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# Imaging study of aseptic loosening of the acetabular cup after cementless total hip arthroplasty: a retrospective study

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## Abstract

**Purpose** The purpose of this study was to provide more accurate imaging diagnostic parameters for acetabular cup loosening through radiological characteristic of acetabular cup aseptic loosening after cementless total hip arthroplasty, especially for patients lacking postoperative baseline or serial follow-up radiographs.

**Methods** The radiographic data of patients who underwent primary unilateral cementless total hip arthroplasty in our hospital from January 2017 to July 2024 were retrospectively studied. Forty-one patients with aseptic loosening of the acetabular cup, confirmed by surgery or consensus between clinicians and radiologists, were included in the loosening group. Sixty-one patients who underwent primary total hip arthroplasty and were evaluated more than one year postoperatively were included as the control group. The absence of postoperative complications was confirmed through discussions between clinicians and radiologists. Radiographic examination of the contralateral hip joint in all included patients showed no significant abnormalities. The following imaging parameters were measured on anteroposterior bilateral hip radiography: acetabular cup inclination (AA), acetabular difference in vertical distance 1 (DVD1), acetabular difference in vertical distance 2 (DVD2), acetabular difference in horizontal distance (DHD), wide radiolucent zones around the acetabular cup (TA), number of wide radiolucent zones around the acetabular cup (NTA) and difference in head-cup edge distance (DHCD).

**Results** The numerical value of TA, DVD1, DHCD, AA and NTA in the loosening group was significantly higher than in the control group, and the differences were all statistically significant ($P < 0.05$). The critical values of DVD1, DHCD, AA and NTA were 1.49 cm, 0.16 cm, 53.2 ° and 1, respectively. The combined imaging diagnostic criteria for acetabular cup loosening are defined as the simultaneous fulfillment of the following two conditions: (1) NTA ≥ 1; (2) AA ≥ 53.2° or DHCD ≥ 0.16 cm. The results of the validation analysis were statistically significant.

**Conclusions** The combined imaging diagnostic criteria for aseptic loosening of the acetabular cup after total hip arthroplasty, established in this study, demonstrate superior diagnostic efficacy compared to single imaging

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parameters. This approach does not rely on postoperative baseline radiographs or serial follow-up radiographs and can accurately determine the specific location of prosthetic loosening.

**Keywords** Total hip arthroplasty, Diagnostic imaging, Multimodal image, Complications, Aseptic loosening

## Introduction

Total hip arthroplasty (THA) is the main approach to treatment of several chronic conditions affecting the hip joint, including advanced hip osteoarthritis, avascular necrosis of the femoral head and other hip diseases [1].Today, total hip arthroplasty is widely performed in hospitals of all levels, and the number of procedures is increasing annually [2]. As the number of total hip replacements increases, so does the number of complications, among which aseptic loosening of the prosthesis is the most common [3].

Currently, the diagnosis of aseptic loosening of prostheses primarily relies on physical examination and radiological characteristics, but these methods have significant limitations. In the early stages of prosthetic loosening, patients often experience no pain, and individual pain thresholds vary widely among patients [4, 5]. Regarding radiological characteristics, X-ray imaging is the most commonly used modality, but no uniform criteria exist for the diagnosis of aseptic loosening. The current diagnostic criteria are as follows. Possible loosening is defined as a radiolucent zone at the cement-bone or implant-bone interface that is > 2 mm in width. Highly possible loosening is defined as progressive widening of the radiolucent zone observed on multiple postoperative X-rays over time. Definite loosening is defined as prosthesis displacement or fracture [6, 7].

With the above criteria, the following limitations exist. Some parameters require comparison with postoperative baseline radiographs or serial radiographs, such as progressive widening of radiolucent zone

s around the prosthesis and prosthesis displacement [8, 9]. In clinical practice, patients are often encountered several years or even more than a decade after hip replacement, with their early postoperative radiographs partially or completely lost. This loss of imaging data limits the ability to make accurate comparisons and complicates the diagnosis of aseptic loosening. Revision surgery is required after aseptic loosening of the prosthesis has occurred [10]. If not diagnosed in time, the lesion will progress gradually, ultimately leading to more difficult and costly revision surgery and a worse prognosis.

Therefore, the aim of this study is to establish diagnostic criteria that do not rely on postoperative baseline radiographs and serial follow-up radiographs by measuring and analyzing multiple parameters on radiographs of the aseptic loosening group and the control group after total hip arthroplasty.

## Method

### Research population

Patients who underwent primary unilateral cementless total hip arthroplasty from January 2017 to July 2024 were selected for this study. There were forty-one patients in the acetabular cup loosening group, and twenty of them also underwent CT and MRI examination of the hip, sixty-one cases in the control group. The data was included with a ratio of 1:1.5 between the loosening group and the control group.

