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Factors influencing the survival status of the hip joint in post-collapse femoral head necrosis

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Abstract

Background Despite hip function typically deteriorating in the post-collapse stage of osteonecrosis of the femoral head (ONFH), some patients can still demonstrate long-term favorable hip function, a state termed "survival with collapse". This study aims to identify the characteristics of patients suitable for "survival with collapse" in cases of ONFH.

Methods This cross-sectional study included 65 patients (87 hips) diagnosed with post-collapse ONFH for ≥ 3 years (average 9.1 years, range 3–23 years). Hip function was assessed using the Harris Hip Score (HHS). Demographic, clinical, and radiographic data were compared between the favorable group (HHS > 80) and the poor group (HHS ≤ 80). Independent protective factors for hip function were identified by multivariate analysis and receiver operating characteristic (ROC) curve analysis was further applied to evaluate these factors' diagnostic efficacy.

Results The favorable and poor groups included 46 and 41 hips, respectively. Significant differences were found in body mass index (BMI), Association Research Circulation Osseous (ARCO) stage, collapse degree, Japanese Investigation Committee (JIC) classification, necrotic size, and hip subluxation between the two groups ($p < 0.05$). Multivariate logistic regression identified collapse < 3 mm(OR:14.49, 95%CI: 3.52–59.68, $p < 0.001$), JIC types B (OR: 11.08, 95% CI: 1.07-115.12, $p < 0.05$) and C1(OR: 5.18, 95% CI: 1.47–18.20, $p < 0.05$) as independent protective factors for hip function, while BMI (OR: 0.76, 95% CI: 0.59–0.97, $p = 0.029$) was an independent risk factor. ROC curve analysis demonstrated that both collapse degree (AUC = 0.798, sensitivity = 91.3%, specificity = 68.3%, $p < 0.0001$) and JIC classification (AUC = 0.787, sensitivity = 80.4%, specificity = 73.2%, $p < 0.0001$) had satisfactory diagnostic value for hip function. Combining JIC classification and collapse degree (AUC = 0.868, sensitivity = 76.1%, specificity = 85.4%, $p < 0.0001$) significantly enhanced diagnostic efficacy compared to using either alone ($p < 0.05$).

Conclusion In ONFH, femoral head collapse does not necessarily determine a poor prognosis. Patients with mild collapse (< 3 mm) and preserved anterolateral wall are more likely to retain satisfactory hip function, making them candidates for "survival with collapse."

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Keywords Osteonecrosis of the femoral head, Survival with collapse, Hip function, Collapse degree, Japanese Investigation Committee classification

Introduction

Osteonecrosis of the femoral head (ONFH) is a highly disabling disease that commonly affects young and middle-aged groups [1, 2]. One of the clinical characteristics of ONFH is its insidious progression, often exhibiting no obvious symptoms in the early stages. Consequently, by the time most patients seek medical attention due to hip pain, the femoral head has already collapsed, seriously affecting their work and quality of life [3]. In the post-collapse stage of ONFH, total hip arthroplasty (THA) serves as an effective intervention [4]. However, for young patients, undergoing THA may necessitate multiple revision surgeries throughout their lifetime, which can cause immense discomfort and pain [5, 6]. Especially in China, due to the enormous work and economic pressure faced by young people, not all patients with ONFH can afford THA. Therefore, preserving the native hip joint as long as possible and delaying or avoiding THA is undoubtedly of great significance in the treatment of ONFH.

"Survival with collapse" is defined as the survival state of the hip joint after collapse of the femoral head in patients with ONFH. In our clinical practice, we have identified a subset of patients in whom imaging examinations reveal a collapsed femoral head, but they experience minimal or no pain and maintain favorable hip function. These patients are capable of managing their daily lives and work normally, with no indications for surgical intervention. We refer to this specific group of patients as "survival with collapse". The epidemiological literature reports that approximately 50% of asymptomatic ONFH cases will progress to femoral head collapse within 4 years during the natural disease course [7]. Consequently, a considerable proportion of patients will confront the reality of "surviving with collapse". However, it is essential to clarify that not all patients with post-collapse ONFH retain satisfactory joint function. Therefore, distinguishing between patients with ONFH who are candidates for "survival with collapse" and those who are not is of great significance in guiding clinical hip-preserving treatment strategies.

