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ORIGINAL PAPER

Lesion size measurement in femoral head necrosis

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Abstract

Background Management of patients with early stages of osteonecrosis of the femoral head remains controversial. Uniform use of an effective method of evaluation and classification, including both stage and lesion size, would allow for comparison and would significantly improve treatment of patients. There is no consensus on how best to determine lesion size. The purpose of this study was to evaluate and compare accuracy and ease of use of different techniques for determining the size of femoral head lesions.

Methods Twenty-five hips with stages I or II osteonecrosis were evaluated with radiographs and MRI. 3-D MRI measurements of lesion size were used as the standard against which to compare visual estimates and angular measurements: necrotic angle of Kerboul, index of necrosis, and adjusted index of necrosis.

Results 3-D measurements (necrotic volume) showed regular progression from 2.2 to 59.2% of the femoral head. There was a rough correlation with angular measurements; index of necrosis was closer than the necrotic angle. Visual estimates from serial MRI images were as accurate as angular measurements.

Conclusions Simple visual estimates of lesion size from serial MRI images are reasonably accurate and are satisfactory for clinical use. Angular measurements provide some indication of prognosis and treatment; however, they have limited accuracy, with considerable variability between techniques. 3-D MRI volumetric measurements are the most accurate. Using current techniques and software, they are easier to use, requiring similar time and effort to angular measurements. They should be considered for clinical research and publications when the most accurate measurements are required.

Keywords Necrotic angle of Kerboul · Index of necrosis · Adjusted index of necrosis · Femoral head · Osteonecrosis · Classification · MRI

Introduction

The optimum treatment for patients with early stages of osteonecrosis of the femoral head (ONFH) remains elusive. Prior to collapse, our goal is to preserve, not replace, the femoral head. Several methods of management have been described, but none is completely satisfactory, and it is difficult to evaluate their relative effectiveness. The routine use of a comprehensive method of evaluation and classification would improve our ability to compare different methods of treatment and to determine how best to manage a patient with ONFH. Several classification systems have been described, and the essential factors to consider have been established. The importance of indicating not only the stage but also the size of the necrotic lesion has been documented. However, we do not yet have a consensus on how best to determine lesion size [1–12].

The purpose of the present study was to evaluate and compare the accuracy and ease of use of different techniques for determining the size of the necrotic lesion. "Lesion size" refers to the necrotic region within the femoral head. Determining the extent of head and joint involvement, seen in later stages of ONFH, is also essential. However, this has been discussed in previous publications, is less controversial, and is included in most comprehensive classifications (Fig. 1); it is beyond the scope of this study.

Hips with stages I or II ONFH were evaluated retrospectively with plain radiographs and magnetic resonance imaging (MRI). 3-D MRI volumetric measurements of lesion size were used as the standard against which to compare visual estimates

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UNIVERSITY OF PENNYSLVANIA CLASSIFICATION OF OSTEONECROSIS

STAGE	CRITERIA	
I	**Normal radiograph; Abnormal bone scan and/or MRI ***	
	A – Mild	(<15% of head affected)
	B – Moderate	(15% to 30%)
	C – Severe	(>30%)
II	**Lucent and Sclerotic Changes in Femoral Head ***	
	A – Mild	(< 15%)
	B – Moderate	(15% to 30%)
	C – Severe	(> 30%)
III	**Subchondral Collapse (Crescent Sign) Without Flattening**	
	A – Mild	(<15% of articular surface)
	B – Moderate	(15% to 30%)
	C – Severe	(> 30%)
IV	**Flattening of Femoral Head**	
	A – Mild	(<15% of surface and <2 mm depression)
	B – Moderate	(15% to 30% of surface or 2 to 4 mm depression)
	C – Severe	(>30% of surface or >4 mm depression)
V	**Joint Narrowing and/or Acetabular Changes**	
	A – Mild B – Moderate C – Severe	Average of femoral head involvement as determined in Stage IV, and estimated acetabular involvement

