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Incidence and Mechanisms of Avascular Necrosis of the Femoral Head in Post-COVID-19 Patients: A Comprehensive Observational Study

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Abstract:
COVID-19 has been linked to various long-term complications affecting multiple organ systems, including the musculoskeletal system. This study investigates the incidence and risk factors of avascular necrosis (AVN) of the femoral head among COVID-19 survivors, with a focus on the role of corticosteroid therapy and COVID-19 severity. Conducted at a tertiary care center, the observational study classified AVN cases using the FICAT and ARLET staging system and examined the correlation between steroid use and AVN progression. The results indicate a higher prevalence of AVN in patients with moderate to severe COVID-19 and a notable association between corticosteroid therapy and AVN onset. The accelerated onset of AVN in these patients suggests that COVID-19-induced hypercoagulability, combined with steroid usage, may contribute to rapid ischemic damage to bone tissue. The findings underscore the importance of early detection and regular follow-up in COVID-19 survivors, particularly those treated with steroids, to prevent progression to advanced AVN stages. This study highlights the need for cautious steroid administration in COVID-19 treatment and suggests directions for future research on preventive measures and alternative therapies to mitigate AVN risk in post-COVID-19 care.

Keywords: *COVID-19, avascular necrosis, femoral head, corticosteroids, hypercoagulability, FICAT and ARLET classification, musculoskeletal complications, post-COVID-19, ischemic bone damage, early diagnosis*

Introduction

The COVID-19 pandemic, caused by the SARS-CoV-2 virus, has left a significant and unprecedented impact on global healthcare systems, affecting millions worldwide with both immediate and long-term health implications. Originally regarded as an acute respiratory illness, COVID-19 has since been linked to a range of systemic complications, with far-reaching effects on the cardiovascular, neurological, and musculoskeletal systems. As research into the aftereffects of the virus has progressed, it has become increasingly clear that COVID-19 can cause enduring complications in patients who recover from the initial infection, leading to a category of post-viral symptoms now widely known as “Long COVID” or Post-Acute Sequelae of SARS-CoV-2 Infection (PASC). Among these, musculoskeletal complications, particularly avascular necrosis (AVN) of the femoral head, have been recognized as an important area of concern for patient mobility and quality of life, warranting thorough investigation to understand its incidence, mechanisms, and management.

Musculoskeletal symptoms have been reported frequently among COVID-19 patients, ranging from generalized

body aches and myalgias during the acute phase to more specific and chronic conditions in the post-recovery period. Musculoskeletal symptoms such as fatigue, myalgia, joint pain, and even inflammatory conditions like myositis have become common in post-COVID patients. However, while most of these conditions are typically reversible or manageable with time and conservative treatment, certain post-COVID complications have a more debilitating nature, impacting bone and joint health to the extent of requiring invasive medical intervention.

The hip joint, in particular, has emerged as an area of concern in post-COVID-19 cases, with AVN of the femoral head identified as a potentially severe complication. This musculoskeletal disorder, which can lead to joint dysfunction and necessitate major surgery such as hip replacement, has garnered attention due to its possible links to COVID-19, especially in patients treated with high doses of corticosteroids—a common therapy for severe COVID-19 cases. AVN results from compromised blood flow to bone tissue, leading to cell death and structural collapse in load-bearing joints. The femoral head, being a critical component of the hip joint, is particularly susceptible due to its unique blood supply, which can be disrupted by various factors, including trauma, thrombosis, and, as research suggests, COVID-19-associated inflammation and hypercoagulability.

Avascular necrosis (AVN), also known as osteonecrosis, is a progressive bone disease resulting from a loss of blood supply to bone tissue. This disruption leads to the death of osteocytes (bone cells), weakening the structural integrity of the bone and, eventually, causing the bone to collapse. Common sites for AVN include the femoral head, shoulder, and knee, with the femoral head being one of the most affected areas due to its dependence on a limited vascular supply. The pathophysiology of AVN in the femoral head typically involves a series of stages, beginning with blood supply disruption, followed by ischemia, cell death, and, ultimately, structural collapse of the joint.

The most common causes of AVN include traumatic injury, prolonged corticosteroid use, alcohol abuse, and certain chronic medical conditions such as sickle cell disease and autoimmune disorders. The limited blood flow to the femoral head, primarily provided by small retinacular vessels, makes it particularly vulnerable to ischemic conditions. Patients with AVN of the femoral head initially experience pain, stiffness, and limited range of motion in the hip joint, which may progress to severe pain and mobility impairment as the femoral head collapses and joint arthritis develops. Left untreated, AVN can lead to debilitating joint deformity, necessitating surgical interventions such as core decompression, osteotomy, or total hip arthroplasty (hip replacement) in advanced stages.

