Journal of Orthopaedic Surgery and Research

RESEARCH | Open Access

Relationship between anterior or posterior femoral head necrosis and collapse based on MRI-defined key necrotic layer sets

Yawei Dong[1,2†], Yan Yan[1,2†], Jun Zhou[1,2], Kaiqiang Tang[1,2], Xiaohan Wang[1,2], Rui Quan[1,2], Jiaming Lin[1,2], Yan Jia[1,2], Zelu Zheng[1,2], Baohong Mi[1,2*] and Weiheng Chen[1,2*]

Abstract

Background Current clinical studies on femoral head necrotic lesions primarily focus on the medial and lateral regions, while detailed MRI-based methods to evaluate the relationship between anterior or posterior necrosis and collapse remain lacking.

Objective By defining the anterior and posterior positions of the femoral head in MRI, a method was proposed for rapid clinical prognosis assessment of femoral head necrosis based on necrotic location.

Metohd A retrospective analysis was conducted on TSE sequence T1W1 coronal plane images from 200 cases of femoral head necrosis. The frequency of necrotic lesions appearing on each MRI layer was statistically analyzed to construct a high-frequency necrotic layer set. Among these cases, 100 hips were randomly selected, and the relationship between femoral head collapse at one-year follow-up and different high-frequency necrotic layer sets was analyzed to identify the key necrotic layer set. Based on this, the anterior and posterior regions of the femoral head were defined on MRI. The remaining 100 hips were used as a validation set to assess the impact of anterior or posterior necrosis of the femoral head, as defined by this method, on collapse.

Results In this study, a total of eight high-frequency necrotic lesion layer sets (S1-S8) were constructed based on MRI data. Among them, S3 (L1 + L2 + L0 + L3) showed the strongest correlation with femoral head collapse, with an AUC of 0.662. Therefore, S3 was defined as the anterior side of the femoral head. Analysis of the validation set revealed that, using this method, the probability of femoral head collapse was 11.4 times higher when necrotic lesions appeared on the anterior side compared to the absence of necrosis on the anterior side.

Conclusion In MRI, the anterior side of the femoral head corresponds to the S3 region, where necrosis increases the risk of collapse by 11.4 times.

†Yawei Dong, Yan Yan and Jun Zhou equally contributed to this work.

*Correspondence:
Baohong Mi
mibaohong12587@163.com
Weiheng Chen
drchenweiheng@bucm.edu.cn
Full list of author information is available at the end of the article

Keywords Osteonecrosis of femoral head, Locatipn of necrotic lesions, Magnetic resonance imaging, Prediction of collapse

Background

Osteonecrosis of femoral head(ONFH) poses a significant treatment challenge. Epidemiological studies show 8.12 million cases of non-traumatic femoral head necrosis, mostly in young individuals, with 10,000–20,000 new cases annually [1–3]. At present, there is no available treatment to reverse the disease once it has occurred [4–6], and it has been reported that more than 50% of patients ultimately undergo joint replacement [7]. During this process, femoral head collapse is a critical factor [8]. In current diagnostic and clinical evaluation criteria for ONFH [1, 7, 9–15], both the size and location of necrotic lesions are considered key factors influencing prognosis. Among these, lesion location has increasingly become a research focus in recent years. Studies have shown that different lesion locations significantly impact the success rate of hip-preserving treatments [16, 17]. However, there is currently no unified standard for determining lesion location.

Currently, studies on the correlation between ONFH lesions location and collapse [18] commonly use the JIC classification [12] and the China-Japan Friendship Hospital (CJFH) classification [13] to categorize necrotic foci by their medial and lateral positions within the femoral head. However, these classification methods are insufficient for accurately determining lesion location. For instance, studies report that 90% of patients are classified as type C under the JIC classification [19], while 83% fall under type L in the CJFH classification [20]. Such overrepresentation within a single category limits the ability to develop personalized diagnostic and treatment plans based on lesion location. In clinical practice, the anteroposterior position of the femoral head is of greater significance. While some studies use the terms “anterior” and “posterior” to describe lesion location [21], these terms lack clear definitions, and there are no ideal methods for accurately localizing necrotic lesions in the anteroposterior plane. Therefore, developing reliable methods to localize necrotic foci from an anterior-posterior perspective is urgently needed.

The team previously established a method for localizing the middle layer of the femoral head in MRI scans. This method identifies the most completely exposed layer of the femoral neck as the middle layer and assigns numbers to the anterior and posterior positions of the femoral head. Using this approach, the distribution of necrotic lesions across anterior and posterior positions in MRI was analyzed [22]. In this study, we applied the aforementioned middle-layer localization method to clearly define the “anterior” and “posterior” regions of the femoral head by examining the distribution of necrotic lesions. Furthermore, based on this MRI-defined localization method, we analyzed the clinical impact of anterior or posterior necrosis on femoral head collapse, providing a method for rapid prognosis assessment in clinical practice.

Methods

Ethics approval and consent to participate

This study was ethically approved by the Third Affiliated Hospital of Beijing University of Chinese Medicine (BZYSY-2021KYKTPJ-01).

Study design

As illustrated in Fig. 1, the study consisted of three parts. First, each MRI layer was assigned a number using the middle-layer positioning method, and the frequency of necrotic lesions was recorded for each layer. Based on this, sets of layers with varying frequencies of necrotic lesions were defined as high-frequency necrotic sets, resulting in eight such sets. Next, statistical analysis was conducted to identify the set most closely correlated with femoral head collapse. Each high-frequency necrotic set was analyzed for its relationship to collapse, and the sets with the strongest correlation were selected. Finally, these selected sets were used to define the accurate ranges of the “anterior” and “posterior” regions of the femoral head, providing a foundation for clinical collapse prediction based on necrotic locations.

Source of cases

The medical records of 140 patients diagnosed with ONFH (ARCO II-IIIa) who underwent hip preservation interventions at the Third Affiliated Hospital of Beijing University of Traditional Chinese Medicine between September 2019 and September 2023, with a follow-up period of over one year, were retrospectively analyzed. A total of 200 hips meeting the inclusion and exclusion criteria were included in the study (Fig. 2). All patients underwent MRI using a PHILIPS Achieva 1.5T superconducting magnetic resonance machine and X-rays captured with digital radiography (DR) equipment. The MRI T1W1 parameters were: TSE TR 500 ms, TE 20 ms, slice thickness 3.5 mm, slice gap 0.3 mm, and FOV 374. All imaging was performed with patients in the same standardized body position.