*Lesion size determined by:

- Simple visual estimate
- Angular measurements
- 3-D MRI measurements

Fig. 1 University of Pennsylvania Classification of Osteonecrosis. It has been simplified from previous versions by combining stage 0 with stage I and stage VI with stage V

of size and angular measurements [3, 4, 12–16]. These included necrotic angle of Kerboul, index of necrosis, and adjusted index of necrosis [1, 2, 5, 6, 12]. Measurements and estimates of lesion size were compared graphically and in tabular form. The primary outcome measures were the accuracy of visual estimates and angular measurements compared to 3-D MRI determination of the size of the necrotic region (necrotic volume).

Materials and methods

Twenty-five hips with stage I or II ONFH as determined by plain radiographs and MRI were included in this study. All images were reviewed retrospectively by two observers: a musculoskeletal radiology fellow (SCO) and a senior orthopaedic surgeon with a special interest in ONFH (MES).

AP and lateral radiographs were viewed initially, and a visual estimate of the stage and size of the necrotic lesion was made using the University of Pennsylvania Classification. Hips were placed into stages I and II, and then into three grade levels based upon the size of the necrotic lesion, expressed as a percent of the femoral head involved (Fig. 1).

MRI was performed on various 1.5-Tesla systems (Siemens, Germany) using a body matrix coil and 8 standardized sequences in axial, coronal, and sagittal planes. Coronal T1-weighted images (5-mm slice thickness), and coronal, axial, and sagittal fat-saturated proton density sequences (3-mm slice thickness) were used for analysis. Six to 11 images were evaluated for each femoral head. Each observer made a visual estimate of stage and lesion size. The entire femoral head and the necrotic region in each coronal image were then outlined manually, and the areas of each were calculated automatically by standard measurement tools available in CENTRICITY®, the General Electric version of our Picture and Archiving Communications System (PACS) (Fig. 2). The three-dimensional (3-D) measurement of lesion size or volume for each hip was determined by taking the sum of the necrotic areas on each coronal MRI section and dividing it by the sum of the areas of the entire femoral head. This represented the 3-D size of the necrotic region, expressed as a percentage of the entire femoral head [1, 2, 4, 10–16]. This was used as the standard against which to compare the visual estimates and angular measurements and will be referred to as the necrotic volume.

The coronal and sagittal images which included the maximum areas of necrosis were identified from the previous measurements and were used to determine the angle subtended by the necrotic segment as described by Koo et al. [6] and Cherian et al [1]. The margins of the lesion were marked manually, and the resulting angle measured using PACS software (Fig. 3). These measurements were used to calculate the necrotic angle of Kerboul [2, 5] and index of necrosis (index of necrotic extent) [1, 6]. Necrotic angle is derived by taking the sum of the angles measured in the coronal and sagittal planes. Index of necrosis is calculated using the following formula: $(X+Y)\times 100/180$, where "X" is the angle in the coronal projection and "Y" is the angle in the sagittal projection. We also calculated an adjusted index of necrosis using 250° rather than 180° as the denominator. This more closely represented the true angular measurement of the anatomic femoral head and gave a more accurate indication of lesion size when compared to necrotic volume. Lesion size determinations made using each of these techniques were compared directly to each other in graphic and tabular form.

