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A CLASSIFICATION SCHEMA FOR OSTEONECROSIS BASED ON MRI QUANTITATIVE MEASUREMENTS

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Summary

A new classification schema for femoral head necrosis, based on the size, location and topographical distribution of the necrotic lesion is presented. The classification schema includes five stages and it is in general more flexible and easily understood than previous ones. In 128 affected hips the size and location of the lesion were estimated using a new volumetric description based on special processing of magnetic resonance imaging slices. Results of the study show that the lesion is in general located towards the superior, medial and anterior areas of the femoral head. The follow-up study shows that hips that collapsed and had to undergo total hip replacement had large lesion that extended beyond the lip of the acetabulum.

Key words: Staging for femoral head necrosis, osteonecrosis quantification.

1. Introduction

Femoral head necrosis is a potentially disabling disease of the hip. It is the result of interruption of the blood supply of the femoral head, but its true pathogenesis is not well understood. Osteonecrosis often shows rapid progression and results to collapse of the articular surface. Staging of osteonecrosis is very important for the selection of the appropriate management, because there are different treatment options for early and late stages of the disease. Staging is also important for the prognosis of the disease progress and the evaluation of the treatment outcome. The use of a commonly accepted method of staging allows the comparison of different treatments and establishes a common tool for reference and comparison of outcome among physicians.

The first classification system for staging osteonecrosis was introduced by Marcus and Enneking in 1973 [15]. The system consists of 6 stages and it was based on clinical symptoms and radiographic findings. The system proposed by Ficat and Arlet [4] is one of the most widely used, also based on clinical features and radiographic findings. It consists of 5 stages plus one transition stage from pre-collapsed to post-collapsed femoral head. Kay *et al.* [9] have shown that there is a high degree of inter- and intraobserver variability in staging osteonecrosis using the Ficat classification system. They claim that plain radiographs alone are inadequate for evaluation and prognosis of femoral head osteonecrosis.

The Japanese Classification Committee presented a classification system where lesions are classified in three types according to the apperance of the lesions in antero-posterior (AP) radiographs (Ohzono *et al.* - [19]). The classification is based on the size and location of the lesion in the femoral head in relation to the weight-bearing surface of the acetabulum. This system is used "in parallel" with the Ficat-Arlet system. Sugano *et al.* [29] presented the Japanese Investigation Committee Classification system. Moreover, they measured the size of the lesion in AP and lateral radiographs and tried to correlate the lesion size with the likelihood for collapse (prognosis).

Kerboul *et al.* [10] evaluating the effectiveness of intertrochanteric osteotomy and "adjusted cup" arthroplasty in the treatment of femoral head necrosis, realized the necessity to assess the arc of the surface involved as measured in AP and lateral radiographs. The sum of the two angles is an indicator of the severity of the case. The position of the lesion (in relation to the weight-bearing area) and the size of the lesion influence the final result. Herring *et al.* [6] introduced a method for the classification of Legg-Calve-Perthes disease using AP radiographs. In his classification based on the measurement of collapse of the lateral pillar of the femoral head, pointing out the importance of the extent of the lesion in relation to the size of the acetabulum.

All these early classification systems use radiographs only and they do not utilise more advanced imaging techniques and especially magnetic resonance imaging (MRI). Some researchers compared the findings of MRI with those of radiographs, bone scan, clinical findings and even intraosseous pressure measurement [8, 17, 20, 30]. Their studies agree that MRI is the most suitable technique for early detection of osteonecrosis. Another major advantage of MRI is that it can reveal important characteristics of the necrotic lesion such as volume and location.

Beltran *et al.* [2] found out that the development of collapse after core decompression is related to the extent of the necrosis rather than the radiographic stage. They tried to estimate the percentage of the lesion (abnormal sign) on a combination of axial and coronal MRI sections. They selected those sections with the largest lesion to perform the estimation. Sakai *et al.* [21] used an analogous method for the evaluation of the size and location of osteonecrosis of the femoral condyle. They used the mid-coronal and the mid-sagittal sections.

As MRI becomes more commonly used, new systems and techniques for the classification and evaluation of femoral head osteonecrosis appear. Steingerg *et al.* [25, 26] presented a system for the staging of femoral head necrosis. The system uses MRI and bone scans for the early stages in addition to clinical symptoms and plain radiographs. The system attempts to quantify the lesion and some of the stages are divided in substages (mild, moderate, severe) according to the extent of the lesion. The main problem with the system presented by Steinberg is that it is complicated, with many stages and substages, so it is not easy to use it in research and in common clinical practice.