Inclusion criteria

(1) Over 18 years old, both men and women are eligible; (2) Meet the diagnostic criteria for ONFH, with ARCO

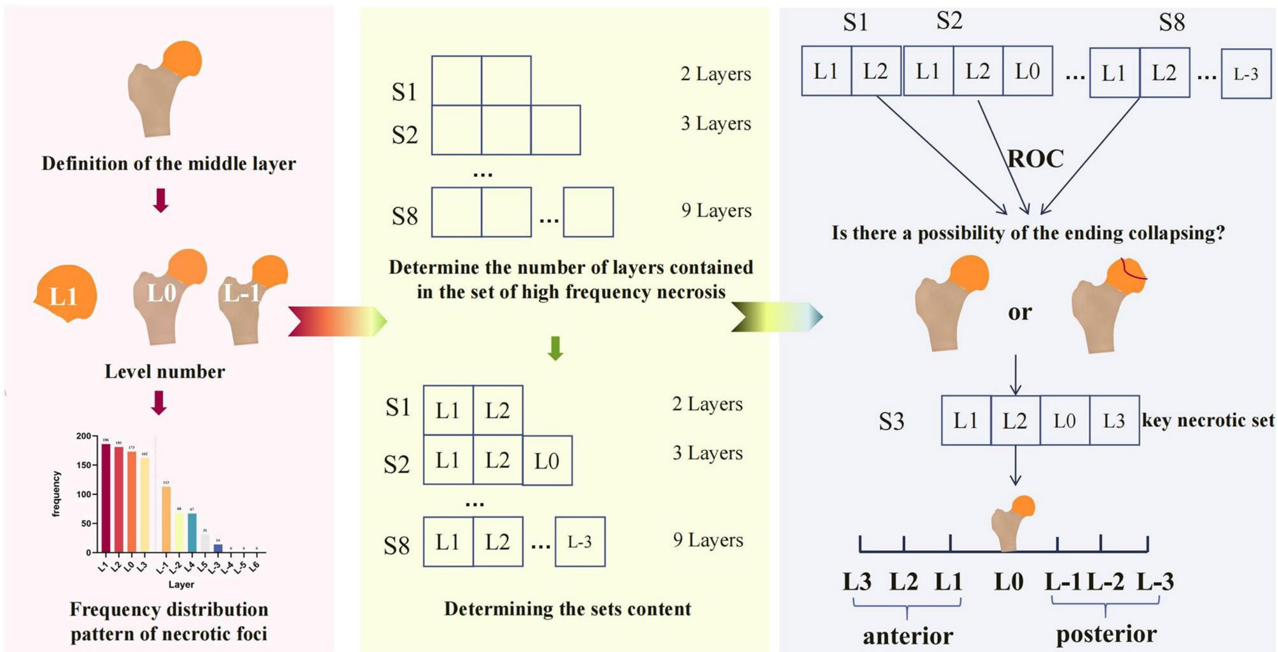

Fig. 1 Diagram of the research methodology model

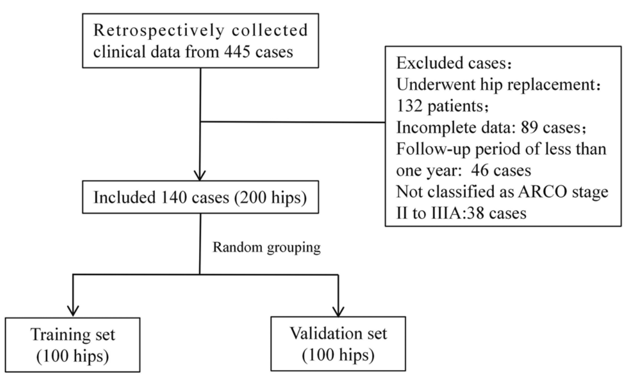

Fig. 2 Patient inclusion flowchart

stage II ~ IIIa; (3) Clear imaging data such as bilateral hip X-rays and MRI.

Exclusion criteria
(1) ARCO I or IV; (2) Patients who have undergone hip replacement; (3) Patients with unclear imaging data.

Method of grouping
In the study of critical necrosis layer set, 200 hip pretreatment were divided into a training group and a validation group, with a sample size of 200 and a seed count of 2023, resulting in 200 random numbers. The medical record data corresponding to the first 100 random numbers are positioned as training group, and the medical record data corresponding to the last 100 random numbers are defined as verification group.

Characteristics of necrotic lesion distribution
Middle-layer positioning method
The most intact layer of the femoral neck exposure was set to be the middle-layer, which was labeled as layer 0 (Layer0; L0). The layers in front layer 0 should be marked sequentially as 1, 2, 3, 4... (L1, L2, L3, L4...) and behind layer 0 marked sequentially as -1, -2, -3...(L-1, L-2, L-3...) (Fig. 3).

Distribution characteristics of lesions at the MRI layer
Two researchers independently identified the presence of necrotic lesions in each MRI layer of 200 hips. Necrotic lesions were marked as 1, and the absence of necrotic lesions was marked as 0. The frequency of necrosis at each layer was then calculated and compared.

Study on key necrotic layer sets
As shown in Fig. 4, since necrotic lesions appear across multiple layers in MRI, it is essential to construct necrotic layer sets that incorporate different numbers of MRI layers. To ensure greater accuracy in the study, the constructed necrotic layer sets must include the layers most likely to exhibit necrosis. Based on the frequency distribution of necrotic lesions, L1 and L2 were initially combined to form S1, which was analyzed in relation to whether femoral head collapse occurred one year later. Subsequently, L0 was added to S1 to form S2, and the same analysis was performed. Following this iterative process, the necrotic layer set was progressively expanded to include additional high-frequency necrotic layers, thereby constructing sets with varying numbers of

