Prediction of Collapse in Femoral Head Osteonecrosis: A Modified Kerboul Method with Use of Magnetic Resonance Images

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Background: The hypothesis that the combined necrotic angle measurement from magnetic resonance imaging scans predicts the subsequent risk of collapse in hips with femoral head necrosis was tested.

Methods: Thirty-seven hips with early stage osteonecrosis in thirty-three consecutive patients were investigated. With use of the modified method of Kerboul et al., we measured the arc of the femoral surface involved by necrosis on a midcoronal as well as a midsagittal magnetic resonance image (rather than an anteroposterior and a lateral radiograph) and then calculated the sum of the angles. On the basis of the magnitude of the resulting combined angle, hips were classified into four categories: grade 1 (<200°), grade 2 (200° to 249°), grade 3 (250° to 299°), and grade 4 (≥300°). After the initial evaluations, the hips were randomly assigned to a core decompression group or a nonoperative group. Patients underwent regular follow-up until femoral head collapse or for a minimum of five years.

Results: Seven grade-4 hips and sixteen grade-3 hips had development of femoral head collapse by thirty-six months. Six of the nine grade-2 hips and none of the five grade-1 hips collapsed (log-rank test, $p < 0.01$). None of the four hips with a combined necrotic angle of ≤190° (the low-risk group) collapsed, all twenty-five hips with a combined necrotic angle of ≥240° (the high-risk group) collapsed, and four (50%) of the eight hips with a combined necrotic angle between 190° and 240° (the moderate-risk group) collapsed during the study period.

Conclusions: The Kerboul combined necrotic angle, as ascertained with use of magnetic resonance imaging scans instead of radiographs, is a good method to assess future collapse in hips with femoral head osteonecrosis.

Level of Evidence: Prognostic Level I. See Instructions to Authors on jbjs.org for a complete description of levels of evidence.

Osteonecrosis of the femoral head is a debilitating disease that usually leads to degenerative arthritis of the hip. The collapse of the femoral head is affected by the location and extent of the necrotic lesion[1-5]. Various methods have been proposed to quantify or categorize the extent of osteonecrosis[6-16]. The ideal clinical evaluation method to determine the extent of necrosis should be simple and easy to use with regard to performing measurements, should be based on magnetic resonance imaging, and should evaluate necrotic extent in the coronal as well as the sagittal plane. It should also be reproducible within and between observers and should successfully predict the progression of early stage osteonecrosis.

In 1974, Kerboul et al. developed a simple and easy method of measuring the extent of necrosis in early stage osteonecrosis of the femoral head that involved measuring the arc of the femoral surface involved by necrosis on an anteroposterior as well as a lateral radiograph and then calculating the sum of the two angles[6].

Magnetic resonance images have been found to be more accurate than radiographs in evaluating the size of osteonecrotic lesions[17,18]. The extent of necrosis should be measured in the coronal as well as the sagittal plane because the measurement in the coronal plane alone is not accurate in quantifying the extent of necrosis or in predicting further collapse of the femoral head.

In the present study, the necrotic angles were measured on midcoronal and midsagittal magnetic resonance imaging scans instead of radiographs. The hypothesis tested was that the sum of the necrotic angles that had been measured on the initial magnetic resonance images would predict the subsequent risk of collapse of the femoral head.

Materials and Methods

Between June 1990 and June 1992, thirty-seven femoral heads in thirty-three consecutive patients who showed definite findings for osteonecrosis of the femoral head but no evidence of collapse on plain radiographs and/or magnetic resonance images[19] (Ficat stages I, IIA, and IIB[20]) were enrolled into this prospective study protocol. There were thirty-one men (thirty-four hips) and two women (three hips) with an average age of forty-seven years (range, eighteen to sixty-eight years). Associated conditions or factors for osteonecrosis included alcohol abuse in twenty-eight patients (thirty-one hips) and a history of high-dose corticosteroid use in three patients (four hips). The remaining two patients (two hips) had no identifiable risk factor. There were twenty-two hips with Ficat stage-I osteonecrosis, eleven with stage-IIA osteonecrosis, and four with stage-IIB osteonecrosis. The initial examination included clinical evaluation, radiographs, and magnetic resonance imaging scans.