Results

The estimated and measured values for the size of necrotic lesions in each of the 25 femoral heads are shown in Table 1. A graphic comparison of the two angular measurements to the necrotic volume is shown in Fig. 4. This volumetric measurement is currently considered the most accurate method of determining lesion size and was used as a standard against which to evaluate the other techniques. It showed a steady and regular progression in the percent of necrosis from 2.2 to 59.2% of the entire femoral head. Values for adjusted index of necrosis and Kerboul-combined necrotic angle were plotted on the graph opposite the necrotic volume for each hip. They, too, showed a general progression in size, but were considerably more variable and larger than the necrotic volume. This was especially true of the necrotic angle. Note that values for the adjusted index of necrosis are shown here, rather than for the standard index of necrosis as described in earlier publications. By relating the necrotic region to a head measurement of 250° rather than to 180°, the accuracy of the index was improved considerably. As shown in Table 2, the values for the original index ranged from 8.6 to 137.6%, whereas values for the adjusted index ranged from 4.4 to 66.0%, and were much closer to the necrotic volume. A rough correlation between necrotic volume using grades A, B, or C, and adjusted index of necrosis and combined necrotic angle, was possible for the 25 hips by setting specific limits for the angular measurements (Table 3). Correlation was seen in 76%. This may prove useful to relate studies where angular measurements are used to those where the percent of necrosis is used to indicate lesion size.

A comparison between the visual estimates of the lesion size made from serial MRI sections and measurements of the necrotic volume is shown in Table 4. Correlation between these two techniques occurred for all small and large lesions, and for five of ten moderate-sized lesions. The overall correlation by grade was 80% (20/25 hips). In 5/25 hips, the estimated size differed from the measured size by one grade (20%). This was similar to the correlation between angular measurements and necrotic volume, and simple visual estimates were easier to make.

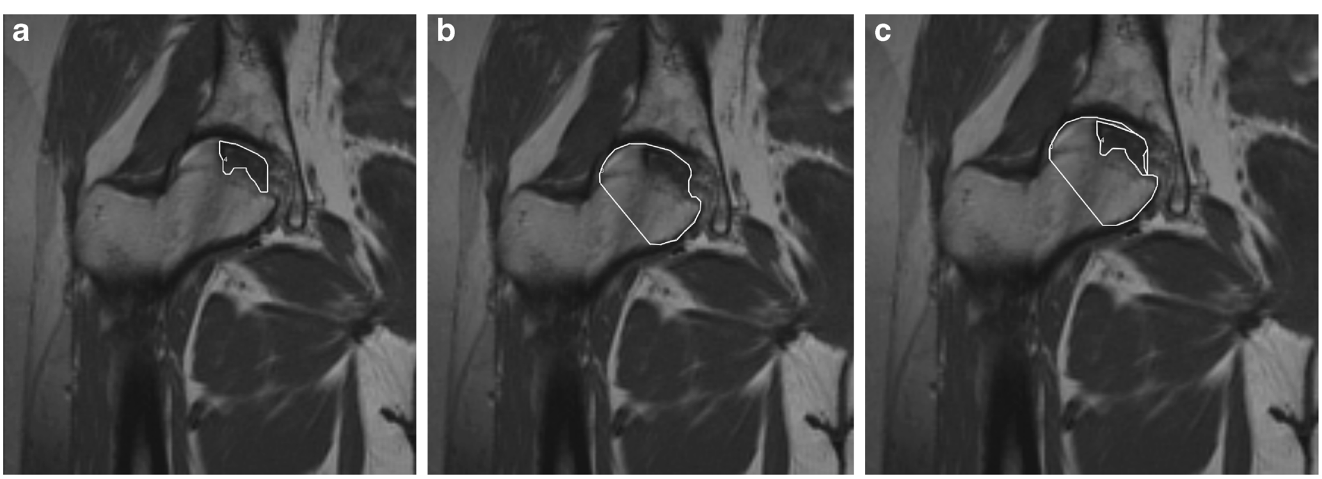

Fig. 2 Coronal T1-weighted MRI images of a hip with osteonecrosis, as used for 3-D volumetric measurements. **a** Outline of the necrotic region. **b** Outline of the entire femoral head. **c** Outline of necrotic region within femoral head (**a** and **b** combined)