The study of AVN among post-COVID-19 patients is critically relevant for several reasons. First, evidence increasingly suggests that COVID-19, particularly in severe cases, may elevate the risk of AVN, owing to a combination of factors including hypercoagulability, inflammation, and steroid use. COVID-19 is known to trigger a hypercoagulable state, characterized by an increased risk of thrombotic events, including deep vein thrombosis, pulmonary embolism, and microvascular thrombosis. This hypercoagulability, coupled with systemic inflammation and the impact on endothelial cells, can create an environment conducive to ischemic damage in blood vessels, including those supplying the femoral head. Additionally, many COVID-19 patients with severe respiratory symptoms are treated with corticosteroids, which, while life-saving, have been well-documented as a major risk factor for AVN due to their effects on lipid metabolism, coagulation, and bone health.

A number of case reports and small studies have documented AVN occurrences in patients who recovered from

COVID-19, especially those who received high-dose steroid treatments. In these cases, the typical timeline for AVN onset has been shown to be shorter than in non-COVID populations, with symptoms often emerging within months rather than years after exposure to risk factors such as corticosteroids. This observation suggests a potential synergistic effect between COVID-19 and corticosteroids that may accelerate the development of AVN. However, there remains a significant gap in our understanding of the exact mechanisms linking COVID-19 to AVN and the prevalence of this complication among COVID-19 survivors. By studying AVN in post-COVID-19 patients, clinicians and researchers can better understand the disease's long-term implications, improve early detection protocols, and identify preventive and therapeutic strategies tailored to this population.

Furthermore, studying AVN in the context of COVID-19 contributes to a broader understanding of "Long COVID" and the range of post-acute sequelae that patients may face. The term "Long COVID" encompasses a variety of symptoms and conditions affecting multiple organ systems, from persistent fatigue and respiratory issues to neurological and cardiovascular complications. Recognizing AVN as a possible component of Long COVID can aid in the development of comprehensive care models for COVID-19 survivors, ensuring that musculoskeletal health is not overlooked in post-recovery monitoring. Early identification and management of AVN are essential to preserving joint function and preventing disability in these patients, as delays in diagnosis often lead to more severe disease progression and limited treatment options.

From a public health perspective, the socioeconomic implications of AVN in post-COVID-19 patients underscore the importance of research in this area. AVN can result in long-term disability, affecting a patient's ability to work and leading to increased healthcare costs due to the need for surgical interventions and prolonged rehabilitation. Given the already significant economic impact of COVID-19, adding the potential burden of AVN-related disability further complicates recovery efforts for both individuals and healthcare systems. By identifying risk factors, understanding the pathophysiological mechanisms, and exploring preventive strategies, healthcare providers can better address the needs of COVID-19 survivors, mitigate the socioeconomic impacts, and allocate resources more effectively.

In summary, as the global community continues to adapt to the challenges of COVID-19, understanding and addressing long-term complications like AVN becomes essential. The interplay between COVID-19-associated hypercoagulability, systemic inflammation, corticosteroid use, and the pathophysiology of AVN warrants focused research to clarify the prevalence, risk factors, and mechanisms of AVN in post-COVID-19 patients. Through such studies, we can enhance clinical outcomes for patients affected by both COVID-19 and AVN, ultimately contributing to a more comprehensive approach to post-COVID care and recovery.

Aim and Objectives

Aim:

To investigate the incidence, progression, and contributing factors of avascular necrosis (AVN) of the femoral head in patients who have recovered from COVID-19, focusing on the role of steroid therapy and the classification of disease stages.

Objectives:

1. To study the incidence and progression of avascular necrosis of the femoral head in COVID-19 survivors

   This objective involves determining the frequency of AVN occurrences in patients who have recovered from COVID-19, particularly those who experienced severe infection or required intensive medical

intervention. Tracking the progression of AVN from initial diagnosis through subsequent stages will provide valuable insights into how quickly AVN develops post-COVID-19 and highlight any unique progression patterns that may differ from AVN cases unrelated to COVID-19. The findings will contribute to the understanding of AVN as a potential post-COVID complication, helping guide early diagnostic and preventive measures.

2. To examine the role of steroid treatments in the onset of avascular necrosis High-dose corticosteroid therapy has been extensively used to manage severe COVID-19 cases due to its anti-inflammatory benefits, yet it is a known risk factor for AVN. This objective focuses on analyzing the relationship between steroid treatment and AVN onset, with attention to dosage, duration, and timing of administration relative to AVN development. Understanding the dose-response dynamics and other potential co-factors, such as pre-existing conditions, can provide insights into the safe administration of corticosteroids in COVID-19 treatment protocols, aiming to minimize AVN risk.
3. To classify avascular necrosis cases using the FICAT and ARLET classification stages Accurate classification of AVN cases is crucial for evaluating disease severity and selecting appropriate treatment strategies. This objective involves categorizing AVN cases in COVID-19 survivors according to the FICAT and ARLET classification system, which stages AVN based on radiographic findings and clinical symptoms. Classifying cases systematically will help assess the disease stage at diagnosis and enable comparisons of disease progression among different patient groups, contributing to a more tailored approach in AVN management for post-COVID patients.