### Inclusion and exclusion criteria

Inclusion criteria for the acetabular cup loosening group.

Forty-one patients were included in the loosening group. Among them, seventeen cases were surgically confirmed, while the remaining twenty-four cases were diagnosed through consensus between clinicians and radiologists. The diagnosis of aseptic loosening was established based on consensus between clinicians and radiologists. In cases where revision surgery was performed, aseptic loosening of the acetabular cup was confirmed intraoperatively. For patients who did not undergo revision surgery, the diagnosis was made based on clinical and radiological findings. (All included patients underwent radiographic examination following the onset of symptoms, such as hip pain and joint discomfort). Clinical and radiological information is complete.

### Exclusion criteria

Fractures or infections were observed around the prosthesis. Additionally, the contralateral hip exhibited abnormalities, including femoral head necrosis and acetabular dysplasia.

Inclusion criteria for control group.

More than one year after hip replacement, discussion between clinicians and radiologists confirmed the absence of postoperative complications. Clinical and radiological information is complete.

### Exclusion criteria

Same exclusion criteria as above for the loosening group.

Clinicians diagnosed loosening in 46 patients and normal in 64 patients, whereas radiologists diagnosed loosening in 44 patients and normal in 66 patients. The kappa value of 0.850 indicates excellent agreement between radiologists and clinicians in diagnosing loosening of the acetabular cup.

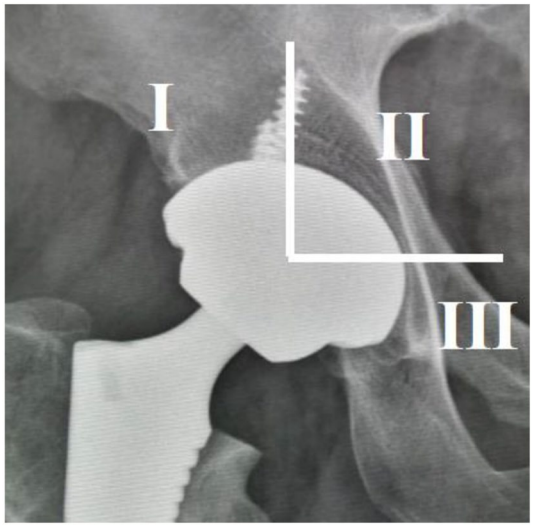


**Fig. 1** Charnley-Delee acetabular zonation, the acetabular cup is divided into three equal zones from lateral to medial, labelled as I, II and III

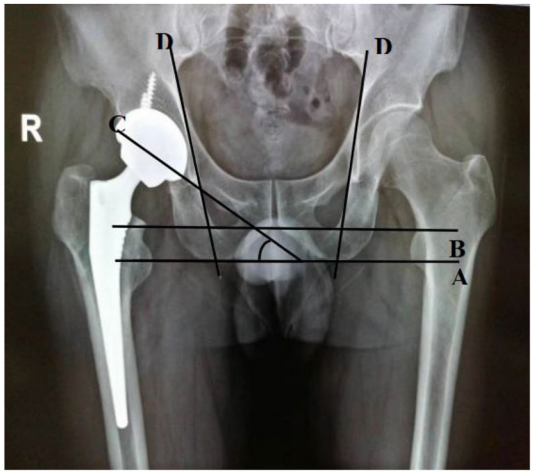


**Fig. 2** Line A is the horizontal line connecting the two ischial tuberosities. Line B is the horizontal line connecting the lower edges of the obturator foramen on both sides. Line C is the tangent to the medial-lateral edge of the acetabular cup. Line D is the tangent to the inner margin of the ischium through the inner margin of the ilium. The angle between lines A and C is AA. DVD1 is the difference in the vertical distance between the center of the femoral head and line A on both sides. DVD2 is the difference of the vertical distance between the inner lower edge of the acetabulum and the line B on both sides. DHD is the difference of the vertical distance between the center of the femoral head and the line D on both sides

### Parameter analysis

Parameters were measured using the hospital picture archiving and communication system, primarily based on anteroposterior hip radiographs [11–13]. Further observation of CT/MRI to clarify the diagnosis when the diagnosis is controversial. The following parameters were measured. To accurately describe the acetabular region, the Charnley-Delee acetabular zones were adopted as the standard classification method [14] (Figs. 1 and 2).