The clinical evaluation was conducted according to the method of Merle d'Aubigné et al.[21]. The plain radiographs included standard anteroposterior and frog-leg lateral views.

Magnetic resonance imaging was then performed with either of two 1.0-tesla superconducting units (Magnetom; Siemens, Erlangen, Germany; or 100X, Shimadzu; Kyoto, Japan). T1-weighted spin-echo images (echo time = 15 to 20 msec, repetition time = 150 to 200 msec) and T2-weighted spin-echo images (echo time = 80 to 90 msec, repetition time = 2000 to 2500 msec) were acquired in the coronal and sagittal planes. Section thickness was 5 to 10 mm with no gap. Images were reconstructed with a 128 × 256 or 256 × 256 matrix. The excitation number ranged from one to four.

The extent of osteonecrosis was estimated by a modification of the combined necrotic angle method of Kerboul et al.[6]. The necrotic angle was measured on coronal and sagittal magnetic resonance imaging scans instead of anteroposterior and lateral radiographs. The midcoronal and midsagittal sections, which show the largest diameter of the femoral head, were used for the measurements. Magnified images of those scans, in which the femoral head diameter ranged from 25 to 35 mm, were acquired. These images showed the largest area of abnormal signal intensity within the femoral head. The arc of the necrotic portion on both the midcoronal and the midsagittal image (B) was measured, and the sum of the two angles was then calculated (Fig. 1).

In a pilot study for the reproducibility of this measurement, ten independent orthopaedic surgeons were asked to measure the combined necrotic angle from the same magnified images of an osteonecrotic femoral head. The coefficient of variation of estimation was 4.3%. Although the variability within observers was not quantified, it was expected to be less than that between observers.

On the basis of the magnitude of the combined necrotic angle, hips were classified into four categories: grade 1 (<200°), grade 2 (200° to 249°), grade 3 (250° to 299°), and grade 4 (≥300°).

After the initial evaluation, eighteen hips were randomized to core decompression with cancellous bone graft and the remaining nineteen hips were randomized to nonoperative management (the use of crutches and the intermittent use of analgesic medication). In the core-decompression group, ten hips were at stage I, seven were at stage IIA, and one was at stage IIB; in the nonoperative group, twelve hips were at stage I, four were at stage IIA, and three were at stage IIB.

The primary end point was collapse of the femoral head as demonstrated on plain radiographs. Patients were evaluated clinically and radiographically every three months for the first two years and every six months thereafter until the time of collapse or for a minimum of five years. Hips that did not collapse were recorded as such at the end of the study.

The selected baseline characteristics were compared with use of the Fisher exact test or the Kruskal-Wallis test (two-tailed; $\alpha = 0.05$). The Kaplan-Meier survival curve was drawn to estimate the survival time, which was defined as the time elapsed from the initial enrollment to the end point or to the end of follow-up. A log-rank test was applied to compare the survival distributions. With use of the Cox proportional-hazards model, we calculated the hazards ratios for grades 3 or 4 (combined necrotic angle ≥250°) compared with the baseline hazards for grades 1 or 2 (combined necrotic angle <250°) before and after adjusting for covariates, such as age, gender, stage of disease, and treatment group. All hips were assumed to be independent in the statistical analysis. The statistical

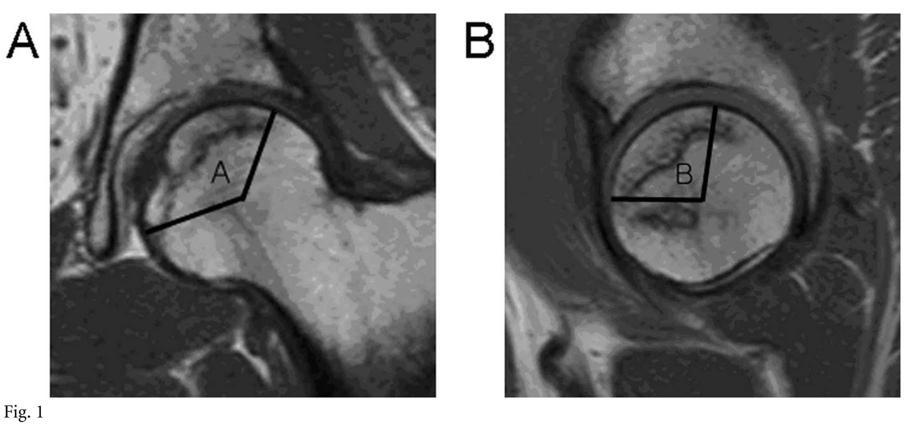

Fig. 1

The calculation of the combined necrotic angle from magnetic resonance imaging scans. A: The angle of necrotic area in the midcoronal image. B: The angle of necrotic area in the midsagittal image. The combined necrotic angle = A+B.