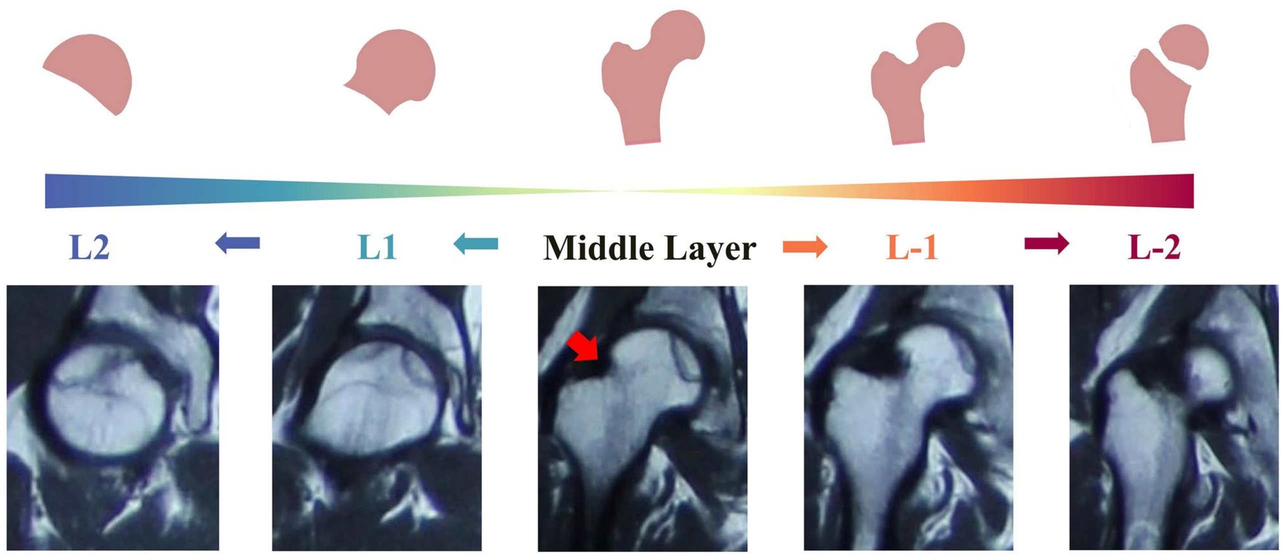

Fig. 3 Middle-layer positioning method

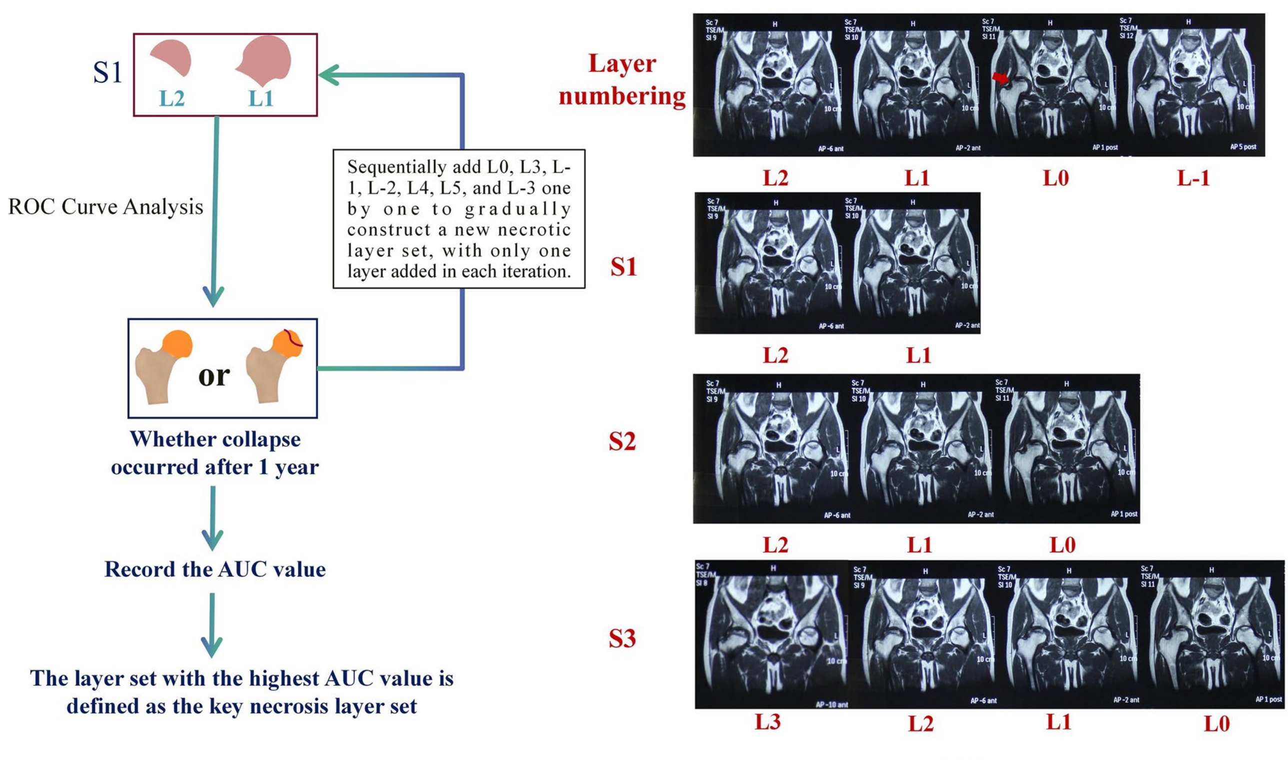

Fig. 4 Process of Constructing the Key necrosis layer set

layers (The right half of Fig. 4 demonstrates an example of constructing a high-frequency necrotic layer set). The AUC values for predicting collapse were recorded for each high-frequency necrotic layer set, and the set with the highest AUC value was defined as the critical necrotic layer set.

Definition of layer sets of high-frequency necrotic lesion

High-frequency necrotic layer sets are defined as groups of MRI layers with the highest frequencies of necrotic lesions, containing varying numbers of layers. Starting with two layers, the layers showing the highest frequency of lesions are identified based on their distribution patterns on MRI. This combination is designated as High-Frequency Necrosis Set 1 (S1). Following the same method, sets containing three or more layers are identified sequentially, forming High-Frequency Necrosis Set 2 (S2), High-Frequency Necrosis Set 3 (S3), High-Frequency Necrosis Set 4 (S4), and so on.

Key necrosis layer set definition and searching

The key necrosis layer set is the location most likely to cause collapse in different layer sets of high-frequency necrotic lesions. That is, all the layer sets of high-frequency necrotic lesions were sequentially analyzed by ROC curve with patient collapse outcome, and the sets with the greatest impact on the collapse was defined as the key necrosis layer set.

Initially, 100 hips in the training group were selected to evaluate the extent of collapse approximately one year after treatment based on the BUCMXE criteria. According to this standard, moderate to severe collapse was defined as femoral head collapse, which was assessed using the concentric circle method in X-rays. This method involves selecting the concentric circle that fits the remaining part of the femoral head most accurately, and measuring the distance between the maximum collapse point and the circle. Collapse was defined as ≥ 2 mm. After that, the collapse status of all high-frequency necrosis sets in the 100 hips was recorded separately by two researchers, and in case of disagreement, a third senior physician made the final judgment. Each high-frequency necrosis set and collapse outcome were analyzed by ROC in turn. The set with the largest area (AUC) under the curve was selected to the key necrosis layer set.

Definition and verification of the anterior and posterior of the femoral head

The layers containing the key necrosis layer set in front of the L0 were defined as the anterior side of the femoral head, while the layers symmetrical to the key necrosis layer set behind the L0 was defined as the posterior aspect of the femoral head. For instance, if the key necrosis layer set were L0, L1, and L2, the anterior side would be defined as L1 and L2, and the posterior side would be defined as L-1 and L-2. Statistical methods were used to investigate the likelihood of collapse in the presence of necrotic foci located anteriorly and posteriorly.

Verify the predictive performance of key necrosis layer set

The 100 hips in the validation group were used to verify the critical necrotic positions. First, the BUCMXE method was applied to assess whether collapse occurred approximately one year after treatment. Next, the necrosis status of all high-frequency necrotic sets was recorded. The location and outcome of each high-frequency necrotic set were analyzed using ROC curves, and the impact of different sets on collapse was compared with the training set. Additionally, based on the anterior-posterior classification of the femoral head, the likelihood of collapse associated with lesions in different anterior-posterior locations was validated within the validation group.