(1) Acetabular cup inclination (AA): the angle between the plane of the acetabular cup and the line of the ischial tuberosity.
(2) Acetabular difference in vertical distance 1 (DVD1): difference of the distance from the center of the femoral head to the ischial tuberosity on both sides. This parameter is obtained by comparison with the opposite side on the same radiograph.
(3) Acetabular difference in vertical distance 2 (DVD2): difference of the distance from the inferior edge of the acetabulum to the obturator foramen line on both sides. This parameter is obtained by comparison with the opposite side on the same radiograph.
(4) Acetabular difference in horizontal distance (DHD): difference of the distance from the center of the femoral head to the Kohler line on both sides. This parameter is obtained by comparison with the opposite side on the same radiograph.
(5) Wide radiolucent zones around the acetabular cup (TA): if there is a radiolucent zone around the acetabular cup with a maximum width of ≥ 2 mm, it is termed as having a wide radiolucent zone around the acetabular cup. Otherwise, it is deemed to be nonexistent.
(6) Number of wide radiolucent zones around the acetabular cup (NTA): according to the Charnley-Delee classification for acetabular zones, involvement of one zone is defined as one unit, two zones as two units, and so on.
(7) Difference in head-cup edge distance (DHCD): difference between the superior and inferior distances from the femoral head to the acetabular cup surface. Femoral head is asymmetrically seated in acetabular cup indicating acetabular liner wear.

### Statistical analysis

The study data were analyzed using SPSS version 25.0 and GraphPad Prism version 8.0, with all statistical tests considered significant at $P < 0.05$.

Initially, normality and homogeneity of variance tests were conducted to assess the distribution of the data. If the data conformed to a normal distribution, they were described using the mean ± standard deviation, otherwise, the median (P25, P75) was selected. Subsequently, spearman correlation analysis was performed to explore the relationship between NTA and DHCD. Following, the statistically significant imaging parameters were selected to use the receiver operating characteristic (ROC) curves for each parameter. The area under the curve (AUC), specificity, sensitivity and cut-off values were calculated for each parameter. The concurrent fulfillment of the following two conditions provides high diagnostic efficiency for acetabular cup loosening: [1] NTA ≥ 1; [2] AA ≥ 53.2° or DHCD ≥ 0.16 cm. Finally, two radiologists with more

**Table 1** Comparison of clinical parameters between the two groups

| | Control group (*n* = 61) | Loosening group (*n* = 41) | *P*-value |
|---|---|---|---|
| Time (months) | 15 (12, 36) | 100(66, 144) | 0.001* |
| Age (years) | 55(42, 63) | 68(65, 73) | 0.001* |
| Gender (M/F) | 31/30 | 16/25 | 0.241 |

**Table 2** Comparison of TA in the two groups

| | | Control group [*n* (%)] | Loosening group [*n* (%)] | $\chi^2$ | *P*-value |
|---|---|---|---|---|---|
| TA | no | 58 (95.10%) | 6 (14.60%) | 67.886 | 0.001* |
| | yes | 3 (4.90%) | 35 (85.40%) | | |

**Table 3** Comparison of various quantitative parameters between the two groups

| | Control group (*n* = 61) | Loosening group (*n* = 41) | Z | *P*-value |
|---|---|---|---|---|
| DVD1(cm) | 0.68(0.27, 1.07) | 1.00(0.40, 2.08) | 2.641 | 0.009 |
| DVD2(cm) | 0.84(0.45, 1.20) | 1.01(0.37, 1.61) | 0.809 | 0.419 |
| DHD (cm) | 0.60(0.33, 0.95) | 0.68(0.24, 1.04) | 0.809 | 0.419 |
| DHCD (cm) | 0.08(0.03, 0.13) | 0.20(0.12, 0.37) | 4.881 | 0.001* |
| AA(°) | 42.30(38.00, 47.40) | 56.60(39.15, 73.60) | 3.512 | 0.001* |
| NTA | 0.00(0.00, 0.00) | 2.00(1.00, 5.00) | 8.457 | 0.001* |

than three years of experience performed a double-blind assessment of acetabular cup aseptic loosening according to these criteria. The validation analysis included 96 cases, among which 35 cases were loosening and 61 cases were normal postoperative. Calculate the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), accuracy and kappa value for the diagnoses made by the two radiologists, and take their average values [15].

## Results

### General information

The time and age of the loosening group were greater than those in the control group, and the difference was statistically significant ($P < 0.001$). There was no statistically significant difference in the gender composition between the two groups ($P > 0.05$) (Table 1).

Table 1 Time, between the primary total hip arthroplasty and the present. * is $P < 0.001$.

The incidence of TA was significantly higher in the loosening group than in the control group, and the difference was statistically significant ($P < 0.001$) (Table 2).