Currently, research on ONFH is primarily focused on the prediction of collapse, concluding that the location and extent of necrosis are the most significant factors in predicting femoral head collapse [8, 9]. However, limited attention has been paid to the hip function and quality of life of patients with collapsed ONFH. According to previous research, conservative treatment can significantly improve joint function and enhance the quality of life in ONFH patients with collapse cessation of <3 mm [10]. This indicates that post-collapse ONFH patients with certain characteristics can also achieve satisfactory hip function through conservative treatment. However, there are numerous factors that may potentially affect hip function, and limited literature exists to summarize the clinical and radiological characteristics of patients who are likely to achieve "survival with collapse". The aim of this study is to investigate the factors that affect joint function in patients with post-collapse ONFH and to identify the characteristics of patients who are candidates for " survival with collapse".

Methods

Participants and design

This cross-sectional study was approved by the Institutional Ethics Committee of our hospital. We collected the clinical and radiological data of patients with post-collapse ONFH who visited our institution between October 2022 and March 2024. We reviewed their historical medical records (including X-rays and diagnostic notes) and recorded the time of the first detection of femoral head collapse. The time interval from the first detection of femoral head collapse to the current visit was defined as the duration of "survival with collapse". Considering the fact that collapse tends to progress in the early stages following femoral head collapse, hip function may deteriorate rapidly in the short-term [11, 12]. Therefore, only ONFH patients with a collapse duration of ≥ 3 years were included in this study. The inclusion criteria were as follows: (1) patients diagnosed with ONFH and experiencing a femoral head collapse of duration ≥ 3 years [13]; (2) conservative treatment only, such as acupotomy therapy, intra-articular injection of hyaluronic acid, and non-weight-bearing lower limb rehabilitation training, with no prior hip-preserving surgery. The exclusion criteria were as follows: (1) patients with severe knee osteoarthritis, degenerative spinal diseases, cardiovascular and cerebrovascular diseases, or other illnesses that may potentially affect Harris hip score (HHS) and quality of life; (2) patients with congenital hip dysplasia or other diseases that could compromise the accuracy of the radiological assessment; (3) patients with missing clinical and imaging data. Ultimately, 65 patients (87 hips) with ONFH and a collapse duration of ≥ 3 years were included in this study, comprising 34 males and 31 females. The mean age was 51.8 years (21–87 years), and the mean duration of collapse was 9.1 years (3–23 years).

Hip function evaluation

Based on the HHS at the time of each patient's current visit, we assessed the functional status of the evaluated

hip joint. The HHS scale is the most commonly used assessment tool for evaluating hip joint function, and its comprehensiveness and practicality have been widely recognized [14]. The scale consists of four components: pain, daily function, deformity, and range of joint motion on a 100-point scale, with higher scores indicating better function. According to the international classification criterion, HHS ≥ 90 is classified as excellent, 80 ≤ HHS < 90 as good, 70 ≤ HHS < 80 as fair, and HHS < 70 as poor. To simplify the grouping and statistical analysis, the hips were divided into two groups in our study: favorable group (HHS > 80 points) and poor group (HHS ≤ 80 points).