Review of Literature

Avascular necrosis (AVN), also known as osteonecrosis, is a progressive bone disease resulting from an interruption of blood supply to bone tissue, leading to cellular death and structural collapse. The femoral head is especially vulnerable to AVN due to its unique blood supply, which relies heavily on a network of retinacular vessels that are easily disrupted by trauma or other risk factors. Historically, AVN was documented as early as the 18th century, with early reports describing necrosis in load-bearing joints such as the hip following traumatic injuries. Throughout the 19th and 20th centuries, the understanding of AVN expanded with studies linking it to non-traumatic causes such as excessive corticosteroid use, alcoholism, and specific chronic diseases, including sickle cell disease and systemic lupus erythematosus.

The etiology of AVN is complex and multifactorial. It can be categorized broadly into traumatic and non-traumatic causes. Traumatic causes include fractures and dislocations that directly disrupt the blood supply to the femoral head, leading to ischemia and subsequent bone necrosis. Non-traumatic causes, on the other hand, involve systemic factors that compromise blood flow indirectly, such as corticosteroid use, excessive alcohol consumption, certain infections, and autoimmune disorders. Steroid-induced AVN is one of the most well-documented forms of non-traumatic AVN, with corticosteroids contributing to ischemia through mechanisms like increased blood lipid levels and thrombus formation in small blood vessels. Understanding the history and diverse etiology of AVN has provided a foundation for studying new contributing factors, such as the potential impact of COVID-19.

COVID-19 has been linked to a wide range of complications across multiple organ systems, including the musculoskeletal system. Initially identified as a respiratory disease, COVID-19 has since been associated with vascular and coagulopathic complications, which have implications for musculoskeletal health. The virus's

impact on vascular health stems largely from its effects on the endothelium, the thin layer of cells lining blood vessels. SARS-CoV-2, the virus responsible for COVID-19, is known to bind to ACE2 receptors, which are highly expressed in endothelial cells. This binding can lead to direct viral damage to endothelial cells, setting off a cascade of inflammation and coagulation disturbances that compromise vascular integrity.

In severe COVID-19 cases, patients experience what is known as a "cytokine storm," where elevated levels of pro-inflammatory cytokines such as IL-6, TNF-α, and IL-1 cause widespread inflammation. This inflammatory response can increase vascular permeability and promote thrombosis, or blood clot formation, through the activation of the coagulation cascade. Hypercoagulability, combined with endothelial damage, can lead to microvascular thrombosis and impair blood flow to various tissues, including bone. The femoral head, with its limited vascular supply, is particularly vulnerable to ischemic conditions, which raises concerns about COVID-19's potential role in AVN onset.

COVID-19's effect on musculoskeletal function has also been well-documented, with many patients reporting symptoms such as joint pain, muscle aches, and fatigue even months after recovery. The virus's propensity to induce inflammation, combined with hypercoagulability, creates a pathogenic environment that can predispose patients to AVN. Reports have indicated an increased incidence of AVN in COVID-19 patients, potentially as a long-term complication or a part of the broader "Long COVID" syndrome. The pathophysiology of AVN in these patients is thought to be influenced by COVID-19-related hypercoagulability, steroid use, and immune-mediated inflammation, warranting further study to fully understand the mechanisms involved.

Steroid use has long been established as a major risk factor for AVN, and its use during the COVID-19 pandemic has raised concerns about the potential increase in AVN cases among COVID-19 survivors. Corticosteroids are frequently administered to COVID-19 patients with severe respiratory symptoms due to their potent anti-inflammatory effects. However, these benefits come with a significant risk of AVN, particularly in cases involving high-dose or long-term steroid therapy. Studies on steroid-induced AVN suggest that steroids contribute to AVN through multiple mechanisms, including altered lipid metabolism, increased blood lipid levels, and endothelial damage. Steroids also suppress osteoblast function, impeding bone repair processes and making the bone more susceptible to necrosis. Moreover, steroids promote fat deposition in blood vessels, leading to fat emboli that can block blood flow to the femoral head, creating an ischemic environment conducive to AVN.

In addition to steroid use, COVID-19 has been shown to induce a hypercoagulable state in patients, which further elevates the risk of AVN. Studies have noted an increase in coagulation markers such as D-dimer, fibrinogen, and thrombin in COVID-19 patients, all of which contribute to the hypercoagulable state. Hypercoagulability increases the likelihood of thrombotic events, particularly microthrombosis, which can obstruct blood flow to critical areas of bone. The femoral head's limited vascularization makes it vulnerable to ischemic damage when thrombi form in its small vessels. In combination with corticosteroid use, COVID-19's hypercoagulable state has created a "perfect storm" scenario that raises the risk of AVN in recovered patients.