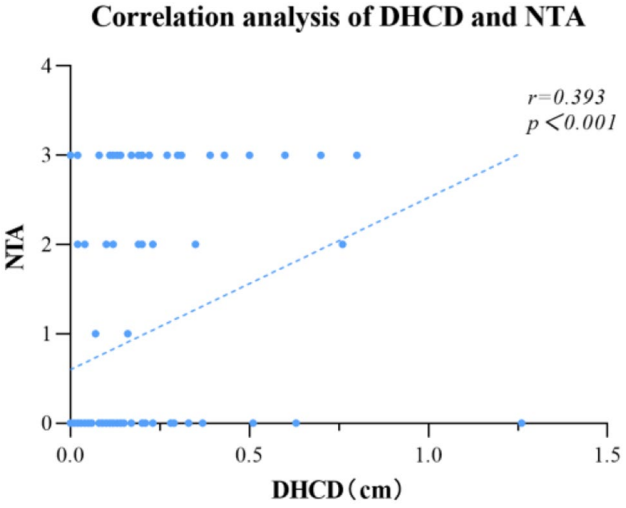


**Fig. 3** Correlation of DHCD and NTA

Table 2 TA, wide radiolucent zones around the acetabular cup. * is $P < 0.001$.

The DVD1, DHCD, AA and NTA in the loosening group were statistically significant greater than those in the control group($P < 0.05$). There were no statistically significant differences in DVD2 and DHD between the two groups ($P < 0.05$) (Table 3).

Table 3 DVD1, acetabular difference in vertical distance (1) DVD2, acetabular difference in vertical distance (2) DHD, acetabular difference in horizontal distance. DHCD, difference in head-cup edge distance. AA, acetabular cup inclination. NTA, number of wide radiolucent areas around the acetabular cup.

### Correlation analysis

It shows that DHCD is weakly positively correlated with NTA ($r = 0.393$, $P<0.001$) (Fig. 3).

### Constructing critical values

The AUC, sensitivity, specificity, P-value and cut-off value of the above imaging parameters with statistically significant differences were calculated (Table 4). The cut-off values of DVD1, DHCD, AA and NTA were 1.49 cm, 0.16 cm, 53.2 ° and 1, respectively. Delong test was further performed on the ROC curves for each parameter. The ROC curve of NTA was compared with DVD1, DHCD and AA respectively and the difference was statistically significant ($P < 0.05$).

**Table 4** Diagnostic efficacy analysis of imaging parameters

| | AUC | Sensitivity | 95%CI | Specificity | 95%CI | *P*-value | Cut-off value |
|---|---|---|---|---|---|---|---|
| DVD1 | 0.653 | 0.415 | 0.397–0.433 | 0.918 | 0.915–0.921 | 0.009 | 1.490 |
| DHCD | 0.786 | 0.659 | 0.646–0.672 | 0.852 | 0.848–0.856 | 0.001* | 0.155 |
| AA | 0.706 | 0.561 | 0.545–0.577 | 0.951 | 0.949–0.953 | 0.001* | 53.150 |
| NTA | 0.922 | 0.854 | 0.848–0.860 | 0.967 | 0.966–0.968 | 0.001* | 0.500 |

Table 4 * is $P < 0.001$

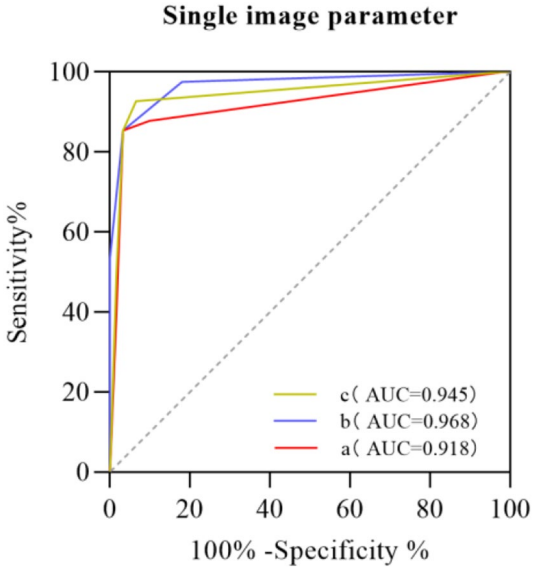


**Fig. 4** The a is composed of DVD1, TA, and NTA. The b is composed of TA, NTA, and DHCD. The c is composed of TA, NTA, and AA