Statistical method

Statistical data shall be processed by SPSS 20.0 software package and R4.2.2. All metering data shall be mean ± standard deviation (± s), counting data shall be chi-square test, and metering data shall be Mann–Whitney t-test. ROC curves were used to study the influence of different high-frequency necrosis layer sets on the collapse outcome.

Results

Overall data situation

A total of 140 patients, meeting the inclusion and exclusion criteria, were selected from 445 cases, comprising 200 hips in total. The average follow-up period was 24.34 ± 7.14 months and the average age was 50.45 ± 12.95. Classified by gender, male 141 hips, female 59 hips. According to the unilateral or bilateral, 64 hips were developed unilaterally and 136 hips were developed bilaterally. Classified by cause, traumatic 5 hips, alcoholic 87 hips, hormone 62 hips, and idiopathic 46 hips.

Inter-group consistency comparison

We compared the consistency of defining the median layer between the two researchers by analyzing the number of layers with necrotic lesions appearing anterior to the defined median layer. The results demonstrated an inter-group ICC value of 0.965 ($P < 0.001$). Among the discrepancies between the two researchers, 2 hips showed a difference of 2 layers in median layer localization, and 7 hips showed a difference of 1 layer. Overall, this method exhibited good inter-group consistency in MRI layer numbering.

Characteristics of MRI layer distribution of necrotic lesions

Figure 5 indicates that among the 12 layers of MRI that can expose femoral head completely, there are 9 layers (L-3 ~ L5) of which the necrosis frequencies of L1, L2, L0 and L3 layers are 186 (93.0%), 181 (90.5%), 173 (86.5%) and 162 (81.0%), which are much higher than those of other layers. Among them, L1, L2, L0 layers are the most obvious.

Frequency distribution of high-frequency necrosis layer sets

According to the distribution pattern of focal layers, necrosis focus appeared in 9 layers of L-3 ~ L5, including 8 different high-frequency necrosis layer sets: S1, L1 + L2; S2, L1 + L2 + L0; S3, L1 + L2 + L0 + L3;

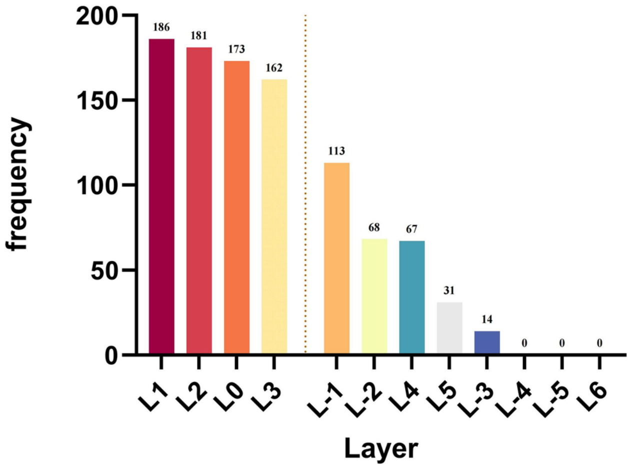

Fig. 5 Patterns of lesion distribution

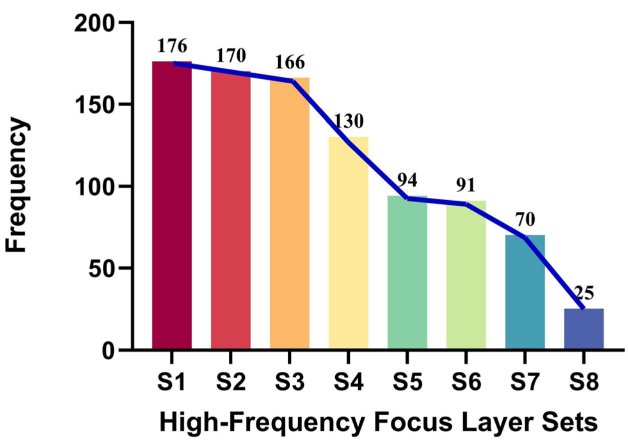

Fig. 6 Patterns of high-frequency focus layer sets distribution

S4, L1 + L2 + L0 + L3+(L-1); S5, L1 + L2 + L0 + L3+(L-1)+(L-2); S6, L1 + L2 + L0 + L3+(L-1)+(L-2) + L4; S7, L1 + L2 + L0 + L3+(L-1)+(L-2) + L4 + L5; S8, L1 + L2 + L0 + L3+(L-1)+(L-2) + L4 + L5+(L-3). From S1 to S8, the frequency of necrosis was 176 (88.0%), 170 (85.0%), 166 (83.0%), 130 (65.0%), 94 (47.0%), 91 (45.5%), 70 (35.0%) and 25 (12.5%) respectively (Fig. 6).

Influence of high-frequency necrosis layer sets of training group on collapse outcome

The femoral head collapse was recorded using the X-ray concentric circle method, and the results showed that the Kappa value between the two researchers was 0.90 ($P < 0.001$). Figure 7 indicates that the predictive performance of S1-S8 in the training group exhibited a low-to-high and then high-to-low pattern of accuracy: S1, L1 + L2, AUC 0.621; S2, L1 + L2 + L0, AUC 0.621; S3, L1 + L2 + L0 + L3, AUC 0.662; S4, L1 + L2 + L0 + L3+(L-1), AUC 0.574; S5, L1 + L2 + L0 + L3+(L-1)+(L-2), AUC 0.537; S6, L1 + L2 + L0 + L3+(L-1)+(L-2) + L4, AUC 0.537; S7, L1 + L2 + L0 + L3+(L-1)+(L-2) + L4 + L5, AUC 0.513; S8, L1 + L2 + L0 + L3+(L-1)+(L-2) + L4+(L-3), AUC 0.485, with the highest point appearing at layer set 3 (S3, L1 + L2 + L0 + L3, AUC 0.662). The highest point occurred at S3, which had a sensitivity of 0.908 and a specificity of 0.417 for predicting collapse (S3,L1 + L2 + L0 + L3, AUC 0.662) (Table 1).

Results of anterior-posterior femoral head position to predict collapse

Based on the above results, the key necrosis layer set of the femoral head were L0, L1, L2, and L3, then the anterior side of the femoral head was defined as L1, L2, and L3, and the posterior side of the femoral head was defined as L-1, L-2, and L-3 using the L0 as the boundary. Statistical analysis showed that the probability of femoral head collapse in the presence of necrotic foci on the anterior side was 11.4 times higher than the probability of collapse in the absence of necrotic foci on the anterior side ($P < 0.05$); the probability of femoral head collapse in the presence of necrotic foci on the posterior side was 3.2 times higher than the probability of collapse in the absence of necrotic foci on the posterior side ($P < 0.05$) (Table 2).

