Correlation of magnetic resonance imaging and radionuclide bone imaging findings of femoral head necrosis

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Abstract

Objectives To investigate the radionuclide bone imaging (RBI) manifestation of femoral head necrosis (FHN) in different magnetic resonance imaging (MRI) findings.

Materials and Methods 72 hips in 42 patients with FHN underwent MRI and RBI examination to observe the RBI manifestation of FHN in different MRI types.

Results There were 23 hips with MRI Type I FHN, 11 hips showing the corresponding RBI manifestation of ‘hands-holding-a-white-ball sign’ and 7 hips showing the ‘doughnut sign’. There are thirty-seven hips with MRI Type II FHN, 16 hips showing the corresponding RBI manifestation of diffusely increased uptake, 7 hips showing the ‘hands-holding-a-black-ball sign’, 7 hips showing the ‘doughnut sign’ and 4 hips showing the ‘hands-holding-a-white-ball sign’. There were 12 hips with Type III FHN, 11 hips showing the corresponding RBI manifestation of diffusely increased uptake and 1 hip showing the ‘hands-holding-a-black-ball sign’. The ‘hands-holding-a-white-ball sign’ in Type I FHN was significantly higher than that of Type II-III FHN (P<0.05), and the diffusely increased uptake in Type I FHN was significantly lower than that of Type II-III FHN (P<0.05).

Conclusions Different MRI findings of FHN lead to diverse RBI findings. In addition, the ‘doughnut sign’, the ‘hands-holding-a-white-ball sign’ and the ‘hands-holding-a-black-ball sign’ also have diagnostic value for FHN.

Introduction

Femoral head necrosis (FHN) is a type of ischemic necrosis that occurs in the subchondral bone of the adult femoral head. Its diagnostic imaging methods mainly include planar X-ray, computed tomography (CT), magnetic resonance imaging (MRI) and radionuclide bone imaging (RBI) [1–5]. MRI has a high resolution for soft tissue and a high bone marrow lesion detection rate, and it can detect the water and lipid composition changes in the bone marrow in relatively early stages before X-ray or CT can detect the changes in the bone density of necrotic bones. The ‘line-like sign’ including ‘double-line sign’ is a specific sign used by MRI to diagnose FHN [5, 6]. RBI is used for functional examinations, and RBI utilizing the bone-imaging agent $^{99m}$Tc-MDP ($^{99m}$technetium methylene diphosphonate) can detect earlier FHN lesions [7]. The ‘doughnut sign’ is a specific sign used by RBI to diagnose FHN, showing a ring-like increase with a cold center [8]. The occurrence of this diagnostic sign, however, is not high [8], limiting the utilization of RBI in FHN diagnosis. Therefore, it is necessary to further analyze RBI diagnostic signs for different findings of FHN and the underlying mechanisms of these signs.

This study determined the corresponding MRI findings of 72 hips with FHN, analyzed the RBI manifestation of the FHN in different MRI findings, and investigated the RBI manifestation of the FHN and its diagnostic value in different MRI findings, thus further improving RBI’s diagnostic level for FHN.

Materials And Methods
Clinical data

Suspected FHN patients with clinical unilateral or bilateral hip pain underwent MRI and RBI over the same period (a difference of no more than 7 days). Forty-two cases (72 hips) with FHN in adult proved by follow-up studies, pathology or typical MRI features, were analyzed (see Table 1). The line-like sign in a femoral head is regarded as the typical MRI feature for diagnosis of FHN [2, 5, 9]. This group of patients included 26 males and 16 females, with 12 cases of a single hip and 30 cases of both hips. The patient's ages ranged from 22 to 62 years, and the average age was 42 years. There were 24 patients who had a treatment history of receiving substantial corticosteroids due to different diseases (10 cases with severe acute respiratory syndrome, 8 cases with rheumatoid arthritis, 4 cases with systemic lupus erythematosus and 2 cases with dermatomyositis), and 18 cases had a long-term history of alcohol abuse. Among the 72 hips, 13 FHN hips underwent the total hip replacement 4 weeks after the MRI and RBI examinations.