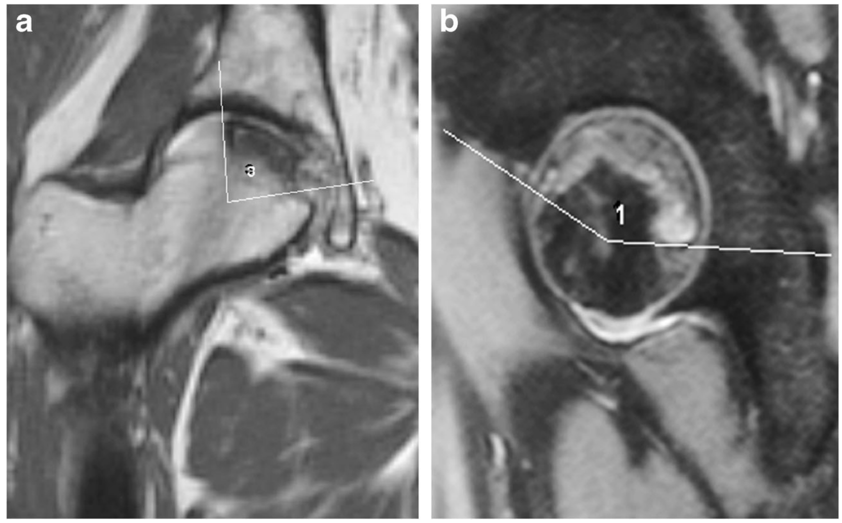

Fig. 3 MRI of the same hip shown in Fig. 2, as used for angular measurements. **a** Coronal T1-weighted image. **b** Sagittal fat-saturated T2-weighted image

Discussion

The importance of determining size of the necrotic lesion, as well as stage of involvement, in evaluating and treating patients with ONFH has been established [1, 2, 5–9, 11, 16, 17]. There has been a steady trend away from the older, non-quantitative classification systems towards the use of comprehensive classifications which include a specific indication of lesion size. Several methods for determining the size of the necrotic region have been described, and most do demonstrate

Table 1 Lesion size in 25 hips with ONFH

Ranking	Grade-estimated	Grade-measured	Necrotic volume %	Necrotic angle of Kerboul °	Adjusted index of necrosis
1	A	A	2.1	106	4.4
2	A	A	5.3	–	–
3	A	A	7.7	243	23
4	A	A	7.9	213	18
5	A	A	9.1	109	4.7
6	A	A	9.9	204	14
7	A	A	12.7	312	38
8	A	A	14	238	21
9	B	B	15.2	271	25
10	A	B	17	272	29
11	A	B	19.2	146	8
12	B	B	22	328	42
13	C	B	22.4	447	62
14	C	B	22.8	306	22
15	C	B	24.8	224	22
16	B	B	26.2	278	27
17	B	B	26.3	260	43
18	B	B	26.8	423	65
19	C	C	34.3	348	48
20	C	C	34.5	295	31
21	C	C	36.5	359	52
22	C	C	37.3	354	49
23	C	C	46.6	336	45
24	C	C	46	410	65
25	C	C	59.2	404	66

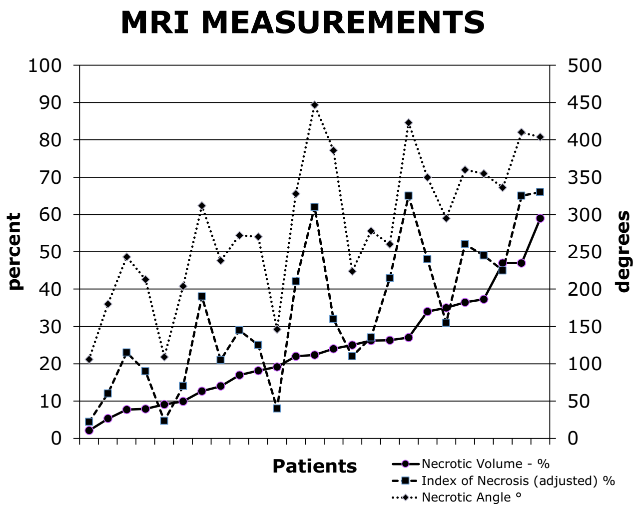

Fig. 4 Comparison of MRI measurements of femoral head involvement

a relationship between size and outcome. However, there is no consensus as to which specific technique is best, and they vary in how measurements are made and evaluated.