Clinical evaluation

During the patients' current visit, we assessed their demographic and clinical data. The demographic data mainly included age, sex, body mass index (BMI), side, and the visual analog scale (VAS) score for hip pain. The VAS score is determined by a 10-cm straight line, with 0 for no pain at all and 10 for the most severe pain, as marked by the patient. The clinical data primarily included the duration of "survival with collapse", etiology (steroid-induced, alcohol-induced, Idiopathic), whether alcohol or corticosteroids had been withdrawn during the period of "survival with collapse", and the condition of the contralateral hip joint. According to previous research suggesting that whether the contralateral femoral head has collapsed or undergone THA may affect the progression of the affected side [11, 15], we classified the status of the contralateral hips into three categories: normal femoral head or had undergone THA due to necrosis, femoral head necrosis without collapse, and femoral head necrosis with collapse.

Image evaluation

Image characteristics were evaluated based on the anteroposterior (AP) and frog-leg lateral (FL) radiographs of bilateral hip joints, as well as magnetic resonance imaging (MRI), during this visit. The hips diagnosed with ONFH were classified using the Association Research Circulation Osseous (ARCO) staging system and Japanese Osteonecrosis Investigation Committee (JIC) classification system. All hips included in this study were ARCO stage III or IV, with a JIC classification of type B, C1, or C2. Using the concentric circle method described by Kubo et al [16], the degree of femoral head collapse was measured and determined by the greater depth on either the AP or FL radiographs, and was subsequently classified as ≥ 3 mm or < 3 mm based on previous studies [10, 17]. Referring to necrosis range classification criteria, the hips were categorized into large lesions (> 30%) and medium lesions (15-30%). The criteria for hip subluxation are as follows: outward displacement of the center of the femoral head, discontinuity of Shenton's line and Calve's line observed on plain radiographs (Fig. 1). To assess the interobserver reliability, three senior orthopedists independently evaluated all imaging characteristics in a blinded manner. The interobserver reliability values of JIC classification, collapse degree, and lesion size were 0.952, 0.946 and 0.931, respectively, indicating perfect reliability.

Statistical analysis

Data were presented as the mean ± standard deviation (SD) for continuous variables and as frequencies for categorical variables. In univariate analysis, continuous values were compared with *t*-test while categorical variables were compared using the x^2 test or Fisher's exact test. Multivariate analysis was performed using

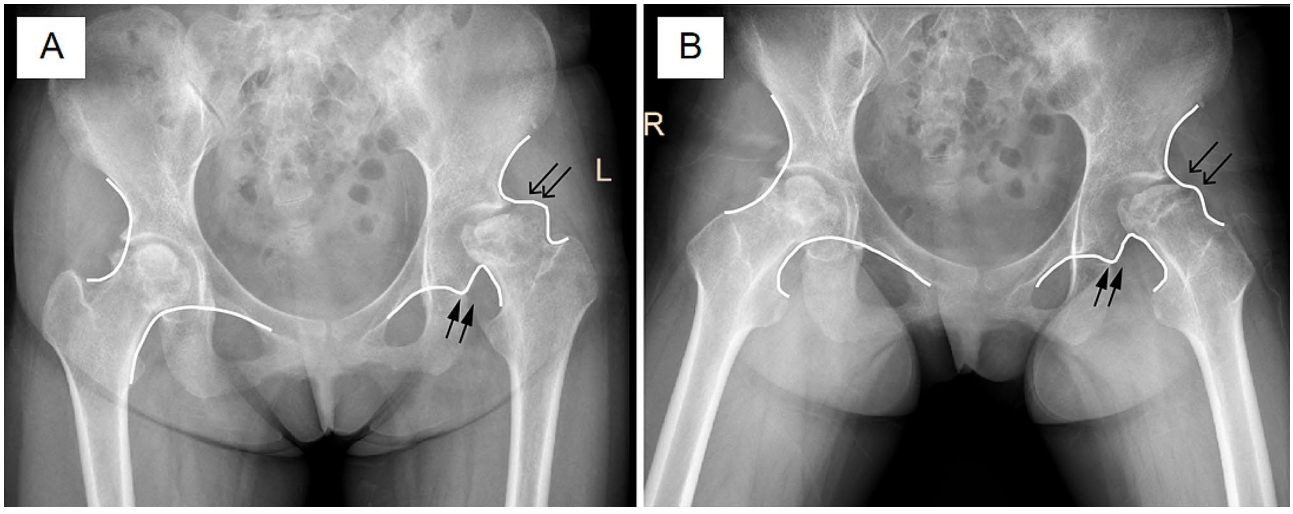

Fig. 1 Schematic representation of hip subluxation. AP (**A**) and FL (**B**) plain radiographs showing left hip subluxation with discontinuity of the Shenton's line (thick arrows) and Calve's line (thin arrows)