Imaging method

All MR examinations were performed using a 1.5T superconducting whole body magnetic resonance scanner (Magnetom Vision Magnetom Trio Tim, Siemens, Medical System, Erlangen, Germany). The patients were in the supine position, with the bilateral anterior superior iliac spine lines at the same level. The body coil scanning was chosen, and the scanning range was from the hip acetabular roof to the lesser trochanter. Coronal spin echo (SE) T₁WI sequences, fast SE fat-suppressed T2WI sequences using the fat pre-saturation method and axial fast SE T₂WI sequences were used for imaging. The scanning parameters were 4 mm slice thickness, 1 mm intervals, TR 460–650 ms and TE 12–20 ms for T₁WI, TR 2500–5000 ms and TE 80–120 ms for T₂WI, a 224 × 512 matrix, a field of view of 360 × 360 mm and an average excitation time of 2–3.

RBI examination used the Scophy DSX SPECT (single-photon emission computed tomography) machine. The patients were in the supine position, were injected with 740 MBq of ⁹⁹ᵐTc-MDP (Tc-methylene phosphonate) via the cubital vein using the bolus injection method and then drank 500–1000 ml of water. After 3–4 hours, the patients were asked to empty their bladders. A low energy parallel collimator probe was used to perform the anterior pelvic static planar imaging, and the examination field included the bilateral hips.

Pathological examination

The necrotic femoral head samples of 13 hips that had been removed by the total hip replacement were washed with normal saline within 2 hours after the surgery. Then they were sectioned into 5 mm thick cross-sectional slices and placed in 10% neutral formalin solution to be fixed for 96 hours. Based on the MRI 'line-like sign' zone, the 'line-like sign' surrounding area and the peripheral area (Figs. 1a, 2a), 2 tissue
blocks were taken from the corresponding areas on the specimen sections according to the section surface (Figs. 1b, 2b). Each block was approximately 5×5×5 mm and was fixed, decalcified, dehydrated, embedded in paraffin and sectioned. The specimens underwent conventional Hematoxylin and eosin (HE) staining and were observed under light microscopy.

**Image analysis**

Two experienced radiologists independently observed and recorded the MRI findings and RBI findings of the FHN. Two pathologists observed and recorded the pathological findings of the 13 hips replaced by surgery and eventually agreed upon a diagnosis.

Based on the relationship between the MRI signal manifestation of the FHN necrotic area and the pathology [10, 11] and the FHN pathological findings at different disease stages [12], the 72 hips with FHN were classified into 3 types according to the shape of the femoral head in the MRI and the signal manifestation of the surrounding area of the ‘line-like sing’ zone. Type I FHN (Fig. 1): the shape of the necrotic femoral head was normal, and the ‘line-like sign’ surrounding area showed a pure fat-like signal, that is, a hyperintense T₁WI signal and a uniformly hypointense fat-suppressed T₂WI signal (Fig. 1c). The manifestation was similar to that of normal yellow bone marrow. Type II FHN (Fig. 2): the shape of the necrotic femoral head was normal, and the ‘line-like sign’ surrounding area showed a fat and granulation-like mixed signal. In other words, the fat signal was mixed with varying amounts of a granulation-like signal, showing a mixed hypointense and hyperintense T₁WI signal (Fig. 2c) and a mixed hyperintense and hypointense fat-suppressed T₂WI signal (Fig. 2d). Type III FHN (Fig. 3): The necrotic femoral head collapsed. The ‘line-like sign’ surrounding area mainly showed the granulation-like mixed signal, mixed with a small amount of fat-like signal (Fig. 3a).

**Statistical analysis**

Chi-squared analysis was performed using the SPSS 13.0 statistical software to compare the occurrence rates of the RBI signs in 72 hips with different findings of FHN, and P<0.05 was considered to be significantly different.