Many attempts for the quantification of osteonecrosis have been presented, as it is evident that the size and location of the necrosis is very important for the prognosis of the disease. Sugano *et al.* [28] presented a method (not a complete classification system) for the quantification of femoral head osteonecrosis based on MRI scans, in which they tried to evaluate the size and position of the lesion. Lafforgue *et al.* [13] introduced a method for the quantification of osteonecrosis on MRI. The four middle coronal sections are used and three parameters are defined in order to describe the size and location of the lesion in relation to the weight-bearing area. These parameters are calculated using angles and distances (axes) of the necrotic area. They tried to correlate the quantification with the patient's outcome.

Most classification methods are based on 2D measurements either in radiographs or even in MR images. None of the methods estimates the corresponding volume of the necrotic lesion. Koo *et al.* [11, 12] tried to evaluate the size and location of osteonecrosis using coronal and sagittal MRI sections. They measured the necrotic angle in the mid-coronal (A) and mid-sagittal (B) sections and calculated the index (A/180)x(B/180)x100. They suggested that this index is *a good approximation* to the actual volume of the lesion. They used this index to evaluate the effectiveness of core decompression for the treatment of osteonecrosis.

Steinberg *et al.* [24] presented two methods for the volumetric measurement of the size of the lesion. The first method is based on measuring the area of the necrotic lesion and the area of the entire head separately in AP and lateral radiographs. The percent of head involvement in each projection is calculated. These two percentages are multiplied to derive an estimation of the affected volume. The second method is based on MRI. The operator traces the outline of the entire head and the outline of the necrotic lesion on each slice. A computer program measures the area of the head and the area of the lesion. These areas are multiplied by the distance between the slices to determine the actual volume of the outlined structures.

In this work we propose a new classification system to overcome some of the major problems of the described systems. The system is based on MRI, which is generally accepted as the most suitable imaging technique for the early diagnosis of osteonecrosis. Since collapse of the articular surface is associated with mechanical factors (e.g. the weight of the body and the forces applied on the head during the gait and other movements), the 3D configuration (size, location and distribution) of the necrotic lesion in the femoral head and its relationship to contact forces with the acetabulum might be of critical importance. Therefore we use the MRI to describe these parameters and mainly the 3D configuration of the lesion.

Our approach is based on a computerized method for the estimation of the affected volume in the femoral head using MRI scans [1]. The method is based on the definition of a sphere equivalent that circumscribes the femoral head. The sphere equivalent is divided into 8 parts (octants) and the percentage of the affected volume in each octant is calculated as well as the total percentage. The result is a good approximation of the volume of the lesion and also its location and distribution. The approximation of the femoral head by the sphere resolves problems related to the definition of the head boundaries.

2. Materials and methods

2a. Database description

We have developed a data repository based on the data from patients with femoral head necrosis referred to the corresponding author. The patient record (Fig. 1) includes personal data, clinical examinations (symptoms, time of appearance, etc.) and information about the presence of one or more etiological factors that lead to osteonecrosis. Laboratory examination data are stored in the database as well as data about the operative management and postoperative examinations (data from the patient's follow up). The osteonecrosis database includes image data, which include pre-operative radiographs, MRI studies, computed tomography (CT) and bone scans and also post-operative images (radiographs, MRI) from the follow up process. New patient records are added to the database and follow up data (images, clinical examinations, new operations) update the existing records. At this time the database has more than 120 patient records.

A number of hips have been classified according to the proposed system and 106 hips of stages II and III have been included in the current study. We have evaluated the necrotic lesion of these 106 hips using the volumetric method. Some of these hips have collapsed within some years after the operation and total hip replacement (THR) has been performed. The pre-operative measurements of the collapsed hips are evaluated.