Influence of high-frequency necrosis layer sets of verification group on collapse outcome

Figure 8 indicates that the predictive performance of S1-S8 in the verification group exhibited a low-to-high and then high-to-low pattern of accuracy: S1, L1 + L2, AUC 0.591;S2, L1 + L2 + L0, AUC 0.637; S3, L1 + L2 + L0 + L3, AUC 0.706; S4, L1 + L2 + L0 + L3+(L-1), AUC 0.645; S5, L1 + L2 + L0 + L3+(L-1)+(L-2), AUC 0.616;S6, L1 + L2 + L0 + L3+(L-1)+(L-2) + L4, AUC 0.594; S7, L1 + L2 + L0 + L3+(L-1)+(L-2) + L4 + L5, AUC 0.617; S8, L1 + L2 + L0 + L3+(L-1)+(L-2) + L4 + L5+(L-3), AUC 0.551, with the highest point appearing at layer set 3 (S3, L1 + L2 + L0 + L3, AUC 0.706). Which is consistent with the training group results, and its sensitivity for predicting collapse is 0.866 and specificity is 0.545 (Table 3).

By validation set risk analysis, the results showed that the probability of anterior femoral head with necrotic foci ultimately collapsing the femoral head was 16.6 times higher than that of anterior without necrotic foci (95% CI 1.9-144.4); the probability of posterior femoral head with necrotic foci ultimately collapsing the femoral head was 2.0 times higher than that of posterior without necrotic foci (95% CI 0.9–4.9); and the probability of femoral head collapsing ultimately in femoral head with purely anterolateral necrosis was 1.2 times higher (95% CI 0.5–3.1) than with both anterior and posterior necrotic foci (Table 4).

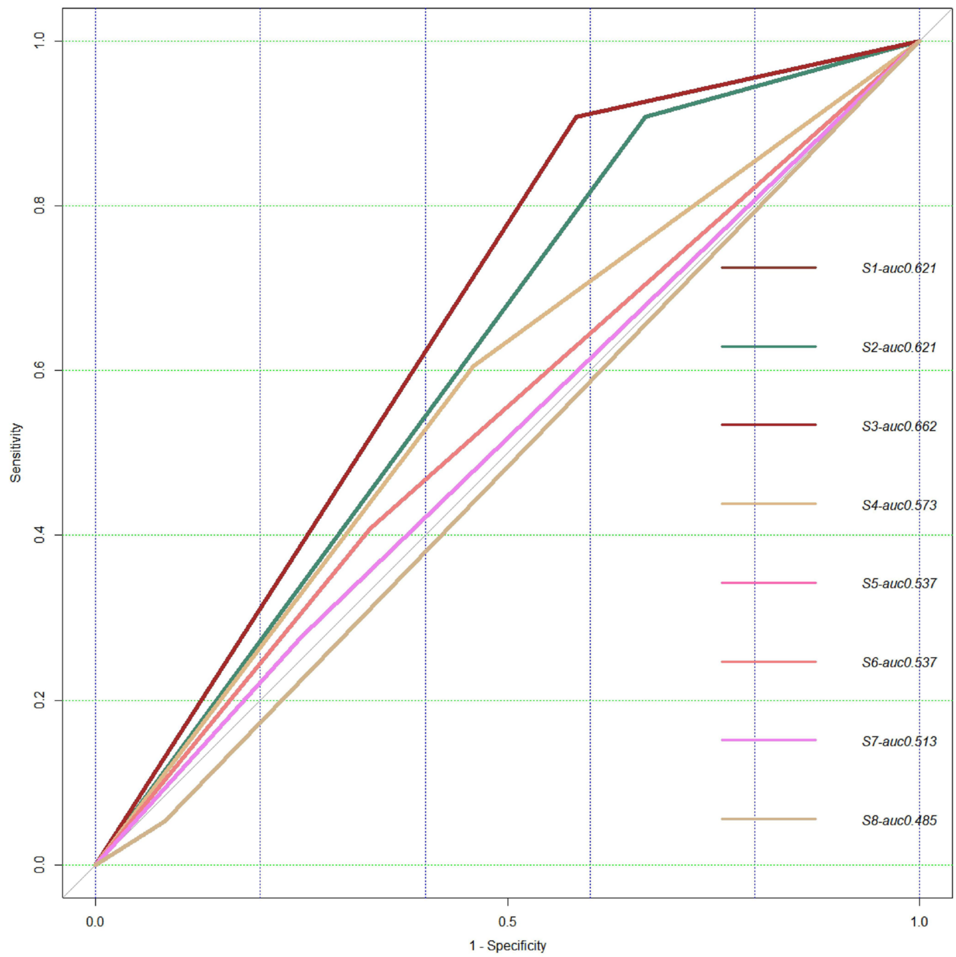

Fig. 7 Effect of high-frequency necrosis layer sets on collapse outcome in the training set

Table 1 Sensitivity, specificity of training set high-frequency necrosis layer sets for predicting collapse

Set	Sensitivity	Specificity
S1	0.908	0.333
S2	0.908	0.333
S3	0.908	0.417
S4	0.605	0.542
S5	0.408	0.667
S6	0.408	0.667
S7	0.276	0.750
S8	/	/

Table 2 Effect of necrosis on collapse at different locations in the training set

	OR score	95%CI
Anterolateral necrosis/anterior side without necrosis	11.4	1.1-115.6
Posterior lateral necrosis/no posterior lateral necrosis	3.2	1.2–8.9
Anterolateral necrosis only/anteroposterior necrosis	2.1	0.8–5.7

Discussion

This study, building upon the MRI-based median layer positioning method developed in our previous research, constructed eight high-frequency necrotic layer sets based on the distribution patterns of femoral head necrotic lesions. Through an analysis of the relationship between these layer sets and prognosis, the key necrotic layer sets located in the anterior or posterior regions of the femoral head were identified. Based on the study of these key necrotic layer sets, we further defined the anterior and posterior regions of the femoral head on MRI and, for the first time, demonstrated that the probability of collapse in cases with anterior necrosis is more than ten times higher than in cases without anterior necrosis.To date, no study has explicitly defined the anterior and posterior regions of the femoral head from an MRI perspective. Previous research analyzing risk factors for femoral head collapse, such as those in the JIC classification, reported that the probability of collapse in type C2 femoral heads without necrosis is 32.3% compared to those with necrosis [23]. However, such studies did not