Table 1 Comparison of demographic data

	Favorable group (*n* = 46)	Poor group (*n* = 41)	*p*-value
Age(years)	53.4 ± 13.9	51.1 ± 15.8	0.477
Sex (male/female)	20/26	26/15	0.063
BMI (kg/m^2)	23.8 ± 2.5	25.2 ± 3.1	0.027
Side(left/right)	27/19	21/20	0.484
HHS	87.9 ± 4.0	68.0 ± 10.1	<0.001
VAS	2.7 ± 0.9	5.2 ± 1.1	<0.001

BMI, body mass index; *HHS*, Harris hip score; *VAS*, visual analog scale, **p*-value < 0.05

Table 2 Univariate analysis of clinical and imaging data

Factor	Favorable group (*n* = 46)	Poor group (*n* = 41)	*p*-value
Duration of "survival with collapse" (months)	107.1 ± 79.0	110.5 ± 73.6	0.834
Etiology			0.304
Glucocorticoid	23	25	
Alcohol	10	10	
Idiopathic	13	6	
Glucocorticoid or drinking			0.920
Withdrawal	28	30	
Persistence	5	5	
Contralateral hip joint			0.154
Normal or THA	8	11	
Necrosis without collapse	16	7	
Necrosis with collapse	22	23	
ARCO stage			0.002
III	37	20	
IV	9	21	
JIC type			<0.001
Type B	10	1	
Type C1	27	10	
Type C2	9	30	
Degree of collapse(mm)			< 0.001
<3	42	13	
≥ 3	4	28	
Lesion size			< 0.001
15–30%	18	2	
> 30%	28	39	
Subluxation			0.045
Yes	0	4	
No	46	37	

THA, total hip arthroplasty; *ARCO*, Association Research Circulation Osseous; *JIC*, Japanese Osteonecrosis Investigation Committee, **p*-value < 0.05

a stepwise binary logistic regression model (forward conditional) for factors that were significant in the univariate analysis. The odds ratio (OR) along with the 95%confidence interval (CI) and respective *p*-values were calculated. Receiver operating characteristic (ROC) curves were constructed to evaluate the diagnostic value of the independent factors and the combined indicators for hip joint functional status, and the area under the curve (AUC) values were calculated. Statistical significance was set at $p < 0.05$. All statistical analyses were performed using SPSS (version 24.0; IBM Corp, Armonk, NY, USA) and MedCalc (22.023; MedCalc Software Ltd, Ostend, Belgium).

Results

General information

In the present study, there were 46 hips in the favorable group (HHS > 80 points) and 41 hips in the poor group (HHS ≤ 80 points). There were significant differences in HHS and VAS score between the two groups ($p < 0.001$). Demographic data indicated that there were no statistically significant differences between the two groups in terms of age, sex, and affected side ($p > 0.05$). However, the average BMI of the favorable group (23.8 ± 2.5 kg/m^2) was significantly lower than that of the poor group (25.2 ± 3.1 kg/m^2) ($p = 0.027$) (Table 1).