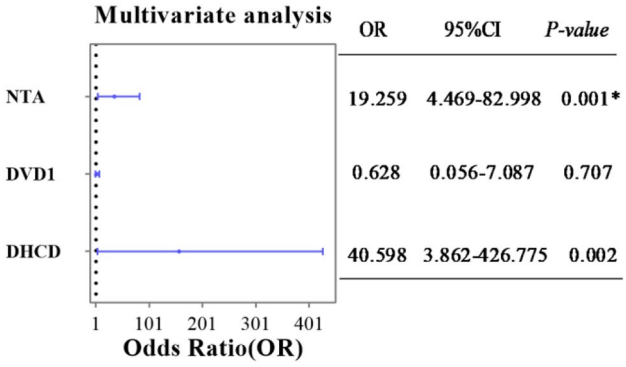


**Fig. 5** * is $P<0.001$

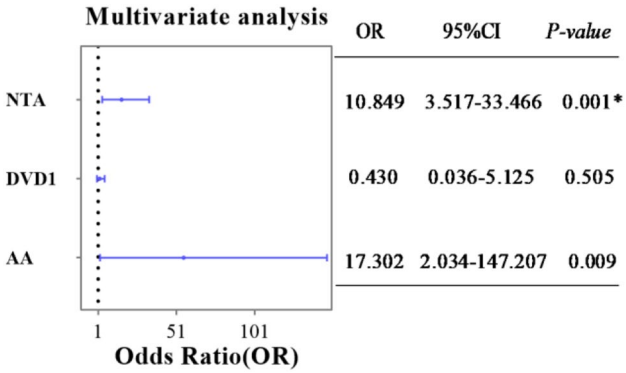


**Fig. 6** * is $P<0.001$

### Construction of predictive models

The above data were transformed into dichotomous data. The AUC of the a, b and c joint parameters were calculated (Fig. 4). The ROC curve of b was compared with that of a by Delong test, and the difference was statistically significant ($P<0.05$), but there was no statistical difference with that of c ($P>0.05$).

The ROC curves of b and c were compared with those of DHCD and AA by Delong test, and the difference was statistically significant ($P<0.05$).

According to the above conclusions, multivariate binary logistic regression validation was performed using two sets of image parameters: the first set (NTA, DVD1, DHCD) and the second set (NTA, DVD1, AA) (Figs. 5 and 6). In the first, NTA (OR = 19.26, 95%CI 4.47-83.00, $P<0.001$) and DHCD (OR = 40.60, 95%CI 3.86-426.78, $P=0.002$) were significantly associated with acetabular cup loosening. In the second, NTA (OR = 10.85, 95%CI 3.52–33.47, $P<0.001$) and AA (OR = 17.30, 95%CI 2.03-147.21, $P=0.009$) were significantly associated with acetabular cup loosening. Based on the aforementioned results, the combined imaging diagnostic criteria for acetabular cup loosening, which were established by selecting the most diagnostically effective parameters, are defined by meeting both of the following two conditions: [1] NTA ≥ 1; [2] AA ≥ 53.2° or DHCD ≥ 0.16 cm.

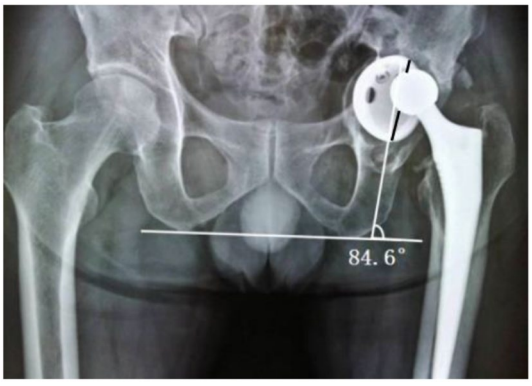


**Fig. 7** A 67-year-old patient who underwent left total hip arthroplasty 6 years ago, presented with left hip pain for 8 months, exacerbated by activity. An anteroposterior radiograph revealed increased AA, the presence of TA in zones I-III, and DHCD>0.16 cm. Acetabular cup loosening was diagnosed based on these findings

### Validation analysis

Using the above combined imaging diagnostic criteria for acetabular cup loosening, the average diagnostic performance of the two radiologists was as follows: sensitivity was 85.7%, specificity was 95.1%, PPV was 90.9%, NPV was 92.1%, accuracy was 91.7%, and the kappa value was 0.818. Cases of acetabular cup loosening (Figs. 7 and 8).