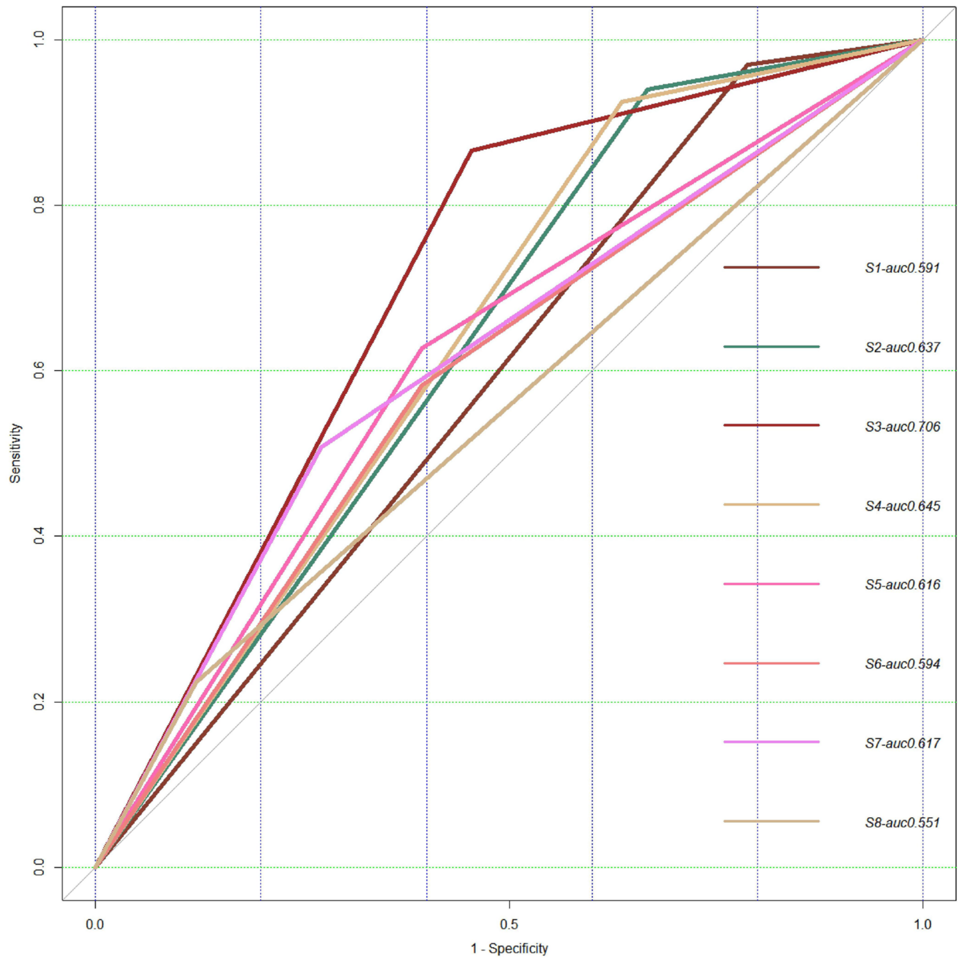

Fig. 8 Effect of high-frequency necrosis layer sets on collapse outcome in the verification set

Table 3 Sensitivity, specificity of verification set high-frequency necrosis layer sets for predicting collapse

Set	Sensitivity	Specificity
S1	0.970	0.212
S2	0.940	0.333
S3	0.866	0.545
S4	0.925	0.364
S5	0.627	0.606
S6	0.582	0.606
S7	0.507	0.727
S8	0.224	0.879

Table 4 Effect of necrosis on collapse at different locations in the verification set

	OR score	95%CI
Anterolateral necrosis/anterior side without necrosis	16.6	1.9-144.4
Posterior lateral necrosis/no posterior lateral necrosis	2.0	0.9–4.9
Anterolateral necrosis only/anteroposterior necrosis	1.2	0.5–3.1

consider the positional distribution of lesions in the anterior or posterior regions of the femoral head. This study addresses this gap by providing insights into the impact of lesion location on collapse risk.

Characteristics of MRI layer distribution of necrotic lesions

Based on the middle-layer positioning method, this paper studied the distribution of necrosis lesions in the femoral head at the MRI layers and the key necrosis layer set from the front and back of the femoral head. Firstly, the distribution of lesions in the anterior and posterior femoral head was studied. The results showed that necrosis lesions occurred in 9 of the 12 study layers that were able to fully expose the femoral head. The frequency of necrosis at L5 ~ L-3 level was 15.50%, 33.50%, 81.00%, 90.50%, 93.00%, 86.50%, 56.50%, 34.00%, 7.00% respectively. The frequency of necrosis was L1, L2, L0, L3, L-1, L-2, L4, L5 and L-3 in sequence from high to low. The frequency of necrosis in L1, L2, L0 and L3 layer was obviously larger than that in other layers. L1 was the layer with the highest frequency. From L1 to L4, the frequency of necrosis decreased from 81.00% to 33.50%, and from L1 layer to L-1 layer, the frequency of necrosis decreased from 86.50% to 56.50%. Among the 9 study layers that included necrosis focus, we further divided it into front, middle and posterior divisions according to its anatomical location, and typed it according to the actual distribution of the focus, which was divided into 12 anterior hips (6.0%), 13 medial hips (13.0%), 0 posterior hips (0.0%), 94 anterior and medial hips (47.0%), 0 medial and posterior hips (0.0%), and 68 total hips (34.0%) (Fig.A.1), which corresponded anatomically to the load-bearing region and was also consistent with the results of HuLB [17] et al. Correlation factor analysis shows that although the frequency of necrosis in each layer of femoral head may vary according to age, sex, side of pathogenesis, and pathogenesis, there may be statistical differences in the frequency distribution between different groups at certain layers, but this does not change the distribution of layered lesions that easily occur, and the layered lesions that easily occur under each factor are still concentrated in the middle layer and 2 to 3 layers before it (Fig.B.1). Only under the age factor, the frequency of necrosis lesions at the L-1 level in the young group was the same as that at the L3 level, reaching 88.9%, which was significantly different from that in the middle-aged group and the middle-aged and elderly group. On one hand, it may be because the young group tends to be more active than the middle-aged group. Studies have shown that higher levels of physical activity can lead to more concentrated stress areas on the femoral head [24], which may cause necrotic lesions to appear over a broader range around the middle layer, resulting in a higher frequency at the L-1 level compared to other groups. On the other hand, this may be because adolescent bones are still developing, and the femoral anteversion angle is relatively larger compared to adults, resulting in the lesions occurring in a more posterior location. This is consistent with previous findings, which suggest that necrotic lesions in adolescents tend to occur in more posterior locations compared to adults [22]. The frequency of L-2 and L-3 lesions in this group was much higher than that in the other two groups, suggesting that the incidence of necrosis in the young group was higher than that in the middle-aged group and the middle-aged and elderly groups, although the frequency of L-1-oriented posterior necrosis began to decrease significantly, from 88.90 to 61.10% of L-2. Through this part of the study, it is found that the distribution of necrosis focus of femoral head is concentrated at L0, L1, L2, L3 level under the influence of age, gender, incidence side and pathogenesis, which also suggests that we should pay more attention to these levels when estimating the area of necrosis focus using MRI.