Univariate analysis

The univariate analysis results of clinical and radiological data between the favorable and poor groups are summarized in Table 2. Regarding clinical data, we failed to identify any significant differences between the two groups with respect to the etiology, duration of "survival with collapse", whether alcohol or corticosteroids had been withdrawn during the period of "survival with collapse", and the condition of the contralateral hip joint ($p > 0.05$). However, in terms of radiological data, there were statistically significant differences between the two groups regarding ARCO stage, JIC classification, degree of collapse, lesion size, and presence of hip subluxation ($p < 0.05$). This indicated that hips in the favorable group tended to exhibit an earlier radiological stage (ARCO stage III) and a milder degree of collapse (collapse of < 3 mm). Additionally, hips with smaller necrotic lesion sizes, necrotic lesions occupying less of the weight-bearing area, and the absence of subluxation, also tended to possess favorable joint function.

Multivariate analysis

To reduce the effect of collinearity among the independent variables, a stepwise binary logistic regression model (forward conditional) was adopted, defining favorable hip function (HHS > 80) as a positive event in the dependent variable. Six variables with significant differences in the univariate analysis were incorporated into the stepwise binary logistic regression model to identify protective factors that affect the functional status of the hip. Multivariate logistic regression results showed that BMI (OR: 0.76, 95% CI: 0.59–0.97, $p = 0.029$) was an independent risk factor for hip function in patients with "survival with collapse". In contrast, femoral head collapse < 3 mm (OR:14.49, 95% CI 3.52–59.68, $p < 0.001$), JIC type B (OR:11.08, 95% CI: 1.07-115.12, $p < 0.05$), and

Table 3 Multivariate analysis of the protective factors for hip function

Factor	OR	95%CI	Multivariate *p*-value[†]
BMI	0.76	0.59–0.97	0.029*
Degree of collapse			
≥ 3 mm	1.00	Reference	< 0.001*
< 3 mm	14.49	3.52–59.68	
JIC Type	1.00	Reference	
Type C2	5.18	1.47–18.20	
Type C1			0.010*
Type B	11.08	1.07-115.12	0.044*

BMI, body mass index; *JIC*, Japanese Osteonecrosis Investigation Committee; [†]stepwise binary logistic regression model (forward conditional); **p*-value < 0.05

JIC type C1 (OR:5.18, 95% CI: 1.47–18.20, $p<0.05$) were each independent protective factors for hip function in patients with "survival with collapse"(Table 3).

ROC curve analysis

The ROC curve analysis showed that BMI had poor diagnostic efficacy for hip function status (AUC = 0.616, sensitivity = 56.5%, specificity = 68.3%, $p=0.057$). Both the degree of collapse (AUC = 0.798, sensitivity = 91.3%, specificity = 68.3%, $p<0.0001$) and JIC classification (AUC = 0.787, sensitivity = 80.4%, specificity = 73.2%, $p<0.0001$) demonstrated satisfactory diagnostic value, with no statistically significant difference in the AUC between the two factors ($p=0.838$). Furthermore, the combined use of the JIC classification and the degree of collapse (sensitivity = 76.1%, specificity = 85.4%) achieved an AUC of 0.868, which was significantly higher than the AUC obtained by using JIC classification or degree of collapse alone ($p<0.05$) (Fig. 2).