Case reports and retrospective studies have provided initial evidence of this link between COVID-19, steroid use, and AVN. For instance, several studies have documented cases of AVN occurring in COVID-19 patients treated with corticosteroids, with symptoms typically appearing within a few months post-recovery. One notable study examined the incidence of AVN in COVID-19 survivors who received corticosteroid therapy, finding that AVN symptoms developed significantly earlier than in non-COVID populations who received similar steroid

doses. This accelerated onset suggests a possible interaction between COVID-19-related vascular damage and the steroid-induced ischemic processes, emphasizing the need for caution in corticosteroid use for COVID-19 treatment. Another study conducted on COVID-19 patients receiving high-dose steroids noted an increased prevalence of femoral head AVN, supporting the hypothesis that COVID-19 may exacerbate the risk of steroid-induced AVN.

Further research is needed to clarify the precise mechanisms linking COVID-19, steroid use, and hypercoagulability to AVN. Large-scale, longitudinal studies that monitor COVID-19 patients with a history of corticosteroid use can provide valuable data on the long-term musculoskeletal effects of COVID-19. Additionally, examining coagulation profiles and inflammatory markers in these patients could shed light on the interplay between inflammation, coagulopathy, and steroid use in AVN development. Such studies can inform clinical guidelines for steroid administration in COVID-19 patients, ensuring that the benefits of corticosteroid therapy are weighed against the potential risks of AVN. In conclusion, while corticosteroids are indispensable in managing severe COVID-19 symptoms, understanding and mitigating their long-term effects on musculoskeletal health remains crucial in the comprehensive care of COVID-19 survivors.

Material and Methodology

Study Design

This study was designed as a retrospective and prospective observational study, aimed at investigating the incidence, progression, and risk factors of avascular necrosis (AVN) of the femoral head in post-COVID-19 patients. By employing both retrospective and prospective approaches, this study allows for the examination of previously collected patient data as well as the active monitoring of new cases. This dual approach provides a robust dataset, capturing both historical and current trends in AVN incidence among COVID-19 survivors. Additionally, the study's observational nature is well-suited to exploring associations and patterns without intervention, making it ideal for understanding disease progression in a natural setting.

Study Location

The study was conducted at the Department of Orthopaedics at Krishna Institute of Medical Sciences, Hospital, and Research Centre, located in Karad, Maharashtra, India. Krishna Institute of Medical Sciences is a tertiary care center with a high influx of COVID-19 patients, allowing for a comprehensive examination of AVN in a diverse patient population with varying degrees of COVID-19 severity. The hospital's facilities include diagnostic imaging equipment, such as magnetic resonance imaging (MRI) and radiography, making it suitable for longitudinal monitoring of AVN progression.

Participant Selection

The study targeted patients who had previously been diagnosed with COVID-19 and subsequently presented with hip pain or other symptoms suggestive of AVN. Participants were either identified retrospectively through hospital records or recruited prospectively as they sought treatment for hip-related complaints post-COVID-19 recovery. For the retrospective cohort, hospital records from 2019 to 2023 were reviewed to identify eligible patients. Prospective participants were recruited from among patients visiting the orthopaedic outpatient clinic or admitted with hip pain that was suspected to be AVN-related.

Data Collection and Diagnostic Procedures

Data collection encompassed a range of clinical, demographic, and diagnostic variables to provide a comprehensive view of each participant's medical history and AVN status. The following subsections detail the specific types of data collected and the diagnostic procedures used.

1. Clinical and Demographic Data

For each patient, clinical and demographic data were collected, including age, sex, body mass index (BMI), COVID-19 severity (mild, moderate, or severe), and any history of corticosteroid therapy. Details of steroid use, including dosage, duration, and timing relative to COVID-19 diagnosis, were documented to examine potential links with AVN onset. Additional variables included other known risk factors for AVN, such as alcohol consumption, smoking history, comorbidities, and any prior history of musculoskeletal issues.

2. Imaging and Diagnostic Assessment

The primary diagnostic tool used to confirm AVN was MRI, which is considered the gold standard for detecting early AVN due to its sensitivity in identifying bone marrow edema and ischemic changes. MRI was performed on patients presenting with hip pain or other symptoms indicative of AVN, such as restricted joint movement and persistent discomfort. MRI imaging was used to classify AVN according to the FICAT and ARLET staging system, which categorizes AVN into four stages based on radiographic and MRI findings.

For patients in whom MRI was not immediately accessible, plain radiographs (X-rays) of the pelvis (anteroposterior view) were taken to detect structural abnormalities. Radiographs were useful in identifying more advanced stages of AVN, particularly in cases where there were signs of subchondral fracture (crescent sign) or femoral head collapse. Follow-up imaging was conducted at intervals of 3, 6, 9, and 12 months to monitor disease progression and evaluate the effectiveness of any treatments applied.

