognition and individualized management.

Keywords: Avascular necrosis, osteonecrosis, femoral head, hip joint, MRI, ARCO classification, core decompression, total hip arthroplasty.

1. INTRODUCTION

Avascular necrosis of the femoral head is an important orthopedic condition characterized by death of bone tissue following inadequate blood supply. The disease can occur in association with trauma or develop without a directly identifiable traumatic event. Because the femoral head depends on a relatively limited vascular network, interruption of its blood supply can have significant consequences.

The clinical importance of AVN lies not only in the initial loss of viable bone but also in the progressive mechanical consequences that may follow. Necrotic bone has reduced structural integrity, and continued physiological loading can contribute to subchondral fracture and eventual collapse of the femoral head. Once collapse and secondary degenerative changes occur, preservation of the native hip becomes considerably more difficult.

AVN is therefore a condition in which **timing of diagnosis is closely related to treatment possibilities**. In early disease, the femoral head may retain its normal contour despite pathological changes being visible on MRI. In later stages, radiographic abnormalities, subchondral fracture, flattening and osteoarthritis become increasingly prominent.

The purpose of this review is to provide an integrated overview of femoral head AVN, focusing on its causes, pathophysiology, clinical manifestations, diagnosis, staging and management. Particular emphasis is placed on imaging-based diagnosis and the distinction between precollapse and post-collapse disease.

2. ANATOMY AND BLOOD SUPPLY OF THE FEMORAL HEAD

The femoral head forms the spherical proximal component of the hip joint and articulates with the acetabulum. Its structural integrity is essential for weight transmission between the pelvis and lower limb.

The principal vascular contribution to the adult femoral head arises from branches of the medial and lateral circumflex femoral arteries. These vessels form an arterial network around the femoral neck and provide branches that travel toward the femoral head. A smaller contribution may arise through the artery associated with the ligamentum teres, although its importance is considerably greater during childhood.

Because the femoral head has limited capacity to compensate for disruption of its major vascular pathways, traumatic interruption of these vessels can produce ischemia. This anatomical characteristic helps explain the association between femoral neck fractures, hip dislocation and subsequent osteonecrosis.

Table 1. Major factors influencing femoral head vascular integrity

Factor	Potential consequence
Femoral neck fracture	Disruption of retinacular vessels
Hip dislocation	Acute vascular compromise
Intraosseous pressure changes	Reduced microvascular perfusion
Vascular occlusion	Ischemia of bone tissue
Hypercoagulability	Microvascular obstruction
Fat-cell hypertrophy	Increased intraosseous pressure
Endothelial dysfunction	Impaired circulation

3. ETIOLOGY AND RISK FACTORS

The causes of femoral head AVN can broadly be divided into **traumatic** and **non-traumatic** categories.

3.1 Traumatic causes

Trauma can directly interrupt blood vessels supplying the femoral head. Femoral neck fractures and posterior hip dislocations are particularly important traumatic associations. The severity of vascular disruption and the characteristics of the injury influence the subsequent risk of osteonecrosis.

3.2 Corticosteroid exposure

Long-term or high-dose corticosteroid exposure is one of the major recognized non-traumatic associations. The biological mechanism is complex and may involve alterations in lipid metabolism, marrow adipocyte changes, vascular endothelial effects and increased intraosseous pressure.

However, steroid exposure should not be interpreted as having a single isolated mechanism. The development of osteonecrosis is considered multifactorial, and individual susceptibility may vary.

3.3 Alcohol consumption

Excessive alcohol consumption has also been strongly associated with non-traumatic osteonecrosis. Proposed mechanisms include alterations in lipid metabolism, changes in bone marrow fat, vascular obstruction and increased intraosseous pressure.

3.4 Hematological disorders

Conditions that alter blood viscosity or microvascular flow may increase the likelihood of osteonecrosis. Sickle cell disease is a recognized example in which abnormal red blood cells can compromise microcirculation and produce bone infarction.

3.5 Autoimmune and systemic disorders

Systemic lupus erythematosus and other inflammatory conditions have been associated with AVN. In such cases, corticosteroid treatment may contribute to the risk, although osteonecrosis can also occur in the absence of corticosteroid exposure.

Other reported associations include metabolic disorders, coagulation abnormalities, certain vascular conditions and exposure to cytotoxic agents.

4. PATHOPHYSIOLOGY

The central event in AVN is inadequate perfusion of the femoral head. When blood flow becomes insufficient, bone marrow cells and osteocytes are exposed to ischemic injury. Persistent vascular compromise results in cellular death and structural weakening of the affected bone.

The pathophysiological process can be conceptualized as follows:

Vascular compromise → ischemia → cellular death → necrotic bone → impaired repair/remodeling → subchondral fracture → femoral head collapse → secondary osteoarthritis

This sequence does not necessarily occur at the same rate in every patient. The size and location of the necrotic lesion, underlying cause, mechanical loading and ability of the bone to repair itself can influence progression. Lesions affecting weight-bearing portions of the femoral head are particularly important because they are exposed to substantial mechanical stress.