Key necrosis layer set

Based on the regularity of the focus, we studied the key necrosis layer set of femoral head necrosis in the anterior and posterior position. Firstly, the location of necrosis was defined according to the distribution law of the lesions and the results showed that there were 8 sets of femoral head necrosis lesions with different layers and high frequencies in the anterior and posterior positions. Frequency of lesions in different layers of high frequency necrosis sites indicates that more than 50% of patients have necrosis in the five layers of MRI, most of which are concentrated in the weight-bearing area, consistent with the results of modern studies, that is, femoral head necrosis is mostly concentrated in the load-bearing region [25]. After statistical analysis with the collapse outcome, it is found that S3 has the highest efficiency in predicting the collapse, with the area under the curve reaching 0.662, and the efficiency of the inclusion layers lower than or higher than S3 has decreased. This suggests that S3 may be a key necrosis layer set for necrosis of the femoral head. At the same time, it can be found that although S4 ~ S8 contain S3, the prediction efficiency of S4 ~ S8 is still gradually decreasing, indicating that the collapse outcome of femoral head can not be obviously affected at layers other than L1, L2, L0 and L3, which may also be related to the position of S3 at the load-bearing region of femoral head [18, 26–27]. In the validation group, we further studied the prediction performance of S3 on the collapse outcome. The results were consistent with the training group. The effect of S3 on the collapse was higher than that of other high-frequency necrosis sets (AUC 0.706), which further suggested that we should pay attention to the occurrence of lesions in S3 before and after the clinic. Although the overall AUC value is not high, this is because this study only conducted qualitative studies on the presence or absence of necrosis focus, and did not consider the interference of necrosis area, pathogenesis, bone marrow edema and other factors [28–30], which can further explain that although the location of necrosis can affect the outcome of the collapse, it is not the only determinant of the outcome of the collapse.

Effect of anterior and posterior femoral head necrosis on collapse

Based on these findings, we have defined the specific meanings of the anterior and posterior femoral head. In combination with key necrosis layer set, we have identified L1, L2, and L3 as the anterior femoral head and L-1, L-2, and L-3 as the posterior femoral head. Our study has shown that the anterior femoral head, as well as necrosis that includes the anterior head, is the primary location for femoral head collapse. Necrosis of the anterior head alone has a 16.6-fold higher probability of eventual collapse compared to anterior necrosis without collapse.

This also explains why current studies suggest that redirecting the necrotic lesion away from the weight-bearing area through osteotomy can delay collapse [31]. At the same time, this suggests that clinical attention should be focused on the middle layer of the femoral head coronal MRI and the three layers in front of it. We have also found no significant difference in the probability of femoral head collapse between purely anterior necrosis and both anterior and posterior necrosis. This indicates that necrosis after the median layer does not have a significant effect on collapse.

Limitations

In this study, we found that L1, L2, L0, L3 are the most prone to lesions in the femoral head through the study of the distribution of lesions in the anterior and posterior positions of the femoral head. At the same time, these four layers are more likely to collapse when lesions appear at the same time, which is the key necrosis layer set. However, there are still some limitions in this study. First, this study primarily focused on the presence or absence of necrotic lesions in the femoral head and did not account for other factors that could influence collapse [32], such as lesion size, disease progression, and patient compliance. We calculated the proportion of lesion volume in the included patients and found that the average lesion volume was 0.24 ± 0.16, with the maximum necrotic area reaching 88% and the minimum necrotic area being less than 10%. These variations likely impact the extent to which anterior and posterior positions influence collapse, resulting in an AUC value of only 0.706 for predicting collapse, even with the critical necrotic layer set. Secondly, as this study is retrospective, it can only ensure that all patients received hip-preserving treatment; however, the specific treatment regimens and their frequencies could not be standardized. With the progression of research, hip-preserving treatment methods have become increasingly diverse. Studies have shown that core decompression combined with various therapies can effectively delay the need for joint replacement [33–34]. Even for adolescents [35], core decompression is considered a favorable hip-preserving treatment option. Different hip-preserving treatments may lead to different prognoses, and this study did not perform subgroup analyses based on the types of hip-preserving treatments. This represents an area for optimization in the next phase of our research. Finally, this study defines the layer sets of high-frequency necrotic lesions in the anterior and posterior positions according to the distribution law of necrosis focus, and this definition method still needs to be further verified by clinical studies.

Conclusion

The frequencies of necrotic lesions in L1, L2, L0, and L3 are the highest in MRI. When necrotic lesions are present in the anterior aspect of the femoral head (L1,L2,L3), patients are 16.6 times more likely to have femoral head collapses than those without anterior collapses, and this is the location that should be emphasized in the clinic.

Abbreviations

ARCO	Association Research Circulation Osseous
AUC	Area Under the Curve
BUCMXE	Beijing University of Chinese Medicine X-ray Evaluation Method
CJFH	China-Japan Friendship Hospital
JIC	Japanese Investigation Committee
MRI	Magnetic Resonance Imaging
ONFH	Osteonecrosis of the Femoral Head
ROC	Receiver Operating Characteristic

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-025-05633-2 .

Supplementary Material 1: Appendix A. Distribution of lesions of femoral head necrosis in anterior and posterior positions. Appendix B. Distribution patterns of lesions in different populations.

Acknowledgements

Not applicable.

Author contributions

Yawei Dong, Yan Yan, and Jun Zhou were mainly responsible for the statistical analysis of this study, Kaiqiang Tang, Rui Quan, Jiaming Lin, Yan Jia, Zelu Zheng and Xiaohan Wang were responsible for the data processing, and Baohong Mi and WeiHeng Chen were responsible for the design of the study.

Funding

This work was supported by the Key Projects of the National Natural Science. Foundation of China (82030122), the Beijing University of Chinese Medicine Graduate Student Independent Projects (90011461220455).

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study was ethically approved by the Third Affiliated Hospital of Beijing University of Chinese Medicine (BZYSY-2021KYKTPJ-01).

Consent for publication

Not applicable in this section.

Competing interests

The authors declare no competing interests.

Author details

[1]The Third Affiliated Hospital of Beijing University of Chinese Medicine, NO.51, Xiaoguan Street, Chaoyang District, Beijing, China
[2]Engineering Research Center of Chinese Orthopaedics and Sports Rehabilitation Artificial Intelligent, Ministry of Education, Beijing, China

Received: 19 November 2024 / Accepted: 20 February 2025
Published online: 07 March 2025