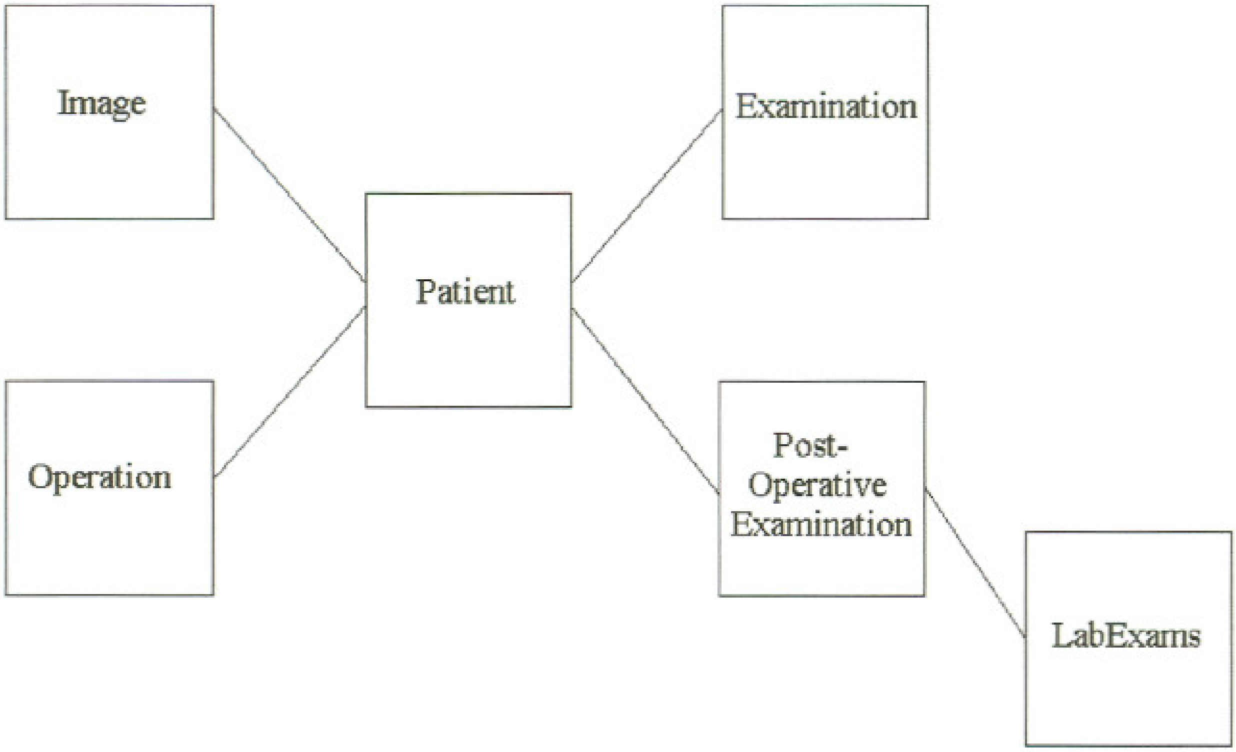


Figure 1: Structure of the Osteonecrosis database

2b. The volumetric method

A computerized image analysis method is used for the precise volumetric assessment of the lesion and for the description of its distribution and location in the femoral head. The method uses coronal slices of T1-weighted magnetic resonance images (MRI). In some cases T2-weighted MRI was additionally used to verify the boundaries of the necrotic lesion. The interval between the slices is 3.3 to 5 mm. A VIDAR VXR 12 Film Digitizer (Vidar Systems Corporation, Virginia, USA) was used to digitize the images. We apply histogram equalization and image sharpening to enhance image characteristics. The measurements were performed on a SUN Sparc 5 workstation (SUN Microsystems, California, USA) using the ANALYZE Version 7.5 image analysis package (Mayo Foundation, Minnesota, USA).

A sphere equivalent is used to approximate the femoral head. The sphere is drawn with the smallest radius that encloses the femoral head. The slice with the largest projection of the femoral head is used for the definition of the radius of the sphere. The sphere equivalent is divided into eight parts (octants). The method calculates the percentage of the affected volume within each octant and the percentage of the total necrotic volume within the sphere equivalent.

The sphere is divided into eight octants[1] by three planes (coronal, sagittal, and transverse) that intersect at the center of the sphere.

[1] The abbreviations of the octants are: ASL-Anterior Superior Lateral, ASM- Anterior Superior Medial, AIL-Anterior Inferior Lateral, PSL- Posterior Superior Lateral, PSM- Posterior Superior Medial, PIL- Posterior Inferior Lateral and PIM- Posterior Inferior Medial

The method works as follows: First the operator draws, on each slice, the smallest slice that circumscribes the femoral head (Fig. 2a). Next, the operator traces the necrotic area (Fig. 2b). In T1 MRI images the lesion is a low signal ("dark") area bounded by a low signal border line. Sometimes it is an area of diffuse low signal intensity so it is difficult to trace the limits of the lesion. The next step is to divide the circle (automatically) into four quadrants (Fig. 2c) and measure the area of the affected region within each quadrant (Fig 2d). The definition of the four quadrants (Superior Lateral, Superior Medial, Inferior Lateral and Inferior Medial) on the right and on the left hip are shown in Figure 3.