**Results**

**MRI types and postoperative pathologic manifestation of 13 hips with FHN**

The 13 hips with FHN that were removed by the total hip replacement were classified into 3 types according to MRI findings (see Table 2).
In Type I FHN (Fig. 1), the pathology of the ‘line-like sign’ surrounding areas showed bone trabecula and bone marrow necrosis with no granulation tissue (Fig. 1d). The medial side of the ‘line-like sign’ zone had large amounts of fibrous granulation tissue (Fig. 1e), the lateral side had a large amount of new bones and fractured bone trabecula (Fig. 1f) and the peripheral area of the ‘line-like zone’ of the abnormal bone marrow signal showed bone marrow edema (Fig. 1g).

In Type II FHN (Fig. 2), the pathology of the ‘line-like sign’ surrounding areas showed bone tissue necrosis and a small amount of granulation tissue and new bone. The medial part of the ‘line-like sign’ zone had a large amount of fibrous granulation tissue (Fig. 2e), the lateral part had a large number of new bones and fractured bone trabecula and the peripheral area of the ‘line-like sign’ zone of the abnormal bone marrow signal showed bone marrow edema.

In Type III FHN, the pathology of the ‘line-like sign’ surrounding areas showed bone tissue necrosis and a large amount of granulation tissue and new bones, and the abnormal signal observed in the ‘line-like sign’ zone and its peripheral area was similar to that of type II FHN.

**Corresponding RBI manifestations of the 72 hips with various MRI types of FHN**

Based on the MRI types criteria developed in this study, this group of 72 hips with FHN comprised 23 Type I hips, 37 Type II hips and 12 Type III hips (Table 3).

Among the 23 hips with Type I FHN, 11 hips presented the ‘hands-holding-a-white-ball sign’ (Figs. 1h, 4), showing an area of decreased radioactive uptake in the upper femoral head (like a white ball corresponding to the ‘line-like sign’ surrounding area of the MRI) and a concave-arc-like area of increased radioactive uptake in the lower femoral head or the femoral head and neck (like a holder corresponding to the MRI ‘line-like sign’ zone and its peripheral area), and 7 hips presented the ‘doughnut sign’ (Fig. 5), that is, where the areas surrounding the femoral head showed a ring-shaped area of increased radioactive uptake (corresponding to the MRI ‘line-like sign’ zone and its peripheral area), and the center of the femoral head did not show a high radioactive uptake level (corresponding to the ‘line-like sign’ surrounding area of the MRI). Two hips showed a limited increased radioactive uptake, and the maximum lesion diameters on the MRI were 1.5 cm and 2.0 cm. One hip showed a limited decreased radioactive uptake. Two hips showed a negative RBI, and the maximum lesion diameters on the MRI were 1.5 cm and 1.2 cm.

Among the 37 hips with Type II FHN, 16 showed diffusely increased radioactive uptake in the femoral head and neck (Fig. 6), and 7 hips showed the ‘doughnut sign’ (Fig. 7). Seven hips showed the ‘hands-holding-a-black-ball sign’ (Fig. 2f), that is, showed an area of slightly increased radioactive uptake in the upper femoral head (like a black ball corresponding to the ‘line-like sign’ surrounding area of the MRI) and a concave-arc-like area of significantly increased radioactive uptake in the lower femoral head or the
femoral head and neck (like a holder corresponding to the MRI 'line-like sign' zone and its peripheral area). In addition, 4 hips showed the ‘hands-holding-a-white-ball sign’, and the MRI ‘line-like sign’ zone and its surrounding area mainly showed a fat signal that was scattered with small amounts of a granulation-like signal. Two hips showed limited areas of diffusely increased radioactive uptake, and the maximum lesion diameters on the MRI were 1.6 cm and 2.0 cm. One hip was RBI negative, and the ‘line-like sign’ surrounding area of the MRI mainly showed a fat signal that was scattered with small amounts of a granulation-like signal.