Previous studies have attempted to evaluate different methods of determining lesion size by examining their ability to predict prognosis and outcome after treatment [1–3, 5, 6]. Although this is important, this approach must consider the many variables, in addition to lesion size, which affect outcome and thus limit its accuracy and value. The present study evaluated different techniques directly by determining their accuracy in measuring the actual size of the necrotic region as compared to 3-D volumetric MRI measurements, which are currently considered the most accurate method for measuring lesion size in ONFH and the standard for measurements of this type [1, 3, 4, 10–16]. The information obtained can then be used to select the appropriate measurement technique for a given situation.

In this study, four commonly used techniques for estimating or measuring lesion size have been evaluated. 3-D volumetric measurements (necrotic volume) have previously been validated; their use in ONFH was first described in the 1980s, but initially, there was a concern that this technique was too complex for routine clinical use [1, 2, 10–12]. Since then, several advances in imaging techniques and software have allowed measurements to now be made directly by certain software programs. In the present study, they were found to require similar time and effort to the angular measurements described. This finding, in addition to the superior accuracy of the 3-D measurements, supports their use in situations where accurate measurements are needed for clinical research and publications.

Angular measurements have been considered more accurate than visual estimates, yet less complex than 3-D volume measurements. The combined necrotic angle, described by Kerboul et al. [5] was used initially to evaluate plain radiographs and was later adapted by Ha et al. for use with MRI [2]. It produced values for lesion size which were greater and more variable than the necrotic volume; it was less accurate than the other techniques evaluated. It also gave measurements in degrees, which made it difficult to relate to other techniques, most of which expressed lesion size as a percentage of the femoral head. Measurements of the necrotic angle of Kerboul would, therefore, appear as the least preferred of the angular measurements evaluated.

The index of necrosis, described by Koo et al. [6], and the modified index of necrosis, described by Cherian et al [1], calculated the percentage of femoral head involvement based on an assumed angle of 180° for the head. Since the anatomical femoral head occupies approximately 250°, these calculations routinely overestimated the actual percentage of necrosis. By using 250° rather than 180°, as we propose, these calculations were much closer to the actual necrotic volume, and are referred to here as the adjusted index of necrosis. This appears to be the most accurate of the angular measurements evaluated. However, considerable variability did occur for some hips, depending upon the size and shape of the necrotic lesion.

Table 3 Correlation between angular and volumetric measurements

3-D volume measurement (necrotic volume)	Adjusted index of necrosis*	Necrotic angle of Kerboul*
"A"—SMALL (< 15%)	< 25%	< 250°
"B"—MEDIUM (15–30%)	25–45%	250–335°
"C"—LARGE (> 30%)	> 45%	> 335°

*Correlation in 19 of 25 cases (76%). Variation in 1 grade in 6 of 25 cases (24%). [see text for more details]

Table 2 Range of values for four methods of determining lesion size

	Smallest value	Largest value
Necrotic volume	2.19%	59.20%
Adjusted index of necrosis	4.40%	66.00%
Original index of necrosis	8.60%	137.60%
Necrotic angle of Kerboul	106°	447°

Table 4 Comparison of estimated to measured lesion size on MRI

Lesion	Measured	Estimated
"A" < 15%	8	8
"B" = 15–30%	10	5
"C" > 30%	7	7

In previous studies, angular measurements of lesion size have demonstrated a rough correlation with prognosis and outcome after treatment, and have been of clinical value [1, 2, 5, 6]. However, two-dimensional angular measurements cannot accurately measure the true size of an irregular, 3-D lesion, as previous publications and the present study confirmed [1, 3, 6, 16, 18]. They are only estimates of lesion size, and the various techniques employed are not equally accurate. However, for those who choose to use these angular measurements, we have derived a preliminary set of values based upon the 25 hips studied which allow them to be roughly correlated with the 3-D volumetric measurement (Table 3), and incorporated into a comprehensive classification of osteonecrosis (Fig. 1).