## Discussion

Aseptic loosening of the acetabular cup is a common complication after total hip arthroplasty and requires timely and accurate diagnosis [16]. Currently, there are still some issues to be addressed in the diagnostic criteria for aseptic loosening of the acetabular cup. Therefore,

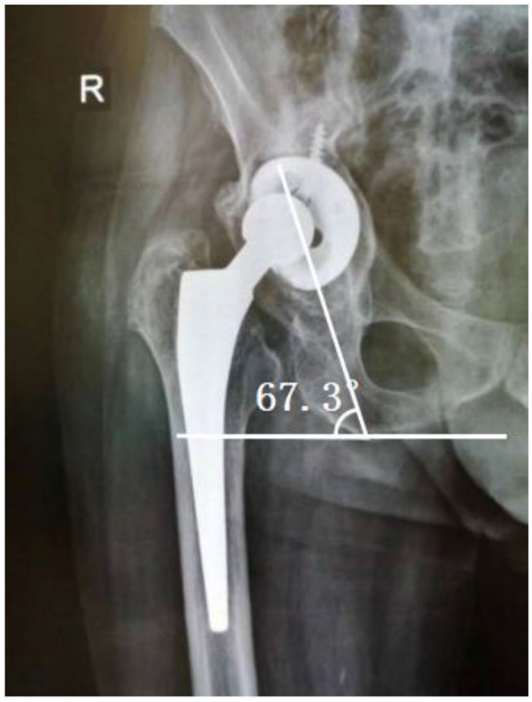


**Fig. 8** A 72-year-old patient who underwent right total hip arthroplasty 16 years ago presented with right hip pain for 9 days. An anteroposterior radiograph revealed increased AA and the presence of TA in zones I-III. Acetabular cup loosening was diagnosed based on these findings

this study aims to provide more precise and practical imaging criteria for the diagnosis of based on its radiological features.

This study demonstrated that each imaging parameter, including AA, DVD1, DHCD and NTA, was valuable in diagnosing aseptic loosening of the acetabular cup. Theoretically, the most reliable method for diagnosing acetabular cup loosening is to compare postoperative baseline and serial follow-up radiographs. This is because patient activity level and variations in surgical techniques, result in differing manifestations of postoperative baseline and serial follow-up radiographs across patients. For those without postoperative baseline radiographs or serial follow-up radiographs, it is necessary to establish diagnostic criteria.

Changes in AA indicate the presence or absence of acetabular cup displacement [17]. The normal AA typically ranges from 30° to 50°. Deviations from this range, whether an increase or decrease, indicate acetabular cup displacement [18]. In cases of acetabular cup loosening, most cases exhibit an increase in AA. Some studies suggest that AA greater than 55° indicates loosening of the acetabular cup [19]. In this study, the cutoff value for AA was set at ≥53.2°, which was used as a diagnostic criterion, yielding an AUC value of 0.706.

Changes in the horizontal and vertical distances of the acetabulum indicate the presence or absence of horizontal and vertical displacement of the acetabular cup. Some studies suggest that horizontal distance difference and vertical distance difference of 0 are considered normal [12]. Other studies propose that horizontal distance difference or vertical distance difference greater than 4–5 mm indicates loosening of the acetabular cup [7, 20]. In this study, the value representing acetabular difference in horizontal distance was DHD, and the results demonstrated its inability to diagnose acetabular cup loosening. Additionally, two other values representing the acetabular difference in vertical distance were selected, namely DVD1 and DVD2. For DVD1, the diagnostic cutoff value was set at ≥1.49 cm, with an AUC value of 0.653 for diagnosing loosening, indicating limited diagnostic efficacy. DVD2 was found to be incapable of diagnosing loosening.

A narrow radiolucent zone parallel to the prosthesis, accompanied by a thin sclerotic margin, can normally appear around the prosthesis. This is caused by fibrous remodeling and indicates prosthesis stability [21]. Most studies consider a radiolucent zone with a width of less than 2 mm to be a normal finding, while a width of ≥2 mm is diagnostic of potential loosening [6, 22]. Progressive widening of the radiolucent zone suggests a high likelihood of prosthesis loosening [11]. Therefore, in this study, only radiolucent zones around the prosthesis with a maximum width of ≥2 mm were analyzed, referred to as TA. The cutoff value for NTA was set at ≥1, which was used as a diagnostic criterion, yielding an AUC value of 0.922, indicating high diagnostic efficacy.

The edges of the TA do not reach the cortical bone and are typically associated with a sclerotic margin. The formation mechanism may be related to the micromotion of the prosthesis and bone resorption [23]. Platelets are activated by cytokines, leading to morphological and biochemical changes that result in the formation of a fibrin matrix. This matrix serves as a scaffold for osteoblasts, which facilitate bone repair and contribute to the development of a periprosthetic sclerotic margin [24]. The edges of the TA reach the cortical bone, often causing cortical thinning. In some cases, the cortical bone expands outward beyond the original contour, forming a thin peripheral osseous shell.