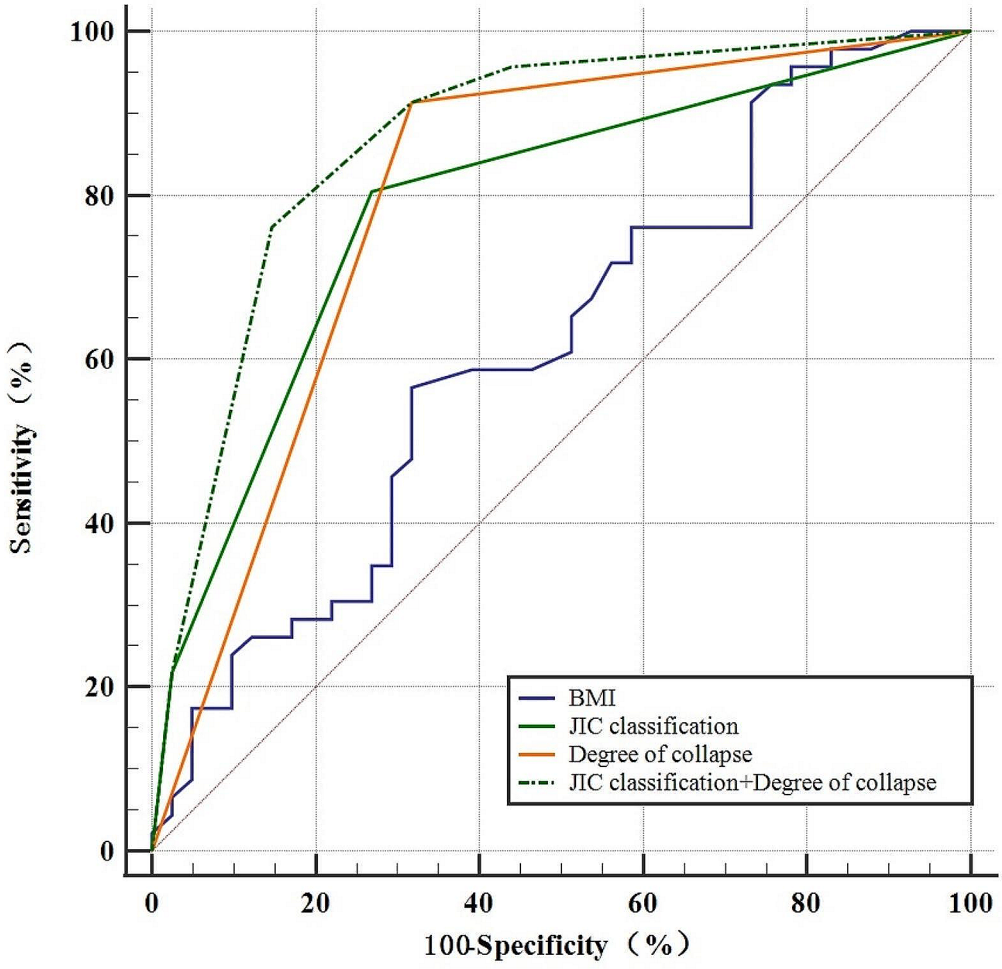

Fig. 2 ROC curve analysis of BMI, degree of collapse, JIC classification, and JIC classification + degree of collapse. *ROC*, receiver operating characteristic; *BMI*, body mass index; *JIC*, Japanese Osteonecrosis Investigation Committee

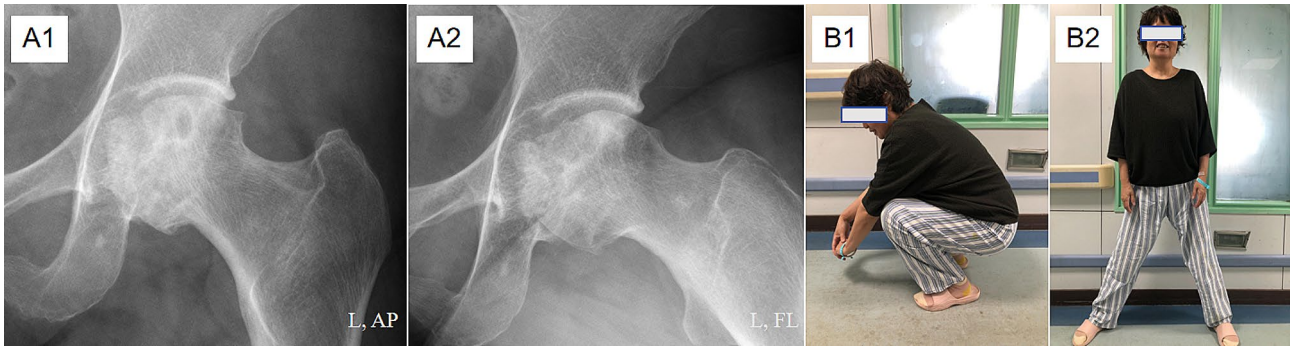

Fig. 3 A 59-year-old woman with left femoral head necrosis, has been surviving with collapse for 8.5 years. (**A1/A2**) AP and FL plain radiographs reveal JIC-type C1, extensive necrosis, and a collapse of < 3 mm. (**B1/B2**) The patient demonstrated favorable hip joint function, with a HHS of 91 and a VAS score of 2