Prior to the availability of MRI, plain radiographs were the primary method of determining stage and extent of ONFH. They continue to play an important role. X-ray and MRI visualize various components of the necrotic lesion differently; radiographs have inferior sensitivity in detecting very early or small lesions compared with MRI. They cannot be used to determine lesion size in stage I, but they are useful in stage II and beyond, where they often reveal the extent of femoral head and joint involvement better than MRI. Previous studies have shown their value in determining prognosis and outcome [2, 5, 7, 11, 12, 17–20].

Visual estimates of lesion size made from serial MRI images are the simplest of the MRI techniques studied, but their accuracy has been questioned. In this study, these visual estimates were compared to 3-D volumetric measurements using grades A, B, and C to indicate small, medium, and large lesions, respectively (Fig. 1). In 20 of 25 hips, the same grade was determined by both techniques. In the remaining five hips, they differed by only one grade (Table 4). The accuracy of these visual estimates was comparable to that of the angular measurements; visual estimates were considerably easier to make. They may, therefore, be valuable for routine clinical use.

The importance of including lesion size into a comprehensive classification, rather than using it as an independent measurement, has been emphasized [8–12, 21, 22]. Although the non-quantitative Ficat and Arlet classification remains popular, classifications which include both size and stage are being used with increasing frequency. Of these, the most often cited were those of the University of Pennsylvania and ARCO, which are quite similar [9, 11, 12, 19–22]. We have, therefore, used this classification as a point of reference for this study. It has been simplified by combining stage 0 with stage I and stage VI with stage V (Fig. 1).

The primary limitations of this study are related to the basic pathophysiology of ONFH. The margins of the lesion are often irregular and indistinct, and varying imaging techniques may give different results. Precise measurements are, therefore, difficult. Although modern imaging technology and software can automatically make many of the important measurements and calculations, they cannot routinely determine the margins of the lesion with accuracy. This must be done by the examiner, introducing an element of subjectivity. However, the reproducibility and clinical usefulness of these various measurement techniques have been established [1, 3, 11, 13–15].

Only hips with stage I and II ONFH, before femoral head collapse, were included in this study, since lesion size can be most accurately measured in the intact femoral head. In clinical practice, size measurements should also be included when evaluating patients with later stages of ON.

This study has evaluated the more popular techniques for measuring lesion size in ONFH to determine both their accuracy and their ease of use. It has concluded that simple visual estimates of size based on MRI studies are reasonably accurate and satisfactory for clinical use. If MRI studies are not available, good-quality plain radiographs may also be of value, although they are less accurate in determining lesion size and are not useful in stage I. Angular measurements have been used by other investigators and do provide some indication of prognosis and treatment. They have been considered more accurate than visual estimates, yet simpler to use than 3-D MRI measurements of lesion size. This study does not support these assumptions. Their accuracy is limited and variable; they are estimates rather than true measurements of lesion size, and not all angular measurements are equal. If used, they should be part of a comprehensive system of classification and should not stand alone as independent measurements. A preliminary set of limits has been provided in this study by which these angular measurements can be roughly correlated with 3-D measurements of lesion size, and thereby incorporated into a comprehensive classification. 3-D volumetric MRI measurements, currently the most accurate method of measuring lesion size, were used as a standard against which to compare the other techniques described. With modern imaging technology and tools for analysis, they are now easier to use and should be considered for clinical research and publications. With continuing advances in the treatment of osteonecrosis, it is important that the most accurate measurement techniques available be used to evaluate their effectiveness and compare them to other methods of management.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval These studies were approved by the Institutional Review Board of the University of Pennsylvania.

Informed consent For this type of study, formal consent was not required.

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