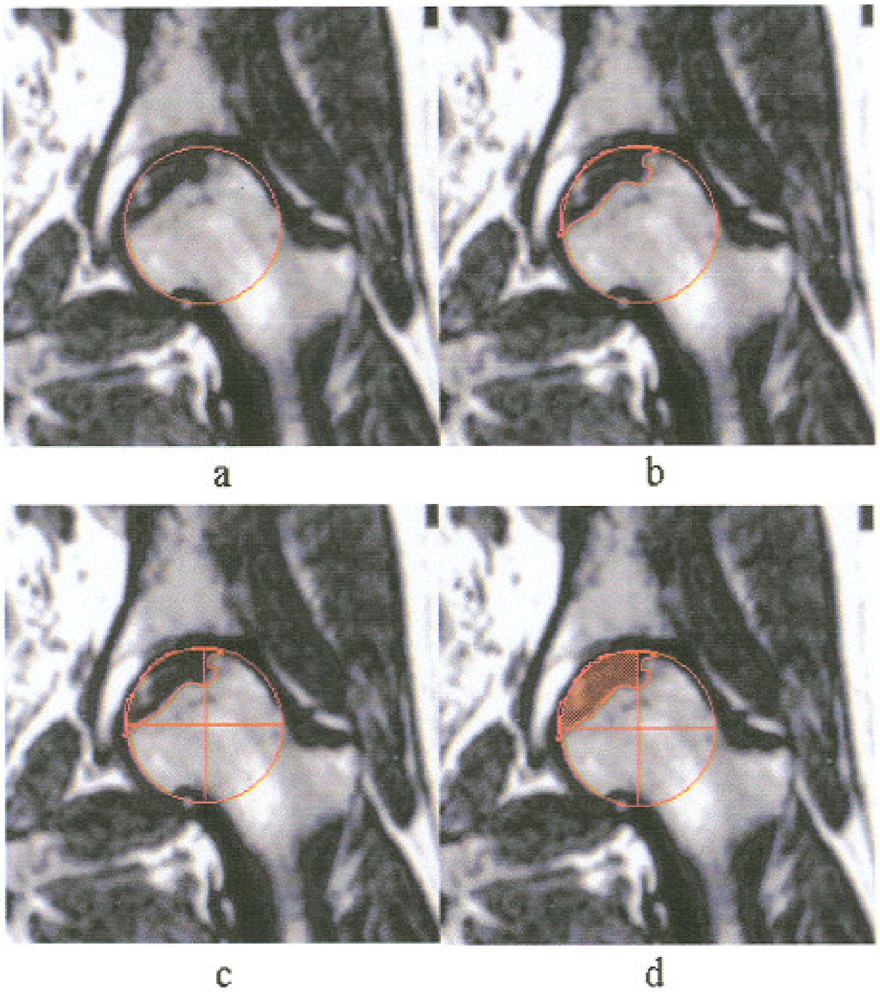


Figure 2: Drawing of the circle that circumscribes the femoral head (a), tracing of the necrotic area (b), division of the circle into four quadrants (c) and measurement of the affected area on each quadrant (d)

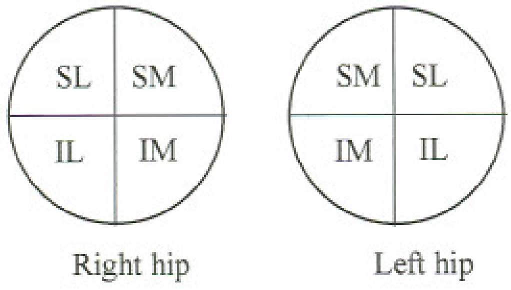


Figure 3: Quadrant definition on right and left hip

After completing the measurements on all MRI slices and storing the data, the method calculates the volume of the affected bone within each octant. The affected volume within each octant is computed with integration along the coronal direction, using a trapezoidal rule. The central slice determines the anterior and the posterior slices and the anterior and the posterior octants respectively. To compute the affected volume of an anterior (posterior) octant, we use the affected area of the corresponding quadrant on all the anterior (posterior) slices, including the central slice. For example, to compute the affected volume of the anterior superior lateral octant we use the measurements from the n anterior slices (n is the central slice).