The disease is consequently both a **vascular problem and a biomechanical problem**. Initial vascular injury initiates the pathological process, while mechanical loading contributes to structural failure after the bone has become weakened.

5. CLINICAL MANIFESTATIONS

Early AVN may remain clinically silent. As the disease progresses, patients commonly develop hip or groin pain. Pain may extend toward the thigh and is frequently aggravated by activities involving weight bearing, such as walking or climbing stairs.

Common clinical manifestations include:

- Hip or groin pain
- Pain during weight-bearing activities
- Reduced hip mobility
- Difficulty walking
- Pain during internal rotation
- Pain during abduction
- Limping in advanced disease
- Functional limitation

The severity of symptoms does not always correspond directly to the extent of structural disease. Some individuals may have imaging evidence of osteonecrosis before significant symptoms develop. This emphasizes the importance of considering risk factors and appropriate imaging when clinical suspicion exists.

6. DIAGNOSTIC EVALUATION

Diagnosis is based on a combination of clinical assessment and imaging.

6.1 Plain radiography

Anteroposterior and lateral radiographs are commonly used as an initial imaging investigation. They are useful for identifying established structural changes such as sclerosis, cystic alterations, femoral head flattening, subchondral fracture and degenerative changes.

However, radiographs may remain normal during early disease. Consequently, a normal X-ray does not necessarily exclude AVN when clinical suspicion remains high.

6.2 Magnetic resonance imaging

MRI is particularly important in the detection of early osteonecrosis. It can identify marrow abnormalities before substantial structural changes become visible on conventional radiography. MRI also helps determine the size and location of the necrotic lesion and evaluate structural changes within the femoral head.

The combination of high sensitivity for early disease and anatomical detail makes MRI an important component of modern AVN evaluation.

6.3 Computed tomography

CT may provide useful information regarding the bony architecture and is particularly helpful in evaluating subchondral fracture and femoral head depression. It can complement MRI and conventional radiographs when structural assessment is important. The revised ARCO system specifically incorporates X-ray or CT findings when assessing stage III disease.

6.4 Laboratory investigations

Laboratory investigations are not generally diagnostic of AVN itself but may assist in identifying associated systemic disorders. Depending on the patient's history, investigations may include complete blood count, lipid profile, inflammatory markers, autoimmune testing and hemoglobin electrophoresis.

7. STAGING OF AVASCULAR NECROSIS

Several classification systems have historically been used to describe osteonecrosis. These include the Ficat system, Steinberg system and ARCO classification.

The **2019 revised ARCO classification** provides a four-stage framework based primarily on imaging findings.

Table 2. Simplified 2019 ARCO staging system

Stage	Principal imaging characteristics
I	X-ray appears normal; MRI demonstrates abnormality
II	Radiographic abnormalities without subchondral fracture or flattening
IIIA	Subchondral fracture with femoral head depression ≤ 2 mm
IIIB	Subchondral fracture with femoral head depression > 2 mm
IV	Osteoarthritic changes involving the hip joint

The distinction between **precollapse** and **post-collapse** disease is clinically important. Stages I and II generally represent disease without established collapse, whereas stage III indicates structural failure of the femoral head. Stage IV represents advanced disease with degenerative joint changes.

8. NATURAL HISTORY AND PROGRESSION

The natural history of AVN varies between individuals. Small lesions may remain stable, whereas larger lesions located in mechanically important regions of the femoral head have a greater potential for progression. Lesion size and location are therefore important considerations when evaluating prognosis.

Once the subchondral bone fails, the shape of the femoral head may progressively deteriorate. Altered joint mechanics can then increase cartilage stress and promote secondary osteoarthritis.

This progression demonstrates why identifying the condition before structural collapse is clinically valuable.

9. MANAGEMENT OF AVASCULAR NECROSIS

Treatment depends on several factors, including:

- Disease stage
- Lesion size
- Lesion location
- Presence or absence of collapse
- Patient age
- Functional requirements
- Symptoms
- Underlying cause
- Associated medical conditions

There is no single treatment that is appropriate for every patient.

9.1 Conservative management

Conservative approaches may include activity modification, reduction of excessive mechanical loading, analgesic treatment and management of underlying risk factors.

Patients with potentially modifiable risk factors should receive appropriate counseling. For example, clinicians may review unnecessary corticosteroid exposure with the treating physician and address excessive alcohol consumption when relevant.

Conservative treatment may provide symptom relief, but it should not be assumed to reverse established structural necrosis.

10. JOINT-PRESERVING PROCEDURES

The primary objective of joint-preserving treatment is to maintain the native femoral head and delay or prevent collapse.

10.1 Core decompression

Core decompression is one of the commonly used surgical approaches for selected precollapse lesions. The procedure involves creating a channel into the affected region of the femoral head to reduce abnormal intraosseous pressure and facilitate a reparative response.

Evidence from reviews suggests that outcomes are generally more favorable when core decompression is performed before collapse.

The effectiveness of the procedure can depend on lesion size, location, disease stage and patient-related factors. Consequently, core decompression should be considered as a stage- and patient-specific intervention rather than a universal treatment.

10.2 Bone grafting and biological augmentation

Core decompression may be combined with bone grafting or biological approaches intended to provide structural support or enhance bone repair.