Discussion

We believe that "survival with collapse" is not about preserving a collapsed femoral head regardless of joint function. Instead, it aims to enable the patient to maintain favorable joint function over the long term after femoral head collapse, thus avoiding the necessity of THA. In this study, we evaluated clinical and radiological factors that could potentially affect hip function status in patients with "survival with collapse". Our findings indicated that a lower BMI, femoral head collapse<3 mm, JIC-type B, and JIC-type C1 were independent protective factors for achieving favorable hip function in these patients. Furthermore, combining the factors of collapse degree and JIC classification provided better accuracy in predicting the hip function status.

Previous studies have confirmed that compared with the pre-collapse stage, the quality of life and hip function of patients in the post-collapse ONFH deteriorate significantly [15, 17]. On the one hand, collapse represents loss of the smooth hemispherical structure of the femoral head, resulting in loss of the concentric structure between the femoral head and the acetabulum. As the degree of collapse progresses, the mismatch between the acetabulum and femoral head intensifies, subsequently leading to an aggravation of pain and hip dysfunction. Iwasa et al. reported that in patients with ONFH, for each 1 mm increase in the degree of femoral head collapse, there was a corresponding deterioration in the VAS scores and quality-of-life scores [18]. Likewise, Osawa et al. found that when using 3 mm as the staging criterion, ONFH patients with collapse of < 3 mm had significantly lower pain intensity and better hip function than those with collapse > 3 mm, which was consistent with the results of our study [10]. On the other hand, multiple studies have reported a strong correlation between the wear of articular cartilage and the degree of femoral head collapse, as well as its duration [19, 20]. Furthermore, the wear of cartilage is recognized as a crucial factor contributing to joint pain and dysfunction. In the present study, the average duration of "survival with collapse" for all included hips was as long as 9 years, and there was no significant difference between the favorable and poor groups. Based on these findings, we speculated that the degree of collapse may indirectly affect hip function by altering the condition of the cartilage. We recommend using the degree of collapse as a crucial criterion for assessing whether post-collapse ONFH patients are suitable candidates for "survival with collapse".

In pre-collapse ONFH, the location of necrotic lesions serves as a significant predictive factor for femoral head collapse. Previous studies have confirmed that when necrotic lesions extend beyond the acetabular edge, collapse is highly likely [21, 22]. Similarly, for patients with post-collapse ONFH, our study demonstrated that hip function in cases of type B and type C1 is notably superior to that of type C2. This suggests that preservation of the anterolateral wall of the femoral head is essential for the prognosis of ONFH, regardless of whether the femoral head has collapsed or not. Biomechanical studies have shown that the anterolateral wall is the primary weight-bearing structure of the femoral head, bearing the majority of the load during our daily activities [23, 24]. Osawa et al. conducted an average follow-up of 4.38 years on 109 symptomatic ONFH patients and found that type C2 cases exhibited a significantly higher risk of re-collapse (with collapse progression ≥ 3 mm) [11]. In our study, we similarly observed that among cases with collapse of ≥ 3 mm, the proportion with type B and type C1 was 21.9% (7/32), while the proportion with type C2 was 78.1% (25/32). This indicates that femoral heads with preserved anterolateral wall tend to experience less severe collapse (Fig. 3). However, for type C1 cases where the anterolateral wall is partially preserved, further research is necessary to quantify the proportion of anterolateral wall preservation and its correlation with hip function.