The affected volume on the ASL octant is computed using the formula

$$V_{aff} = \frac{d}{2}\left(A_1 + 2A_2 + \ldots + 2A_{n-1} + A_n\right) \quad (1)$$

where d is the distance between two consecutive MRI slices (slice thickness plus gap between slices), and A_i is the affected area of the superior lateral quadrant on slice i .

The last step is to compute the percentage p of the affected volume within the octant. The octant volume is

$$V_{oct} = \frac{1}{8}V_{sphere} = \frac{1}{8}\frac{4}{3}\pi R^3 = \frac{1}{6}\pi R^3 \quad (2)$$

where R is the radius of the circle on the central slice (largest head circle).

The percentage p of the octant volume is

$$p = \frac{V_{aff}}{V_{oct}} \quad (3)$$

The total affected volume V_{aff_total} in the sphere is the sum of the eight volumes calculated on the eight octants. The total percentage p_{total} is

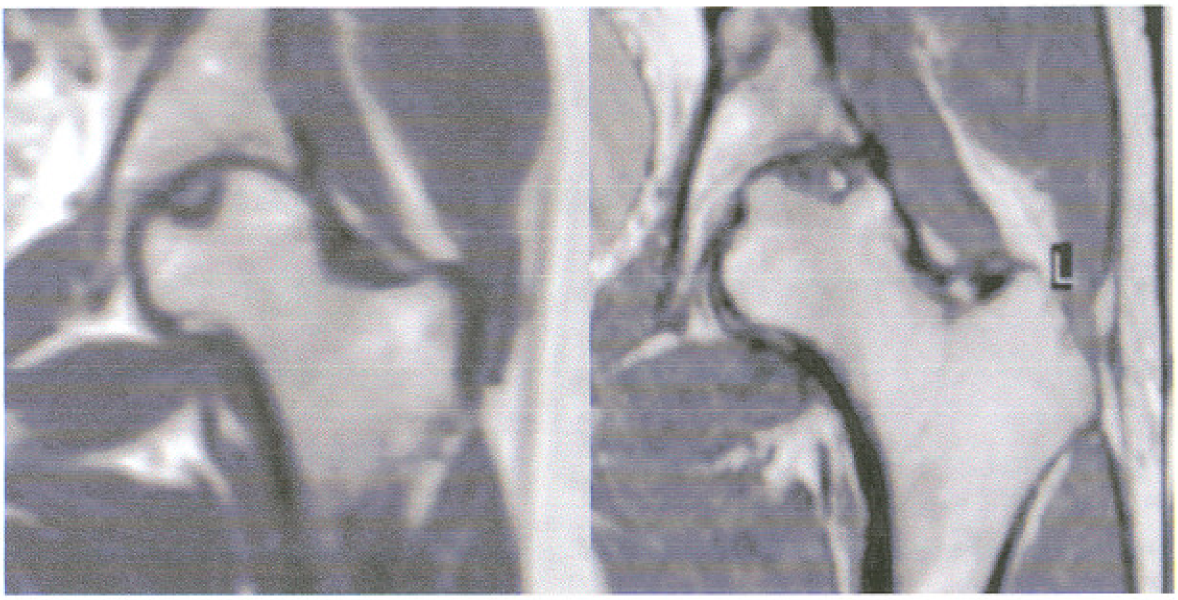
$$p_{total} = \frac{V_{aff\_total}}{V_{shpere}} \quad (4)$$

The above process is fully computerized and integrated.

2c. The classification schema

The proposed classification schema is based on the size and the location of the necrotic lesion, which are estimated using MRI series. The number of classes and subclasses is limited so that the system is easy to use. The criteria used by the classification schema are the following:

- Risk factors (steroids, alcoholism, anaemia, SLE, trauma etc).
- Detection of osteonecrosis on MRI or radiographs.
- Intact or flattened (collapsed) articular surface.
- Location of the lesion in the femoral head in relation to the acetabulum. Narrow lesions contained within the acetabulum leave an intact pillar of bone (Fig. 4a), that accepts the main load from the body weight so the necrotic bone takes a smaller load. Wide lesions that extend outside the acetabulum lip (Fig. 4b) indicate that the weak necrotic bone accepts the entire load and finally collapses.



a b

Figure 4: Picture of a narrow lesion with an intact pillar (a) and picture of a wide lesion without pillar (b)

The proposed classification schema includes 5 classes (0 through IV).