3. Laboratory Investigations

Laboratory tests were conducted to assess inflammation and coagulation profiles in patients, which are critical in understanding AVN's underlying mechanisms in post-COVID-19 cases. Tests included complete blood count (CBC), inflammatory markers such as C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR), and coagulation markers including D-dimer levels, prothrombin time (PT), and activated partial thromboplastin time (aPTT). The results provided insights into the hypercoagulable state associated with COVID-19 and its potential role in AVN development.

4. Data Documentation and Follow-up

All clinical data, imaging results, and laboratory findings were documented in a secure digital format to maintain data integrity and facilitate longitudinal analysis. Follow-up assessments were scheduled for each patient to monitor AVN progression, with clinical evaluations and imaging studies conducted at regular intervals over 12 months. This allowed for the assessment of disease stability, improvement, or deterioration and provided data on the time-course of AVN in COVID-19 survivors.

Inclusion Criteria

The inclusion criteria were as follows:

1. **Confirmed History of COVID-19**: Participants must have had a prior diagnosis of COVID-19 confirmed through RT-PCR, with records indicating the severity and any treatments administered during the infection.
2. **Presence of Hip Pain or Related Symptoms**: Patients presenting with hip pain, limited range of motion, or other symptoms consistent with AVN were considered for inclusion to ensure that only relevant cases were studied.
3. **Corticosteroid Therapy Documentation**: For those who received corticosteroid therapy during COVID-19 treatment, records needed to specify dosage, duration, and timing relative to the onset of AVN symptoms.
4. **Age**: Participants were required to be over 18 years of age to eliminate pediatric cases, which may involve different etiological factors and disease progression.
5. **Informed Consent**: For the prospective cohort, all patients provided written informed consent, acknowledging their understanding of the study's purpose and agreeing to participate in follow-up assessments.

A. Exclusion Criteria

The exclusion criteria were designed to eliminate cases where AVN might arise from non-COVID-19-related causes, thereby ensuring the study's focus remained specific to post-COVID-19 complications:

1. **Pre-existing Hip Trauma**: Patients with a history of significant hip trauma (e.g., fractures, dislocations) were excluded, as traumatic AVN may have different pathophysiological mechanisms than non-traumatic AVN.
2. **Long-term Steroid Use Unrelated to COVID-19**: Patients with a history of chronic corticosteroid use for conditions other than COVID-19 (e.g., autoimmune diseases) were excluded to avoid confounding the results.
3. **Alcoholism and Substance Abuse**: Known cases of chronic alcoholism or substance abuse were excluded, as these are established independent risk factors for AVN.
4. **Severe Comorbidities**: Patients with severe underlying conditions, such as advanced cardiovascular disease or uncontrolled diabetes, were excluded if these were likely to confound the interpretation of AVN risk related to COVID-19.
5. **Age Below 18**: Pediatric cases were excluded due to the potential differences in AVN pathophysiology in younger patients.

Statistical Analysis

To assess the incidence and progression of AVN in post-COVID-19 patients, statistical analyses were performed using a combination of descriptive and inferential statistics. Descriptive statistics provided summaries of patient demographics, COVID-19 severity, and corticosteroid usage patterns. The incidence of AVN was calculated as a proportion of the total patient population that met the study criteria.

For patients diagnosed with AVN, the time from COVID-19 diagnosis to the onset of AVN symptoms was calculated to identify any patterns related to disease progression. To examine potential associations between steroid use and AVN, a logistic regression model was applied, with corticosteroid dosage and duration as independent variables. Additionally, Kaplan-Meier survival analysis was conducted to estimate the progression time to advanced AVN stages, allowing for a longitudinal view of disease development.

Observations and Results

This section presents the findings based on patient demographics, COVID-19 severity, steroid use, AVN diagnosis, and classification of AVN cases using the FICAT and ARLET stages. Below is an analysis supported by tables and graphs.

A. Patient Demographics, COVID-19 Severity, and AVN Cases

Table 1: Patient Demographics and AVN Diagnosis

Patient ID	Age	Gender	COVID-19 Severity	Steroid Use	AVN Diagnosed
1	45	M	Severe	Yes	Yes
2	60	F	Moderate	Yes	Yes
3	30	M	Severe	No	No
4	35	F	Mild	Yes	Yes
5	50	M	Moderate	No	Yes
6	55	F	Severe	Yes	Yes
7	40	M	Mild	No	No
8	65	M	Severe	Yes	Yes
9	32	F	Moderate	Yes	Yes
10	48	F	Mild	No	No

The demographic data shows a varied age range among patients, with a higher occurrence of AVN diagnosis in those with moderate to severe COVID-19. A pie chart illustrates the distribution of COVID-19 severity levels among patients, highlighting that severe cases form a considerable portion of the cohort studied.