TABLE I Baseline Characteristics by the Categories of the Combined Necrotic Angle*

Baseline Characteristic	Grade 1 (N = 5)	Grade 2 (N = 9)	Grade 3 (N = 16)	Grade 4 (N = 7)	Total
Mean age *(yr)*	53 ± 7.8	36 ± 13.7	49 ± 11.5	49 ± 11.9	47 ± 12.9
Gender					
Male hips	5	6	16	7	34
Female hips	0	3	0	0	3
Associated risk factors					
Alcohol	5	5	15	6	31
Corticosteroid	0	3	0	1	4
Idiopathic	0	1	1	0	2
Ficat stage					
I	5	5	8	4	22
IIA	0	3	6	2	11
IIB	0	1	2	1	4
Hip pain at initial presentation					
Present	5	6	9	3	23
Absent	0	3	7	4	14
Treatment					
Nonoperative	4	6	6	3	19
Core decompression	1	3	10	4	18

*N = Number of hips. Grade 1 denotes hips with a combined necrotic angle of <200°; Grade 2, 200° to 249°; Grade 3, 250° to 299°; and grade 4, ≥300°. With use of the Fisher exact test or the Kruskal-Wallis test, there were no significant differences among the four groups in any of the selected characteristics.

analysis was performed with use of Statistical Package for the Social Sciences (SPSS) software (version 7.5 for Windows; SPSS, Chicago, Illinois).

Details of the study design, including the protocols for treatment and the earlier two to three-year follow-up results from the analysis that compared the effectiveness of core decompression and nonoperative management, have been reported previously[14,22]. All patients gave informed consent for participation, and the protocol was approved by our institutional review board.

Results

None of the baseline characteristics were different between the two treatment groups. Fourteen femoral heads in the core decompression group and fifteen in the nonoperative group collapsed within three to thirty-six months. Eight femoral heads, which did not collapse, had a duration of follow-up of five to eight years.

It has been reported in earlier studies that core decompression has a notable effect on the prevention of collapse and on clinical improvement in hips with osteonecrosis of the femoral head[13,20]. However, later studies have shown that core decompression has no greater value than nonoperative management in preventing collapse in hips with early stage osteonecrosis[22-26]. In the current study, the median time to failure was nine months in both the core-decompression group and the nonoperative group. By survival analysis, there was no significant difference in the time to collapse between the two groups (log-rank chi-square = 0.05, p = 0.83). Because of this finding of no difference in results, the two treatment groups did not undergo separate size-of-lesion assessments.

There were five grade-1 hips, nine grade-2 hips, sixteen grade-3 hips, and seven grade-4 hips. Table I shows the baseline characteristics of the four groups. Except for gender, there were no significant differences among the four groups in any selected

TABLE II Summary Statistics for the Survival Time to Collapse by Grade*

	Number of Hips		Time to Collapse *(mo)*		
Grade	Total	Collapsed	Median	Mean	Range
1	5	0	—	—	—
2	9	6	9.0	9.5	6 to 15
3	16	16	9.0	10.7	3 to 36
4	7	7	6.0	6.9	3 to 12
Overall	37	29	9.0	9.5	3 to 36

*Mean and median survival times were based on Kaplan-Meier estimates. Grade 1 denotes hips with a combined necrotic angle of <200°; Grade 2, 200° to 249°; Grade 3, 250° to 299°; and Grade 4, ≥300°. The overall total medium, mean, and range pertain to the twenty-nine collapsed femoral heads.