The normal value of DHCD is 0, and an increase in DHCD indicates liner wear of the prosthesis. The greater the value, the more severe the wear [7]. Wear particles themselves do not directly cause prosthesis loosening. Under normal conditions, the prosthesis-bone interface possesses a biological barrier that prevents wear particles from entering. Even if wear particles enter, they will not induce osteolysis unless they bind with inflammatory molecules. Even when bound to inflammatory molecules, they may only cause transient osteolysis, which resolves upon clearance of the inflammatory factors [25].

However, wear particles are associated with the presence of radiolucent zones and prosthesis loosening to some extent. In this study, the cutoff value for DHCD was set at ≥0.16 cm, which was used as a diagnostic criterion, yielding an AUC value of 0.786. DHCD showed a weak positive correlation with NTA. In the loosening group, some cases exhibited signs of liner wear, while others did not. Similarly, in the control group, some cases also demonstrated signs of liner wear. The degree of liner wear in the loosening group was higher than that in the control group. Therefore, this study suggests that wear particles generated from liner wear are associated with acetabular cup loosening to some extent, but they are not a necessary condition for acetabular cup loosening.

Currently, there is no unified diagnostic standard for imaging parameters of aseptic loosening of the acetabular cup following total hip arthroplasty [6, 22]. The diagnostic thresholds established in this study are comparable to those previously reported in the literature, although not entirely consistent. This discrepancy may be attributed to several factors. First, this discrepancy may be attributed to the fact that early diagnostic criteria for prosthetic loosening were predominantly established for cemented prostheses, with limited data available for cementless prostheses. The diagnostic criteria for cementless prosthetic loosening differ from those for cemented prostheses, and the incidence of complications in patients with cemented total hip replacements is 1–2 times higher than that in patients with cementless total hip replacements [26–28]. Second, the study included patients who had undergone primary total hip arthroplasty. These patients typically exhibit a lower incidence of periprosthetic foreign body reactions, a more limited inflammatory extent, and a milder disease severity compared to those who have undergone revision surgeries or have been excluded due to infection. In contrast, several cases reported in the literature involve patients who have undergone revision surgeries [29]. Third, variations in surgical techniques, the materials and configurations of the prostheses, and the complexity of the patients' underlying conditions are significant determinants [11, 30].

Each of the aforementioned imaging parameters for diagnosing aseptic loosening of the acetabular cup possesses distinct diagnostic value. While certain parameters exhibit high diagnostic efficacy, others demonstrate lower sensitivity but higher specificity. For instance, the single parameter DHCD for diagnosing acetabular cup loosening is characterized by relatively lower sensitivity but higher specificity. Owing to the inherent interindividual variability among patients, reliance on a single diagnostic parameter may result in false-positive or false-negative findings. To enhance the diagnostic accuracy of aseptic loosening of the acetabular cup, a multiparametric approach is recommended. In this study, the combined imaging parameters for diagnosing acetabular cup loosening were established through statistical methods such as ROC curve analysis and logistic regression, and were defined by the simultaneous fulfillment of the following two conditions: [1] NTA ≥ 1; [2] AA ≥ 53.2° or DHCD ≥ 0.16 cm. The AUC values were 0.945 and 0.968, respectively, indicating superior diagnostic performance compared with single parameters. If the radiographic findings are consistent with the conclusions of this study, surgical intervention is recommended, as it is also commonly advised by clinicians. Delayed treatment may exacerbate loosening and complicate revision surgery. Nonetheless, in clinical practice, some patients with mild symptoms may choose to defer surgery due to financial constraints or personal preferences.

The combined imaging parameters for diagnosing aseptic loosening of the acetabular cup established in this study offer the following advantages compared to the diagnostic criteria reported in the literature. On the one hand, in this study, the established criteria do not require comparison of the current radiographs with the postoperative baseline or serial follow-up radiographs. In current diagnostic criteria, the diagnosis requires comparison with baseline radiographs taken after total hip arthroplasty and serial follow-up radiographs [31]. In the early stages of prosthesis loosening, both clinical and imaging manifestations are often inconspicuous [4, 32]. Schmalzried et al. reported that the diagnosis of prosthesis loosening is often established based on the presence of progressive widening of radiolucent zones in conjunction with hip pain [33]. In clinical practice, a significant limitation is the frequent absence of serial follow-up radiographs required for comparative analysis. Patients typically present to the hospital several years or more than a decade after hip replacement surgery, primarily due to persistent hip pain and discomfort. Additionally, most patients had undergone surgery at other institutions, and their preoperative radiographs were frequently unavailable. However, if previous radiographs of the patient are available, they should also be compared and analyzed. This is because individual differences exist among patients, and variations in surgical techniques and habits among surgeons mean that personalized diagnosis is more reliable. On the other hand, this method enables precise localization of prosthetic loosening, thereby minimizing the extent and duration of surgical incisions, and significantly enhances clinical decision-making.