Class 0

Hips of class 0 present no pain or other clinical symptoms. The MRI, bone scan and radiographs are normal, but osteonecrosis has been already detected on the opposite hip and the patient presents one or more risk factors (steroids, alcoholism, anaemia, SLE etc). The presence of the risk factors indicates that there is a high probability for osteonecrosis to appear on that hip. Observation of the hip is required.

Class I

The patient has no pain or other clinical symptoms (silent hip). MRI and/or bone scan is positive, although the radiographs are still negative. MRI is much more sensitive than radiographic methods for the diagnosis in the early stages of the osteonecrosis because it detects changes of the bone marrow that happen at this stage. The inorganic component of the bone (bone matrix) is still intact.

Class II

In hips of stage II clinical symptoms (pain, limitation of movement) are present. All imaging techniques are positive, but the femoral head retains its shape (there is no collapse of the articular surface). Class II is divided into two sub-classes:

Class IIa: The ***lesion is contained*** within the acetabulum weight bearing area. A pillar of intact bone shields the necrotic area from the weight forces. Those hips have good prognosis and better outcome when treated surgically.

Class IIb: The affected area is ***not contained*** within the weight bearing area. The weak necrotic bone is bearing the full load of the body weight, and microfractures appear that subsequently lead to collapse of the articular surface.

Class III

Severe clinical symptoms are usually present in hips of class III. The articular surface has collapsed (head flattening). Class III is divided into two subclasses:

Class IIIa: The lesion is contained within the weight bearing area. The remaining pillar protects the necrotic area, so the necrosis progresses slowly.

Class IIIb: The lesion extends beyond the lip of the acetabulum. As a result, the necrosis progresses rapidly and destroys the joint. Surgical methods (FVFG) for the preservation of the femoral head can be applied in cases of small, contained lesion (class IIIa), although the prognosis for them is worse than that of Class II hips.

Class IV

Advanced joint degeneration, with severe pain and restriction of movements.

Table 1 gives a brief description of the 5 classes. MRI sections of hips of classes IIa, IIb, IIIa and IIIb are shown in Figures 5a – 5d.

Table 1: Classification schema

Class	Description
0	Normal hip, but necrosis on opposite hip and presence of some risk factor.
I	Silent hip (no symptoms) – MRI or bone scan detectable. Radiographs negative.
II	Clinical symptoms. MRI, bone scan, radiographs are positive. Non collapsed articular surface.
IIa	Affected area contained within the accetabulum weight bearing area.
IIb	Affected area non-contained.
III	Clinical symptoms. MRI, bone scan, radiographs are positive. Collapsed articular surface
IIIa	Affected area contained
IIIb	Affected area non-contained.
IV	Joint degeneration

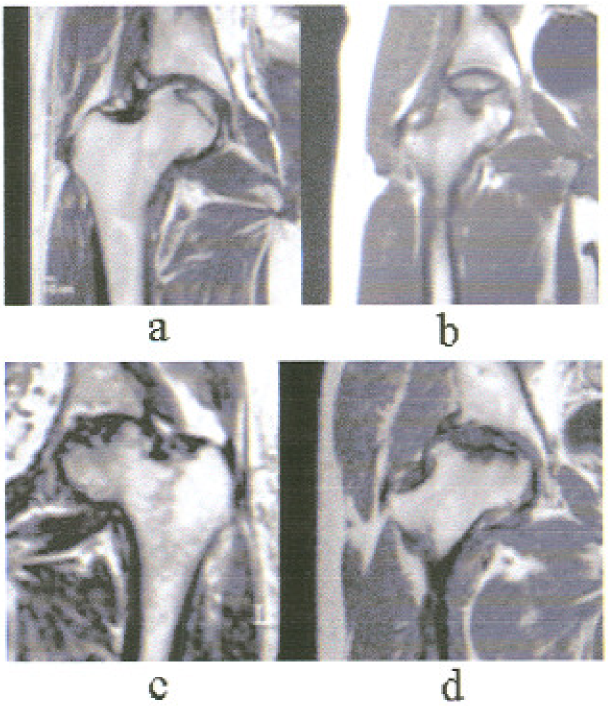


Figure 5: Hips for classes IIa (a), IIb (b), IIIa (c) and IIIb (d).

3. Results

The present study includes 106 hips from 67 patients (46 men and 21 women). The hips examined and evaluated are of classes II and III. The classification of the hips was based on magnetic resonance imaging observations. Lesions that extend beyond the lip of the acetabulum (in one ore more MRI slices) were classified as non-contained (class IIb or IIIb). The collapse of the femoral head was clearly seen on most MRI's. Additionally, radiographs were used in cases of confusion because they better show collapse of the articular surface (broken contour of the head).