TABLE III Unadjusted and Adjusted Hazards Ratios Obtained with Use of Cox Proportional-Hazards Modeling by the Dichotomous Categories of the Combined Necrotic Angle*

Grade	Unadjusted Hazards Ratio	Unadjusted 95% Confidence Interval	P Value	Adjusted Hazards Ratio	Adjusted 95% Confidence Interval	P Value
1 or 2	1.0	—	—	1.0	—	—
3 or 4	4.6	1.8 to 11.7	0.00	8.2	2.5 to 26.9	0.00

*Grade 1 or 2 denotes hips with a combined necrotic angle of <250°, and Grade 3 or 4 denotes hips with a combined necrotic angle of ≥250°. The hazards ratio and the confidence interval were adjusted for age, gender, stage, and treatment group.

characteristics (age, etiologic factors, radiographic stage, symptoms of hip pain at initial presentation, and treatment).

Figure 2 shows the Kaplan-Meier survival curve by the combined necrotic angle, and Table II summarizes the survival time to collapse. None of five hips with grade-1 lesions collapsed though the end of the study (median follow-up period, seven years; range, five to eight years). Six of nine grade-2 hips collapsed within fifteen months (median time to collapse, nine months; range, six to fifteen months). All sixteen grade-3 hips collapsed by thirty-six months (median time to collapse, nine months; range, three to thirty-six months). All seven grade-4 hips collapsed by twelve months (median time to collapse, six months; range, three to twelve months). Survival distributions for the four groups were statistically signifi-

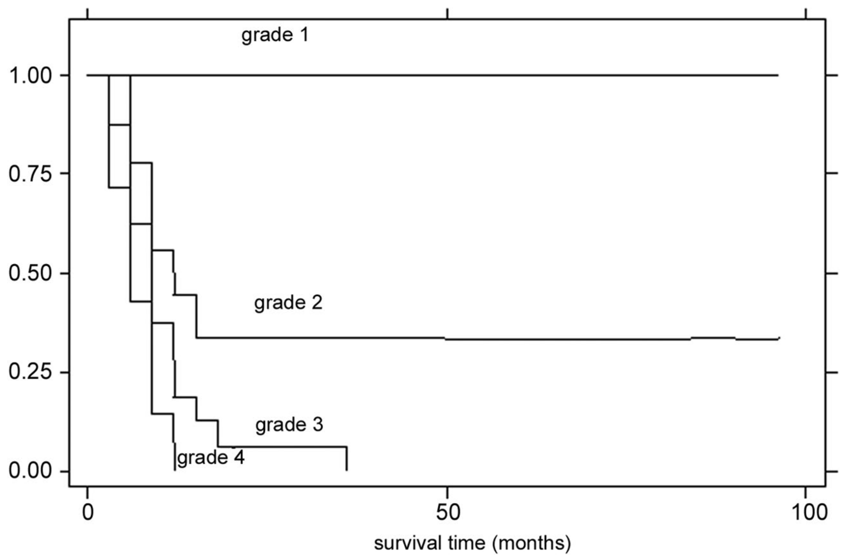

Fig. 2

Kaplan-Meier survival curve according to the categories of the combined necrotic angle, which were classified by a priori cut points. Grade 1 denotes hips with a combined necrotic angle of <200°, Grade 2 denotes hips with a combined necrotic angle between 200° and 249°, Grade 3 denotes hips with a combined necrotic angle between 250° and 299°, and Grade 4 denotes hips with a combined necrotic angle of ≥300°. Survival distributions for the four grades were significantly different by log-rank test ($p < 0.01$).