Currently, cementless total hip arthroplasty is the predominant technique utilized in the field of total hip replacement. Consequently, this study focused on cementless total hip arthroplasty to provide an analysis. The diagnosis of prosthesis loosening after cemented total hip arthroplasty can be referred to the results of this study. In addition, many parameters in this study

require comparison with the contralateral side. Patients who have undergone bilateral total hip arthroplasty may exhibit greater complexity and variability than those with a normal contralateral hip, potentially leading to inaccurate parameter measurements. Therefore, this study selected patients with a normal contralateral hip. The criteria established in this study can also serve as a reference for diagnosing aseptic loosening in patients who have undergone bilateral total hip arthroplasty.

This study primarily utilized radiographs because they are currently the main imaging modality following total hip arthroplasty, free from metal artifacts and associated with relatively low radiation doses [34]. However, under certain circumstances, CT provide better visualization of periprosthetic low-density areas compared to X-rays. Aseptic loosening of the prosthesis needs to be differentiated from infection. X-rays have relatively low sensitivity and specificity, whereas CT and MRI offer better contrast and can reveal subtle structural changes, such as the presence of joint effusion, sinus tracts or lymph node enlargement, which aid in distinguishing between the two conditions [35]. Therefore, in numerous instances, especially when periprosthetic radiolucent zones are not obvious or when infection cannot be ruled out, CT and MRI should be performed to further clarify the diagnosis.

### Limitations

This study did not combine X-ray, CT and MRI images to construct a multi-parameter diagnosis model at the same time. In some cases within the loosening group, revision surgery was not performed. Instead, loosening was determined through a consensus discussion between clinicians and radiologists. However, absolute confirmation of loosening could not be achieved, which may introduce selection bias into the results. In this study, time was significantly different between the loosening group and the control group. The mean time was 8 years in the loosening group and 1 year in the control group. Asymptomatic patients rarely undergo imaging 8 years after total hip replacement, resulting in a limited sample size of control patients available for multi-year follow-up. This may have some impact on the results. However, according to the literature, there is no significant change in the imaging of asymptomatic patients after 1 year [10]. Therefore, the impact on the results is not significant. Moreover, the present study is limited by its small sample size and single-center design. Therefore, the generalizability of the diagnostic model requires further validation in a larger, multicenter cohort. Future investigations should aim to enhance the generalizability of our findings by expanding the study cohort and incorporating a more diverse range of clinical cases, including hemi-hip arthroplasty and cemented total hip arthroplasty. And this approach will facilitate improved diagnostic accuracy for prosthesis loosening and provide enhanced clinical utility.

## Conclusions

The combined imaging diagnostic criteria for acetabular cup loosening are defined as the simultaneous fulfillment of the following two conditions: [1] NTA ≥ 1; [2] AA ≥ 53.2° or DHCD ≥ 0.16 cm. Compared with the single diagnosis model, the combined parameters diagnosis in this study has higher diagnosis efficiency, and can be used as one of the effective means to diagnose the specific location of hip prosthesis loosening before operation.

#### Abbreviations

| | |
|---|---|
| THA | Total Hip Arthroplasty |
| AA | Acetabular Cup Inclination |
| DVD1 | Acetabular Difference in Vertical Distance 1 |
| DVD2 | Acetabular Difference in Vertical Distance 2 |
| DHD | Acetabular Difference in Horizontal Distance |
| TA | Wide Radiolucent Zones Around the Acetabular cup |
| NTA | Number of Wide Radiolucent Zones Around the Acetabular Cup |
| DHCD | Difference in Head-Cup Edge Distance |
| ROC | Receiver Operating Characteristic |
| AUC | The Area Under the Curve |
| PPV | Positive Predictive Value |
| NPV | Negative Predictive Value |

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#### Author contributions

A.H. and J.L. designed the research study and wrote the manuscript. Z.Z. participated in the data collection and analysis. Y.Z., C.L., L.C. participated in the data collection. J.L. provided experimental guidance during the study and revised the paper critically. All authors read and approved the final manuscript.

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#### Data availability

The data and materials are available from the medical records department of the Hebei Medical University Third Hospital. The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

#### Ethics approval and consent to participate

This material has not been published and is not under consideration elsewhere. This study is approved by the Medical Ethics Committee of the Hebei Medical University Third Hospital and receives the financial support (KS2025-023-1). All authors have confirmed that all methods were performed in accordance with the relevant guidelines and regulations. This study obtained the informed consent of all patients or their legal guardians, and all patients or their legal guardians agreed to participate in this study. This study adhered to the Declaration of Helsinki.

#### Consent for publication

Not Applicable.

#### Competing interests

The authors declare no competing interests.

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