Bone marrow-derived cellular techniques and other biological augmentation strategies have been investigated, but evidence remains variable and further high-quality studies are needed before uniform recommendations can be made.

11. TOTAL HIP ARTHROPLASTY

When substantial femoral head collapse or secondary osteoarthritis has developed, joint-preserving procedures may no longer provide adequate structural restoration.

Total hip arthroplasty (THA) replaces the damaged femoral head and acetabular components with prosthetic surfaces. It is an established treatment for advanced disease in appropriately selected patients.

The decision to perform THA depends on the degree of structural damage, symptoms, functional impairment, patient age and overall health status.

The progression from an early, potentially joint-preserving stage to advanced degenerative disease illustrates the importance of early recognition and appropriate referral.

12. ROLE OF EARLY DIAGNOSIS

Early diagnosis represents one of the most important aspects of AVN management.

A patient with risk factors and persistent hip pain may have normal radiographs despite having early disease. MRI can reveal pathological changes before collapse becomes apparent on conventional imaging.

Early identification allows clinicians to:

1. Identify and modify relevant risk factors.
2. Determine the size and location of the lesion.
3. Establish the stage of disease.
4. Monitor progression.
5. Consider joint-preserving treatment when appropriate.
6. Avoid unnecessary delay before specialist intervention.

Therefore, a combination of **clinical suspicion, appropriate imaging and stage-based management** is essential.

13. MULTIDISCIPLINARY ROLE IN PATIENT MANAGEMENT

Management of AVN may involve several healthcare professionals, particularly in patients with systemic risk factors.

The multidisciplinary team can include:

- Orthopedic surgeon
- Radiologist
- Physiotherapist
- Primary care physician
- Rheumatologist or hematologist when indicated
- Nursing professionals
- Rehabilitation specialists

Nurses and allied healthcare professionals play an important role in patient education, medication adherence, postoperative care, mobility assistance, rehabilitation and recognition of complications.

14. DISCUSSION

Femoral head AVN is a multifactorial disease in which vascular impairment initiates a pathological process that may ultimately produce mechanical failure of the hip. The condition may result from trauma or a variety of systemic and environmental factors.

One of the most important observations from contemporary literature is that **the structural stage of the disease strongly influences treatment selection**. A femoral head that has not yet collapsed offers greater opportunity for joint-preserving intervention than a head with established collapse and secondary arthritis.

Imaging therefore has a central role. Conventional radiography is valuable for detecting structural abnormalities, but MRI is particularly useful during the earlier phases of disease. The revised ARCO classification further emphasizes the importance of recognizing subchondral fracture and the extent of femoral head depression.

Core decompression remains an important joint-preserving strategy, particularly for appropriately selected precollapse lesions. However, its success is influenced by disease stage and lesion characteristics. Current literature also explores biological augmentation and regenerative strategies, but these approaches require additional evidence to determine their long-term effectiveness and appropriate indications.

For advanced disease, total hip arthroplasty remains an important treatment option. Thus, the management pathway should not be viewed as a single standardized procedure but rather as a continuum based on disease severity.

An important limitation of the available literature is the heterogeneity of patient populations, etiologies, staging methods and treatment protocols across studies. Future research should focus on standardized outcome measures, better prediction of lesion progression and improved identification of patients who are most likely to benefit from joint-preserving interventions.

15. FUTURE PERSPECTIVES

Future research in AVN is likely to focus on improving early detection, predicting disease progression and developing treatments capable of restoring vascularity and bone structure.

Potential areas of investigation include:

- Advanced MRI-based assessment
- Quantitative evaluation of lesion size and location
- Biological and regenerative therapies
- Bone marrow-derived cellular approaches
- Improved surgical navigation
- Patient-specific treatment algorithms
- Biomarkers for early disease detection
- Long-term comparative studies of joint-preserving procedures

The development of reliable predictive models could eventually allow clinicians to identify which lesions are likely to progress and which patients can safely be managed with observation and risk-factor modification.

16. CONCLUSION

Avascular necrosis of the femoral head is a clinically significant disorder caused by impaired blood supply to the proximal femur. Its progression from ischemic bone injury to structural collapse and secondary osteoarthritis can substantially affect mobility and quality of life.

The major risk factors include traumatic hip injuries, corticosteroid exposure, excessive alcohol consumption, hematological disorders and systemic inflammatory conditions. Clinical presentation commonly includes hip or groin pain and restricted movement, although early disease may be asymptomatic.

Radiography remains an important first-line imaging technique, while MRI provides substantial value in identifying early disease and defining the extent of involvement. The revised ARCO classification provides a useful framework for distinguishing early disease from subchondral fracture, femoral head depression and advanced degenerative changes.

Management should be individualized according to disease stage, lesion characteristics and patient factors. Joint-preserving procedures such as core decompression are primarily relevant to appropriately selected precollapse disease, whereas advanced collapse and secondary osteoarthritis may require total hip arthroplasty.

Ultimately, **early recognition, accurate staging, modification of relevant risk factors and timely orthopedic evaluation are central to improving outcomes in patients with femoral head AVN.**

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