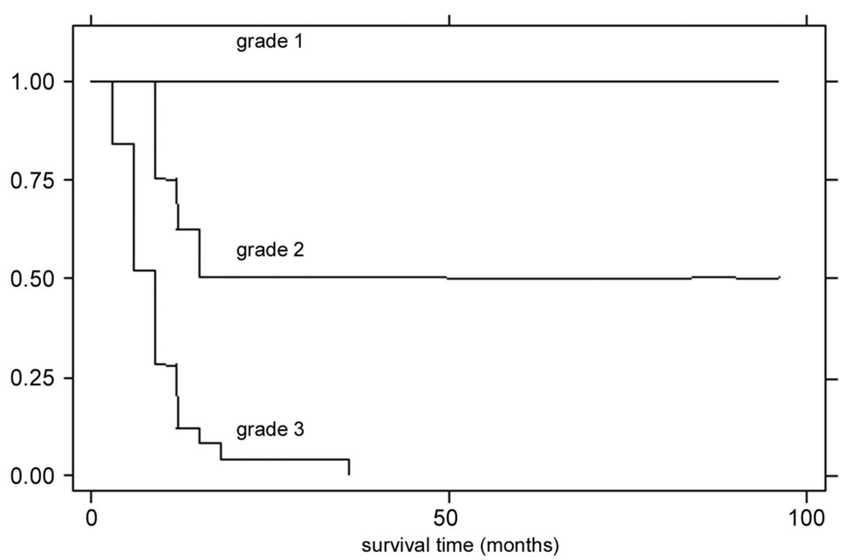

Fig. 3

Kaplan-Meier survival curve according to the categories of the combined necrotic angle, which were classified by retrospectively defined alternative cut points. Grade 1 denotes hips with a combined necrotic angle of ≤190°, grade 2 denotes hips with a combined necrotic angle between 191° and 239°, and grade 3 denotes hips with a combined necrotic angle of ≥240°. Survival distributions for three grades were significantly different by log-rank test ($p < 0.01$).

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The unadjusted hazards ratio for a combined necrotic angle that was ≥250° was 4.6 (95% confidence interval; 1.8 to 11.7) compared with the baseline hazards ratio for a combined necrotic angle that was <250°. The ratio was much larger (8.2; 95% confidence interval, 2.5 to 26.9) after adjusting for covariates such as age, gender, stage of disease, and treatment group with use of the Cox proportional-hazards model (Table III).

Various criteria of cut points were assessed retrospectively to find alternative cut points that might better differentiate hips with a better prognosis from those with a worse prognosis. None of four hips with a combined necrotic angle of ≤190° collapsed, all twenty-five hips with an angle of ≥240° collapsed, and four (50%) of eight hips with an angle between 190° and 240° collapsed during the study period (Fig. 3). This would suggest that hips with a combined necrotic angle of ≤190° belong to a low-risk group, that those with an angle between 190° and 240° are in a moderate-risk group, and that those with an angle of ≥240° are in a high-risk group.

Discussion

The extent of the necrotic lesion is an important risk factor for predicting collapse in femoral head osteonecrosis[1-16]. The Ficat and Arlet staging system that is currently often used for treatment decisions is based on the radiographic stage and clinical symptoms, without consideration of the extent of necrosis[20]. This study showed that the combined necrotic angle, as measured on magnetic resonance imaging scans according to the modified method of Kerboul et al.[6], is an important method to predict collapse in femoral head osteonecrosis.

To date, various methods to quantify or categorize the extent of osteonecrosis have been proposed[6-16]. An ideal evaluation method—one that would be most useful to clinicians—would need to meet several conditions. It should be simple and easy to use with regard to performing measurements. It should include the measurement of necrotic extent in the coronal as well as the sagittal plane because the measurement in one plane alone is not accurate for predicting further collapse of the femoral head. It should be reproducible within and between observers and should successfully predict the progression of early stage osteonecrosis. It should be based on magnetic resonance imaging rather than radiography because magnetic resonance imaging is more accurate in the evaluation of the extent of osteonecrosis and can provide a three-dimensional assessment of the extent of the lesion[17,18].

In 1974, Kerboul et al. developed a simple and easy-to-use method of combined necrotic angle measurement[6]. They measured the arc of the femoral surface involved by necrosis on both an anteroposterior and a lateral radiograph of the femoral head and then calculated the sum of the two angles. When the sum was ≥200°, the clinical outcome was worse than when the sum was <200°. In our study, midcoronal and midsagittal magnetic resonance imaging scans were used instead of anteroposterior and lateral radiographs, and the combined angles predicted the subsequent risk of collapse more successfully. In the current study, the combined necrotic angle for ten of fifteen hips with Ficat stages IIA and IIB could not be measured with use of the conventional Kerboul method because the necrotic margin was not evident in the subchondral area on the radiographs. In the remaining five hips, the combined necrotic angle differed by 1° to 58° (mean, 26°) between the measurements made from the radiographs and those made from the magnetic resonance images.