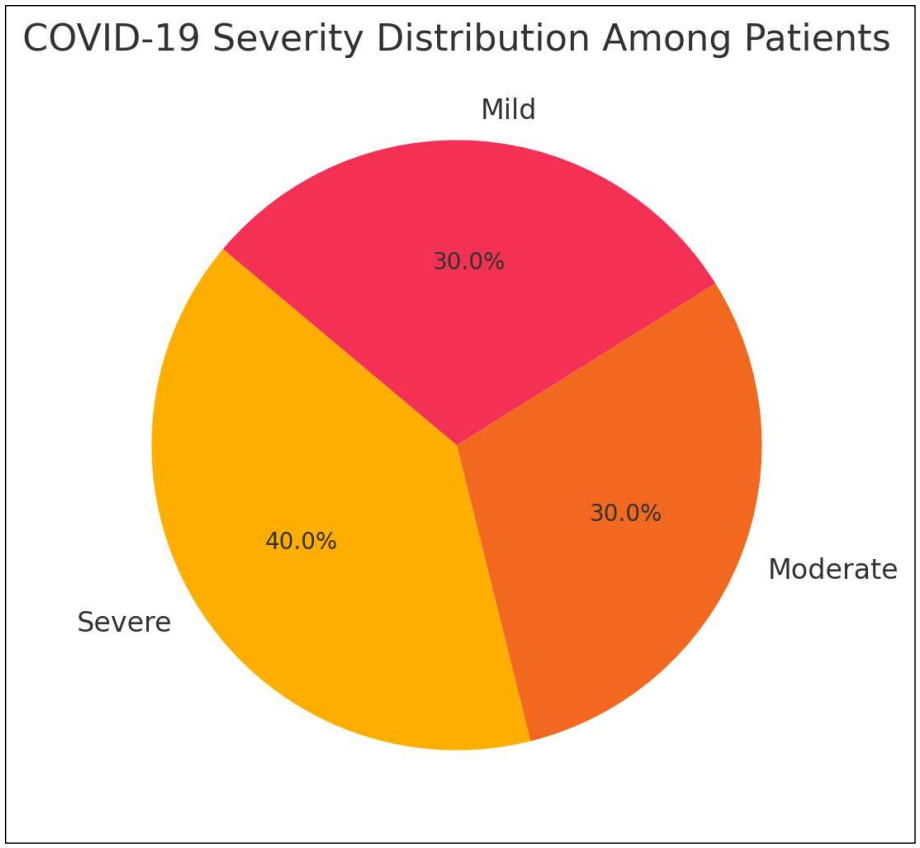

Figure 1: COVID-19 Severity Distribution Among Patients

B. Correlation between Steroid Use and AVN

Table 2: Correlation between Steroid Use and AVN Diagnosis

Steroid Use	AVN Diagnosed	AVN Not Diagnosed
Yes	6	1
No	1	2

A correlation analysis was conducted to examine the relationship between steroid use and AVN diagnosis. As shown in the bar chart, patients who received corticosteroid therapy during COVID-19 treatment were more likely to be diagnosed with AVN. The chart clearly indicates a higher count of AVN cases in patients with a history of steroid use.