The mean size of the lesion is 30.7% of the volume of the sphere equivalent. There were 19 hips of class IIa, 23 hips of class IIb, 8 hips of class IIIa and 56 hips of class of class IIIb. The mean affected volume for each class is summarized on Table 2.

The necrotic lesion is generally located towards the superior, medial and anterior areas of the femoral head. The most affected octants are ASM and PSM, in all classes. The next most affected octants are ASL and PSL, followed by AIM and PIM. The least affected hips are AIL and PIM. Table 3 and Figures 6, 7 present the percentage of affected volume in each quadrant for each of the four classes. ASL and PSL are the octants that present the greatest variability of all. ASL and PSL are slightly affected in cases of narrow lesions that are contained within the weight bearing area of the acetabulum (classes IIa and IIIa). In such cases these is an intact pillar of healthy bone that protects the head from collapse under the body weight. These hips have a better prognosis than hips where the lesion is not contained within the limits of the acetabulum (IIb and IIIb). Of cource ASL and PSL octants are much more affected in IIb and IIIb hips compared to IIa and IIIa hips.

Table 2: Number of hips in each class and the corresponding average affected volume

Class	Number of Hips	Mean % affected	Range
IIa	19	17	2.3 – 34.2
IIb	23	33.2	15.6 – 68.5
IIIa	8	29	12.9 – 50.3
IIIb	56	34.5	10.2 – 55.5

Table 3: Mean affected volume of each quadrant for each class and for the entire population.

Class	ASL	ASM	AIL	AIM	PSL	PSM	PIL	PIM
IIa	20.5	46.5	3.6	9.2	11	39.5	1.2	4.1
IIb	61	74.2	11.6	20.4	34.5	52.3	3.7	7.5
IIIa	34	66.5	6.9	26.3	28.9	57.5	2.6	9.7
IIIb	54.6	72.4	8.9	15.4	45.7	66.2	3.5	9.6
All Classes	48.3	67.7	8.4	16.2	35.8	57.8	3	8.2