In 1984, Steinberg et al. developed staging systems for osteonecrosis on the basis of plain radiographic findings[7]. The major contribution of their classification was the addition of quantitation of femoral head involvement. The extent of head involvement with osteonecrosis was quantified by angular measurements of the arc of involvement from standard radiographs. In 1995, Steinberg et al. proposed a comprehensive quantitative system[13]. Hips affected with osteonecrosis were grouped into seven stages (0 to VI) and three grades (mild, moderate, and severe) for stages I to V. The merit of their method was the maximized utility of routine anteroposterior and lateral radiographs in the staging and grading of hips of stages II through V, and they have now incorporated magnetic resonance imaging into their system. However, the method was too complicated to be used by clinicians and the reproducibility of the method was not acceptable.

In 1991, Ohzono et al. introduced the concept of radiographic location of the lesion to correlate with prognosis. The findings on anteroposterior radiographs were used to classify the lesions into three categories[8]. Type-A lesions occupied the medial one-third or less of the weight-bearing portion of the femoral head and rarely progressed. Type-B lesions occupied the medial two-thirds or less of the weight-bearing portion and had a prognosis of intermediate severity. Type-C lesions occupied more than the medial two-thirds of the weight-bearing portion and had the worst prognosis. In 1994, Sugano et al. used coronal magnetic resonance imaging scans instead of anteroposterior radiographs[12]. This system was based on coronal-plane images and described the location of the lesion. However, measurement in the coronal plane alone was not accurate to quantify the necrosis.

In 1993, Lafforgue et al. measured three quantitative parameters on contiguous magnetic resonance imaging sections, corresponding to the 2-cm-wide medial portion of the femoral head: the angle filled by the osteonecrosis, the percentage of weight-bearing femoral cortex involved with osteonecrosis, and the percentage of the femoral head surface involved with osteonecrosis[10]. The values were strikingly lower in the group with good clinical or radiographic outcomes compared with those with poor outcomes and appeared to be accurate for use in the prediction of the outcome of osteonecrosis. However, this method was rather complicated for clinical application.

In 1995, Koo and Kim estimated the extent of osteonecrosis as determined from a combination of coronal and sagittal magnetic resonance imaging scans[14]. The arc of the necrotic portion in the midcoronal image (A) and that in the midsagittal image (B) were used to quantify the extent of necrosis by the formula: $(A/180) \times (B/180) \times 100$. There was a strong correlation between this index and the risk of collapse, and the index was a major predictor of future collapse. However, to obtain the index, a conversion table or a calculator was necessary.

The combined necrotic angle of the current study can be calculated in a simple, easy-to-use, and reproducible manner. It is based on biplanar magnetic resonance imaging scans and provides a three-dimensional assessment of the extent of the necrosis. The categorization of femoral head osteonecrosis according to the combined necrotic angle measurement from midcoronal and midsagittal magnetic resonance imaging scans may accurately predict the risk of subsequent collapse of the femoral head. We believe that studies of the effectiveness of any surgical treatment to prevent collapse should be limited to hips in the moderate and high-risk groups because surgical intervention in the low-risk group may be hard to justify. Further studies concerning the reliability of this method are required. ■

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References

1. Bonfiglio M, Bardenstein MB. Treatment by bone-grafting of aseptic necrosis of the femoral head and non-union of the femoral neck (Phemister technique). J Bone Joint Surg Am. 1958;40:1329-46.

2. Sugioka Y, Katsuki I, Hotokebuchi T. Transtrochanteric rotational osteotomy of the femoral head for the treatment of osteonecrosis. Follow-up statistics. Clin Orthop Relat Res. 1982;169:115-26.

3. Bassett LW, Gold RH, Reicher M, Bennett LR, Tooke SM. Magnetic resonance imaging in the early diagnosis of ischemic necrosis of the femoral head. Preliminary results. Clin Orthop Relat Res. 1987:214:237-48.

4. Beltran J, Knight CT, Zuelzer WA, Morgan JP, Shwendeman LJ, Chandnani VP, Mosure JC, Shaffer PB. Core decompression for avascular necrosis of the femoral head: correlation between long-term results and preoperative MR staging. Radiology. 1990;175:533-6.

5. Mont MA, Jones LC, Pacheco I, Hungerford DS. Radiographic predictors of outcome of core decompression for hips with osteonecrosis stage III. Clin Orthop Relat Res. 1998;354:159-68.

6. Kerboul M, Thomine J, Postel M, Merle d'Aubigné R. The conservative surgical treatment of idiopathic aseptic necrosis of the femoral head. J Bone Joint Surg Br. 1974;56:291-6.