In the early stages of ONFH, patients are typically advised to walk with crutches to reduce weight-bearing. However, the "survival with collapse" cohort in our study had discarded crutches completely in their daily lives, leaving their

hip joints unprotected and potentially exposed to stress several times their body weight [25]. This explained the finding in our study that an increase in BMI was a risk factor for hip function in these patients, suggesting that weight loss can benefit these patients in achieving better hip function.

In this study, we also considered several other factors that might affect joint function. The results indicated that the etiology, whether alcohol or corticosteroids had been withdrawn, and the condition of the contralateral hip joint did not significantly affect hip function of the "survival with collapse" patients. Although studies have reported that these factors may affect the prognosis of pre-collapse ONFH [26, 27], their effect on post-collapse ONFH remains to be confirmed by larger sample studies. Referring to the criteria for the classification of necrosis lesion size, we categorized the lesion size by visual estimation into large size (>30%) and medium size (15–30%), which may involve some inaccuracy. Nevertheless, the results of the multivariate analysis indicated that the necrotic lesion size was not an independent factor for predicting hip function. Even with extensive necrosis, hip with lesions that do not involve the anterolateral wall may still exhibit favorable hip function. As for hip subluxation, only four hips in our study exhibited such changes, all of which belonged to the poor group. More importantly, we found that all four hips were classified as JIC type C2 and exhibited collapse of ≥3 mm, indicating that hips with a damaged anterolateral wall and severe collapse are more susceptible to progressing to subluxation. Once ONFH progresses to hip subluxation, it signifies that the normal anatomical alignment between the femoral head and the acetabulum has been altered, indicating that the disease has reached its terminal stage. For patients in this category, "survival with collapse" is no longer a viable option.

Our study has several limitations. First, this is a cross-sectional study with a small sample size, which may have introduced some biases. Moreover, considering the dynamic changes of the imaging following femoral head collapse [22, 28], we plan to investigate the correlation between the evolution of imaging and hip function changes at different stages in patients with "survival with collapse" in future studies. Second, using the HHS as an evaluation criterion may not fully reflect the functional status of the hip joint, despite the reliability of the HHS scale and its high correlation with quality of life having been confirmed in numerous studies [14, 17]. Third, we are uncertain whether there are other significant factors affecting the hip function of patients with "survival with collapse" not included in this study, since the hip functional status of patients may be affected by a superposition of multiple complex factors. Further large-sample studies are needed in the future to verify potential factors. Nonetheless, this is the first study to systematically investigate the clinical and radiological characteristics of collapsed ONFH patients who are candidates for "survival with collapse". We believe our findings will be helpful in guiding hip-preservation strategies for post-collapse ONFH.

In conclusion, the results of this study indicated that mild collapse (collapse of <3 mm), JIC type B, and JIC type C1 are independent protective factors for hip function, and ONFH patients with these characteristics are more likely to achieve "survival with collapse".

Abbreviations

ONFH	Osteonecrosis of the femoral head
HHS	Harris Hip Score
VAS	Visual analog scale
ROC	Receiver operating characteristic
BMI	Body mass index
ARCO	Association Research Circulation Osseous
JIC	Japanese Investigation Committee
OR	Odds ratio
CI	Confidence interval
THA	Total hip arthroplasty
AP	Anteroposterior
FL	Frog-leg lateral
MRI	Magnetic resonance imaging
SD	Standard deviation
AUC	Area under the curve

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Author contributions
CZ, BX: study design, writing the original manuscript. JW, YL: data collection, statistic analysis. CZ, GZ: statistical graph. BX, DL: performed the formal analysis, conceptualized the study. WC, HH: reviewed and proofread the final manuscript.

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Data availability
The datasets used or analysed in this study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The Ethics Committee of Wangjing Hospital, China Academy of Chinese Medical Sciences approved this study.

Consent for publication
Written informed consent for publication was obtained from all patients included in this study.

Competing interests
The authors declare no competing interests.

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