References

1. Zhao DW, Hu YC, Li ZR. Chinese guidelines for clinical diagnosis and treatment of osteonecrosis of the femoral head in adults(2020). Chin J Orthop. 2020;20(40):p1365–1376.
2. Vardhan H, Tripathy SK, Sen RK, Aggarwal S, Goyal T. Epidemiological profile of femoral head osteonecrosis in the North Indian population. Indian J Orthop. 2018;52(2):140–6.
3. Steinberg ME, Steinberg DR. Osteonecrosis: historical perspective. In: Koo KH, Mont M, Jones L, editors. Osteonecrosis. Berlin, Heidelberg: Springer; 2014. https://doi.org/10.1007/978-3-642-35767-1_1.
4. Jordan E, Varady NH, Hosseinzadeh S, Smith S, Chen A, Mont M, et al. Femoral head osteonecrosis: computed tomography not needed to identify collapse when using the association research circulation osseous staging system. Arthroplast Today. 2023;24:101244. Published 2023 Oct 14.
5. Mont MA, Salem HS, Piuzzi NS, Goodman SB, Jones LC. Nontraumatic osteonecrosis of the femoral head: where do we stand today?? A 5-Year update. J Bone Joint Surg Am. 2020;102(12):1084–99.
6. Mont MA, Cherian JJ, Sierra RJ, Jones LC, Lieberman JR. Nontraumatic osteonecrosis of the femoral head: where do we stand today?? A Ten-Year update. J Bone Joint Surg Am. 2015;97(19):1604–27.
7. Yoon BH, Mont MA, Koo KH, Chen CH, Cheng EY, Cui Q, et al. The 2019 revised version of association research circulation osseous staging system of osteonecrosis of the femoral head. J Arthroplasty. 2020;35(4):933–40.
8. Chen WH. Misunderstandings and countermeasures in diagnosis and treatment of femoral head necrosis. J Traditional Chin Orthop Traumatol. 2013;25(03):p3–5.
9. JWM G, ARCO Committee on Terminology and Staging. Report on the committee meeting at Santiago de Compostella. ARCO Newsl. 1993;5(5):79–82.
10. Jawad MU, Haleem AA, Scully SP. In brief: Ficat classification: avascular necrosis of the femoral head. Clin Orthop Relat Res. 2012;470(9):2636–9.
11. Steinberg ME, Hayken GD, Steinberg DR. A quantitative system for staging avascular necrosis. J Bone Joint Surg Br. 1995;77(1):34–41.
12. Sugano N, Atsumi T, Ohzono K, Kubo T, Hotokebuchi T, Takaoka K. The 2001 revised criteria for diagnosis, classification, and staging of idiopathic osteonecrosis of the femoral head. J Orthop Sci. 2002;7(5):601–5.
13. Li ZR. The classification of osteonecrosis of the femoral head based on the three pillars structure: China-Japan friendship Hospital(CJFH)classification. ChinJ Orthop. 2012;32(6):p515–520.
14. Huang Z, Li T, Lin N, Cui Q, Chen W. Evaluation of radiographic outcomes after core decompression for osteonecrosis of the femoral head: the Beijing university of Chinese medicine X-ray evaluation method. J Bone Joint Surg Am. 2022;104(Suppl 2):25–32.
15. WH Chen. Criteria for evaluating the therapeutic effect of traditional Chinese medicine on femoral head Necrosis(2019 editional). J Trad Chin Orthop Trauma. 2019;31(06):p3–6.
16. Utsunomiya T, Motomura G, Yamaguchi R, Hamai S, Sato T, Kawahara S et al. Effects of the location of both anterior and lateral boundaries of the necrotic lesion on collapse progression in osteonecrosis of the femoral head. J Orthop Sci, 2023.
17. Hu LB, Huang ZG, Wei HY, Wang W, Ren A, Xu YY. Osteonecrosis of the femoral head: using CT, MRI and gross specimen to characterize the location, shape and size of the lesion. Br J Radiol. 2015;88(1046):20140508.
18. Asada R, Abe H, Hamada H, Fujimoto Y, Choe H, Takahashi D, et al. Femoral head collapse rate among Japanese patients with pre-collapse osteonecrosis of the femoral head. J Int Med Res. 2021;49(6):3000605211023336.
19. Kuroda Y, Tanaka T, Miyagawa T, Kawai T, Goto K, Tanaka S, et al. Classification of osteonecrosis of the femoral head: who should have surgery? Bone Joint Res. 2019;8(10):451–8.
20. LH Liu. Analysis of the factors affecting the efficacy of hip preservation operation for femoral head necrosis based on the classification of China-Japan friendship hospital. Chin J Orthop, 2021(05): p271–279.
21. Z Liu. Guidance and prospect of collapse prediction method combined with staging for treatment of femoral head necrosis. Chin J Tissue Eng Res. 2021;25(06):P929–934.
22. Lu C. Study on the distribution of necrosis lesions of femoral head. Orthop J China. 2014;22(05):p396–400.
23. Yang TJ, Sun SY, Zhang L, Zhang XP, He HJ. A delphi-based model for prognosis of femoral head collapse in osteonecrosis: a multi-factorial approach. J Orthop Surg Res. 2024;19(1):762. Published 2024 Nov 16.
24. Lu C. A Biomechanical study on osteonecrosis of femoral head medicated by Jianpihuogu Decoction with dynamic simulation based on 3D finite element Analys[D]. China Academy of Chinese Medical Sciences; 2014.
25. Lin T, Zhang W, He X, He M, Li Z, He W, et al. Lateral classification system predicts the collapse of JIC type C1 nontraumatic osteonecrosis of the femoral head: a retrospective study. BMC Musculoskelet Disord. 2023;24(1):757.
26. Li TX, Huang ZQ, Li Y, Xue ZP, Sun JG, Gao HH, et al. Prediction of collapse using Patient-Specific finite element analysis of osteonecrosis of the femoral head. Orthop Surg. 2019;11(5):794–800.
27. Li TX. Biomechanical mechanism and risk factors of collapse of nontraumatic femoral head necrosis treated by Jianpi Huogu recipe, 2019, China Academy of Chinese Medical Sciences.
28. Wei C, Yang M, Chu K, Huo J, Chen X, Liu B, et al. The indications for core decompression surgery in patients with ARCO stage I-II osteonecrosis of the femoral head: a new, comprehensive prediction system. BMC Musculoskelet Disord. 2023;24(1):242.
29. Iwasa M, Ando W, Uemura K, Hamada H, Takao M, Sugano N. Is there an association between femoral head collapse and acetabular coverage in patients with osteonecrosis?? Clin Orthop Relat Res. 2023;481(1):51–9.
30. Su J, Zhang Y, Cao B, Li X. Analysis of factors influencing postoperative femoral head collapse in patients with Ficat I, II, and III stages of aseptic necrosis of the femoral head. J Am Acad Orthop Surg. 2022;30(24):1184–90.
31. Quaranta M, Miranda L, Oliva F, Aletto C, Maffulli N. Osteotomies for avascular necrosis of the femoral head. Br Med Bull. 2021;137(1):98–111.
32. Migliorini F, Maffulli N, Baroncini A, Eschweiler J, Tingart M, Betsch M. Prognostic factors in the management of osteonecrosis of the femoral head: A systematic review. Surgeon. 2023;21(2):85–98.
33. Sadile F, Bernasconi A, Russo S, Maffulli N. Core decompression versus other joint preserving treatments for osteonecrosis of the femoral head: a meta-analysis. Br Med Bull. 2016;118(1):33–49.
34. Migliorini F, Maffulli N, Eschweiler J, Tingart M, Baroncini A. Core decompression isolated or combined with bone marrow-derived cell therapies for femoral head osteonecrosis. Expert Opin Biol Ther. 2021;21(3):423–30.
35. Migliorini F, La Padula G, Oliva F, Torsiello E, Hildebrand F, Maffulli N. Operative management of avascular necrosis of the femoral head in skeletally immature patients: A systematic review. Life (Basel). 2022;12(2):179.

Publisher's note