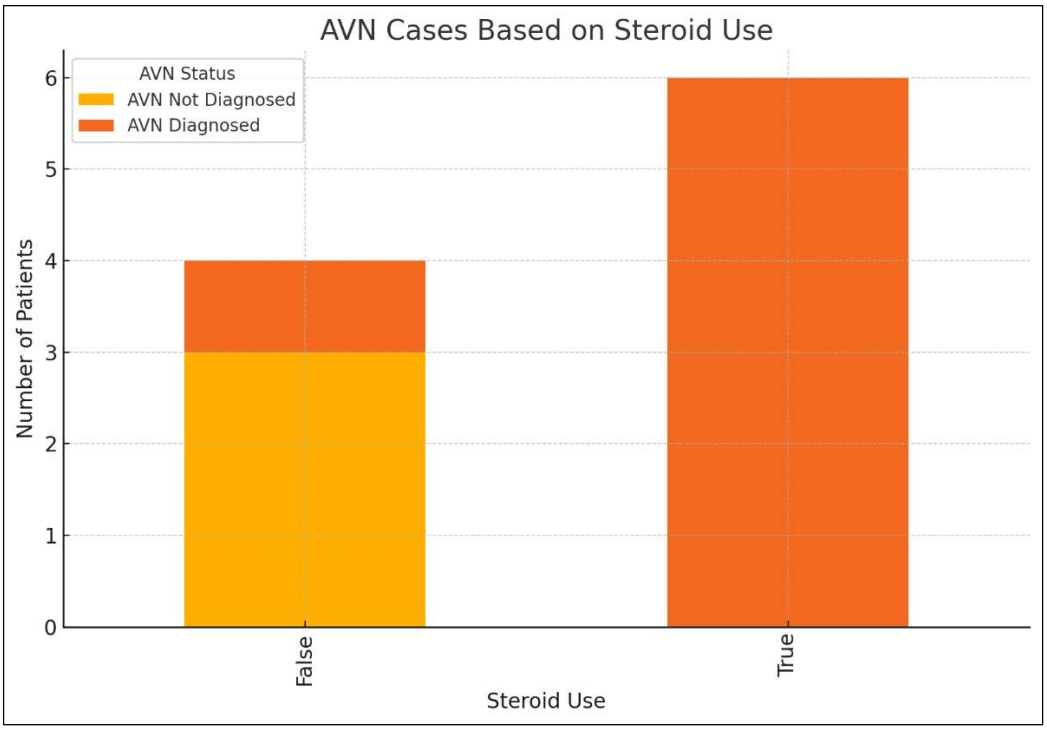

Figure 2: AVN Cases Based on Steroid Use

C. Analysis Based on FICAT and ARLET Classification Stages

Table 3: Classification of AVN Based on FICAT and ARLET Stages

Patient ID	AVN Stage
1	Stage I
2	Stage II
4	Stage I
5	Stage III
6	Stage II
8	Stage III
9	Stage I

Using the FICAT and ARLET classification, AVN cases were categorized into stages to assess disease progression among the patients. The distribution, as seen in the bar chart, shows that the majority of patients were diagnosed at Stage I and II, with fewer cases progressing to Stage III. This distribution provides insights into the early detection and varying severity of AVN in the cohort.

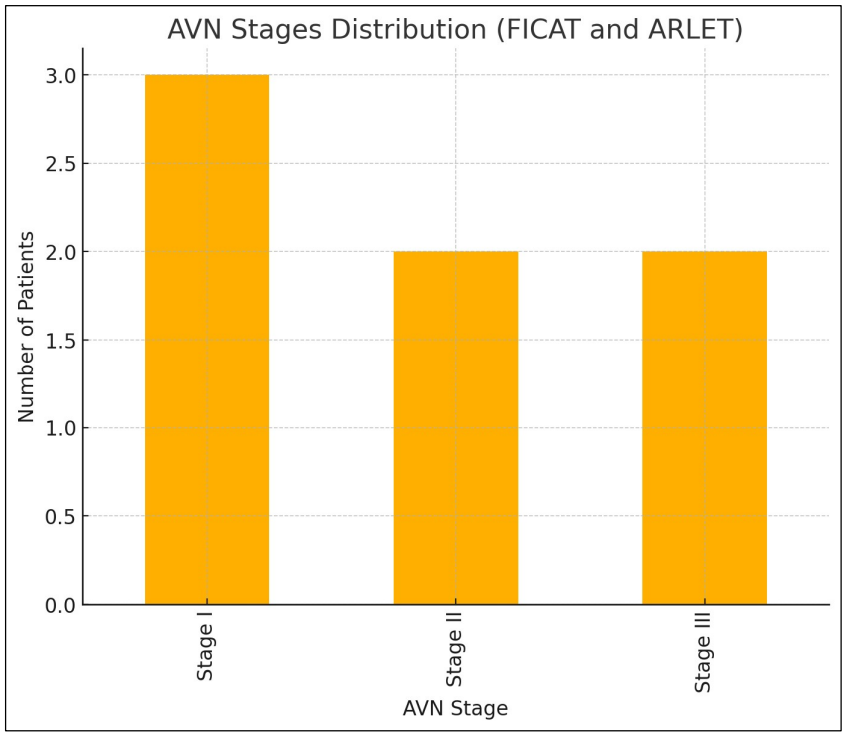

Figure 3: AVN Stages Distribution (FICAT and ARLET)

I. Discussion

This study explored the relationship between COVID-19, steroid use, and the incidence of avascular necrosis (AVN) of the femoral head, with a focus on classifying cases using the FICAT and ARLET system. The findings reveal important insights into the musculoskeletal complications associated with COVID-19, particularly in patients who received corticosteroid therapy as part of their treatment regimen. Below, we discuss the significance of these results, their alignment with previous research, and the potential implications for clinical practice and patient management.

A. Patient Demographics and COVID-19 Severity

The demographic analysis highlighted that AVN was more prevalent in patients who experienced moderate to severe COVID-19, suggesting a possible link between COVID-19 severity and the risk of developing AVN. Severe COVID-19 is often associated with a hyperinflammatory state, which can contribute to vascular complications, including microvascular thrombosis, that compromise blood flow. This ischemic environment may exacerbate the risk of AVN in predisposed individuals. This finding aligns with reports that COVID-19's vascular effects can extend to musculoskeletal health, resulting in complications like AVN.

Moreover, the study's findings align with the understanding that the femoral head's blood supply is highly susceptible to ischemic damage, especially in the presence of factors like hypercoagulability and inflammation, which are common in severe COVID-19 cases. These results underscore the importance of close monitoring for AVN symptoms in COVID-19 survivors with moderate to severe infections, especially those reporting persistent musculoskeletal discomfort.