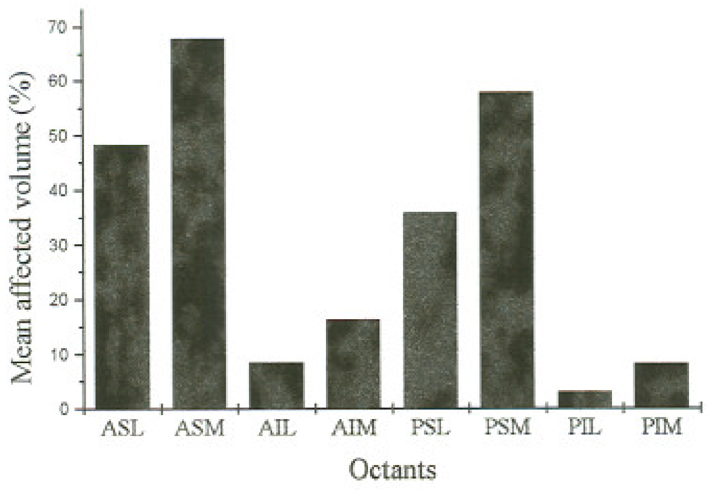


Figure 6: The mean affected volume per quadrant for the entire population

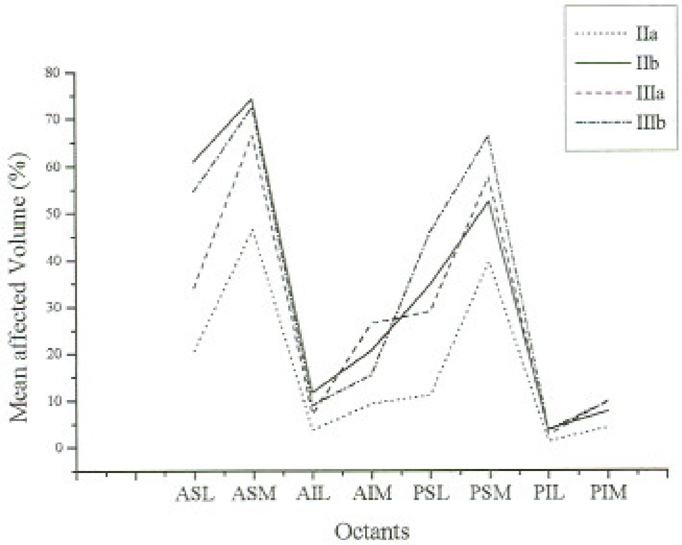


Figure 7: The mean affected volume per quadrant for each of the four classes

From the follow-up process it was found that 11 hips (from 10 patients) treated with free vascularized fibular grafting have failed and they collapsed within 2-3 years after the operation. Total hip replacement (THR) has been applied to 8 cases, whereas 3 more patients are scheduled for hip replacement. Of these 11 hips, 1 hip (9%) was of class IIIa at the time of the initial operation, and the other 10 (91%) were of class IIIb. This means that all of these hips were treated after collapse of the femoral head. None of the hips treated prior to the head collapse have progressed to failure. This finding is compliant to the classification of the 11 hips in late stages, according to the proposed system. Table 4 presents the correlation between the class and the need for THR.

The mean affected volume of the 11 hips that had to undergo total hip replacement is 38.9%, which is quite higher than the mean volume of the total population (30.7%). Also the volume of each of the 8 octants of the 11 hips is higher than the volume of the corresponding octant of the total population. PSM, PSL and ASL are the octants with the highest differences from the total population. Table 5 presents the total volume percentage and the percentage for each octant for the 11 hips, compared to the total population statistics (Fig 8).

Table 4: Number of hips that need THR per class

Class	Number of Hips	Need THR	Percentage (%)
IIa	19	0	0
IIb	23	0	0
IIIa	8	1	12.5
IIIb	56	10	17.9

Table 5: Mean affected volume of each quadrant for THR hips and for the entire population.

	ASL	ASM	AIL	AIM	PSL	PSM	PIL	PIM	Total
THR	58.8	77.2	11.1	19.7	52.7	77.1	4.6	9.8	38.9
All	48.3	67.7	8.4	16.2	35.8	57.8	3	8.2	30.7

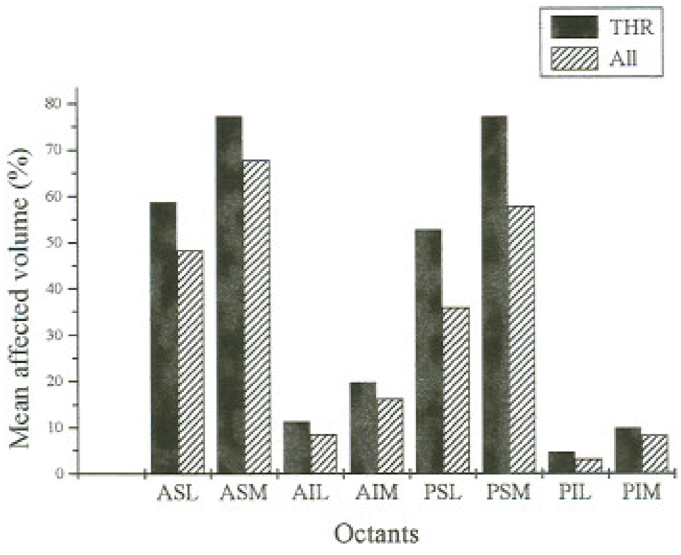


Figure 8: The mean affected volume per quadrant for THR hips and for the entire population

4. Discussion

The proposed classification schema for femoral head necrosis is based on MRI findings. Computerized processing of coronal MRI slices allowed accurate three-dimensional description of the femoral head and precise configuration of the lesion. The schema includes five classes (0 through IV). Class II is subdivided into IIa and IIb and class III into IIIa and IIIb. The limited number of classes makes the schema easy in the clinical practice. The major advantage of the proposed system is its prognostic value. Follow up studies show that hips of class IIIb have the higher possibility for rapid joint deterioration. The possibility is lower for hips of class IIIa and least for hips of classes IIa and IIb.

The proposed system is quite simple (with a limited number of stages and substages). It is easy to apply in the clinical practice since it does not require excessive time and effort.

The size and the location of the necrotic lesion in a hip affected by femoral head necrosis are crucial factors for the prognosis of the fate of the disease. The presented volumetric method uses MRI slices to evaluate the size and location of the lesion. A sphere equivalent model is used to avoid ambiguities in the identification of the femoral head in MRI slices. The sphere is divided into octants and the percentage of the affected volume in each octant is computed based on slice affected area measurements.

From the follow up study it is concluded that hips with large lesions and especially those with lesions extended laterally, have higher possibilities for collapse of the head.

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