7. Steinberg ME, Brighton CT, Steinberg DR, Tooze SE, Hayken GD. Treatment of avascular necrosis of the femoral head by combination of bone grafting, decompression and electrical stimulation. Clin Orthop Relat Res. 1984;186:137-53.

8. Ohzono K, Saito M, Takaoka K, Ono K, Saito S, Nishina T, Kadowaki T. Natural history of nontraumatic avascular necrosis of the femoral head. J Bone Joint Surg Br. 1991;73:68-72.

9. Takatori Y, Kokubo T, Ninomiya S, Nakamura S, Morimoto S, Kusaba I. Avascular necrosis of the femoral head. Natural history and magnetic resonance imaging. J Bone Joint Surg Br. 1993;75:217-21.

10. Lafforgue P, Dahan E, Chagnaud C, Schiano A, Kasbarian M, Acquaviva PC. Early-stage avascular necrosis of the femoral head: MR imaging for prognosis in 31 cases with at least 2 years of follow-up. Radiology. 1993;187:199-204.

11. Shimizu K, Moriya H, Akita T, Sakamoto M, Suguro T. Prediction of collapse with magnetic resonance imaging of avascular necrosis of the femoral head. J Bone Joint Surg Am. 1994;76:215-23.

12. Sugano N, Takaoka K, Ohzono K, Matsui M, Masuhara K, Ono K. Prognostication of nontraumatic avascular necrosis of the femoral head. Significance of location and size of the necrotic lesion. Clin Orthop Relat Res. 1994;303:155-64.

13. Steinberg ME, Hayken GD, Steinberg DR. A quantitative system for staging avascular necrosis. J Bone Joint Surg Br. 1995;77:34-41.

14. Koo KH, Kim R. Quantifying the extent of osteonecrosis of the femoral head. A new method using MRI. J Bone Joint Surg Br. 1995;77:875-80.

15. Kim YM, Ahn JH, Kang HS, Kim HJ. Estimation of the extent of osteonecrosis of the femoral head using MRI. J Bone Joint Surg Br. 1998;80:954-8.

16. Cherian SF, Laorr A, Saleh KJ, Kuskowski MA, Bailey RF, Cheng EY. Quantifying the extent of femoral head involvement in osteonecrosis. J Bone Joint Surg Am. 2003;85:309-15.

17. Gillespy T 3rd, Genant HK, Helms CA. Magnetic resonance imaging of osteonecrosis. Radiol Clin North Am. 1986;24:193-208.

18. Glickstein MF, Burk DL Jr, Schiebler ML. Avascular necrosis versus other diseases of the hip: sensitivity of MR imaging. Radiology. 1988;169:213-5.

19. Totty WG, Murphy WA, Ganz WI, Kumar B, Daum WJ, Siegel BA. Magnetic resonance imaging of the normal and ischemic femoral head. AJR Am J Roentgenol. 1984;143:1273-80.

20. Ficat RP. Idiopathic bone necrosis of the femoral head. Early diagnosis and treatment. J Bone Joint Surg Br. 1985;67:3-9.

21. Merle d'Aubigné R, Postel M, Mazabraud A, Massias P, Gueguen J, France P. Idiopathic necrosis of the femoral head in adults. J Bone Joint Surg Br. 1965; 47:612-33.

22. Koo KH, Kim R, Ko GH, Song HR, Jeong ST, Cho SH. Preventing collapse in early osteonecrosis of the femoral head. A randomised clinical trial of core decompression. J Bone Joint Surg Br. 1995;77:870-4.

23. Camp JF, Colwell CW Jr. Core decompression of the femoral head for osteonecrosis. J Bone Joint Surg Am. 1986;68:1313-9.

24. Hopson CN, Siverhus SW. Ischemic necrosis of the femoral head. Treatment by core decompression. J Bone Joint Surg Am. 1988;70:1048-51.

25. Learmonth ID, Maloon S, Dall G. Core decompression for early atraumatic osteonecrosis of the femoral head. J Bone Joint Surg Br. 1990;72:387-90.

26. Warner JJ, Philip JH, Brodsky GL, Thornhill TS. Studies of nontraumatic osteonecrosis. The role of core decompression in the treatment of nontraumatic osteonecrosis of the femoral head. Clin Orthop Relat Res. 1987;225:104-27.