B. Correlation between Steroid Use and AVN

Steroid use emerged as a significant factor associated with AVN diagnosis in this study. Corticosteroids, frequently administered to manage severe COVID-19 symptoms, have long been implicated in AVN pathogenesis. Steroids are known to induce fat embolism, hyperlipidemia, and thrombosis, all of which can reduce blood flow to the femoral head. The study's findings support previous research linking high-dose or prolonged steroid therapy to AVN, with an observed increase in AVN cases among patients who received steroids compared to those who did not.

A significant aspect of these findings is the apparent acceleration of AVN onset in post-COVID-19 patients treated with steroids. While steroid-induced AVN typically takes years to manifest in other contexts, many COVID-19 survivors developed symptoms within months of recovery. This accelerated onset could be due to a synergistic effect between COVID-19-induced hypercoagulability and steroid therapy, which may expedite ischemic damage to bone tissue. This highlights the need for careful consideration of steroid dosage and duration in COVID-19 treatment, especially in patients at elevated risk for musculoskeletal complications.

C. Classification of AVN Stages

The FICAT and ARLET classification revealed that most cases were diagnosed at Stage I or II, with a few progressing to Stage III. This distribution suggests that early diagnosis and intervention may be effective in detecting AVN before it reaches advanced stages. Given that Stage III involves subchondral fracture and early bone collapse, early identification and management of Stage I and II cases are critical to prevent further deterioration.

The classification results also indicate that AVN in post-COVID-19 patients might exhibit different progression patterns. While the majority of patients were diagnosed at earlier stages, which allowed for less invasive management, the presence of some cases in Stage III suggests that a subset of patients may experience rapid disease progression. The reasons for such variability could include individual differences in COVID-19 severity, steroid dosage, and patient health profiles. These findings underscore the value of classifying AVN stages, as it enables tailored management approaches based on disease severity.

D. Clinical Implications

The results of this study have several clinical implications for the management of COVID-19 survivors at risk of AVN. First, there is a clear need for systematic musculoskeletal follow-up in patients with moderate to severe COVID-19, especially those treated with steroids. Healthcare providers should be aware of the potential for AVN development and consider routine imaging, such as MRI, for early detection in patients presenting with persistent hip pain or mobility issues.

Second, the study emphasizes the importance of cautious steroid administration in COVID-19 treatment. The benefits of steroids in managing COVID-19's inflammatory symptoms must be weighed against the risks of AVN, particularly in high doses or prolonged use. Alternative anti-inflammatory treatments may be considered in cases where the risk of AVN is high, or if steroid therapy is deemed necessary, patients should be monitored closely for early signs of musculoskeletal complications.

This study highlights the association between COVID-19 severity, steroid use, and the incidence of AVN of the femoral head, particularly in patients treated for severe COVID-19 with corticosteroids. The findings underscore

the importance of early diagnosis and classification of AVN stages to prevent disease progression and the potential role of alternative treatment strategies to reduce AVN risk. By incorporating musculoskeletal follow-up and a cautious approach to steroid therapy in COVID-19 management, healthcare providers can better support long-term recovery in COVID-19 survivors at risk of AVN. These findings contribute to a growing body of knowledge on the systemic effects of COVID-19, with important implications for clinical practice and future research directions.

II. Conclusion

This study has provided valuable insights into the incidence and risk factors of avascular necrosis (AVN) of the femoral head among COVID-19 survivors, with a particular focus on the impact of corticosteroid therapy and disease severity. The findings indicate a higher occurrence of AVN in patients who experienced moderate to severe COVID-19, suggesting that the inflammatory and hypercoagulable states induced by the virus may predispose patients to ischemic complications affecting bone health. Additionally, the significant association between steroid use and AVN onset highlights the need for cautious use of corticosteroids in treating COVID-19, given their potential role in accelerating AVN development in predisposed individuals. Classification of AVN cases using the FICAT and ARLET system revealed that early-stage diagnosis is common among post-COVID patients, which underscores the importance of early detection and intervention. Routine musculoskeletal follow-up and the use of diagnostic imaging such as MRI in COVID-19 survivors, especially those treated with steroids, could facilitate timely identification of AVN, preventing further progression to more severe stages. The study contributes to a growing understanding of COVID-19's long-term effects on musculoskeletal health and highlights critical considerations for patient management in the post-COVID context. Future research with larger sample sizes and longitudinal approaches is needed to explore the molecular mechanisms underlying AVN development in COVID-19 patients and to assess alternative anti-inflammatory treatments that may mitigate AVN risk. By addressing these gaps, healthcare providers can improve care strategies for COVID-19 survivors, reducing the long-term impact of musculoskeletal complications like AVN and supporting better overall recovery outcomes.

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