Among the 12 hips with Type III FHN, 11 showed diffusely increased radioactive uptake in the femoral head and neck (Fig. 3b), and 1 hip showed the ‘hands-holding-a-black-ball sign’.

A chi-squared test for the occurrence rates of the RBI signs in the various types of FHN listed in Table 3 was performed. The results are as follows.

The ‘hands-holding-a-white-ball sign’ was observed in MRI Type I and II FHN. There were statistically significant differences among the occurrence rates of the ‘hands-holding-a-white-ball sign’ in MRI Type I FHN (11/23 hips), Type II FHN (4/37 hips), Type III FHN (0/12 hips) and Type II-III FHN (4/49 hips) (P<0.05).

The ‘doughnut sign’ was observed in MRI Type I and II FHN. There was no significant difference between the occurrence rates of the ‘doughnut sign’ in Type I FHN (7/23 hips) and Type II FHN (7/37 hips) (P>0.05). There were also no significant differences between its occurrence in these 2 types and in Type III FHN (0/12 hips) (P>0.05).

The ‘hands-holding-a-black-ball sign’ and the sign of diffusely increased uptake were found only in MRI Type II and III FHN and not in MRI Type I. The occurrence rate of the ‘hands-holding-a-black-ball sign’ in MRI Type II-III (8/49 hips) was higher than that in Type I FHN (0/23 hips), although the difference between the types was not statistically significant (P>0.05). There was no significant difference between the occurrence rates of diffusely increased uptake in MRI Type II (16/37 hips) and Type III (11/12 hips) (P>0.05), but the occurrence rates were statistically significantly different in Type I (0/23 hips) vs Type II and Type I vs Type III (P<0.05).

The total occurrence rate of the ‘hands-holding-a-white-ball sign’, the ‘hands-holding-a-black-ball sign’ and the ‘doughnut sign’ in FHN was 51.4% (37/72 hips). The diagnostic accuracy was 51.4% while using these three RBI specific signs for the diagnosis of FHN. Moreover, RBI showed the positive findings in 69 hips of 72 hips with FHN. So the rate of RBI diagnostic sensitivity was 95.8%.

**Discussion**

MRI achieves excellent sensitivity for FHN diagnosis [5]. The ‘line-like sign’ zone is the interface between the necrotic tissue and viable tissue, where the area consists of the reparative granulation tissue and new bone [5, 10, 13]. The area of bone necrosis consists of the cancellous bone area surrounded by the ‘line-
like sign' zone alone or together with the femoral articular surface. The necrotic areas show different MRI signals due to their distinct repair types, and the peripheral surviving area surrounding the necrotic area may show bone marrow hyperemia and edema [6,12,14]. The pure fat-like signal areas surrounded by ‘line-like sign’ on MRI are pathologically pure necrotic areas, and those with mixed fat and granulation-like signals are areas with mixed necrosis and repair in pathology. Our FHN types based upon the MRI findings is supported by the corresponding pathological evidence and can reflect the pathological process of bone necrosis and repair quite well.

After osteonecrosis of the femoral head, the reparative granulation tissue in the peripheral surviving areas slowly crawls to the femoral head necrotic area. Osteogenesis occurs on the surface of the bone trabecula, and the necrotic bone is absorbed. There are multiple microfracture lines in the interface between the necrotic tissue and the normal tissue. The reparative granulation tissue proliferates and accumulates at the microfracture lines and forms new bones in the lateral area, thus generating the area corresponding to the MRI 'line-like sign' zone [5,10]. The areas with the granulation tissue form the hyperintense areas on T2WI and fat-suppressed T2WI. The broken and intercalated microfracture lines and new bone form the hypointense areas on T1WI and T2WI. The 'line-like sign' zone is revealed as the area with increased radioactive uptake in the RBI because of the rich blood supply and active bone metabolism. If the 'line-like sign' zone alone surrounds the necrotic area, it is shown in the RBI as a femoral head ring shape with increased radioactive uptake. If the 'line-like sign' zone and the articular surface of the femoral head together surround the area of bone necrosis, it is shown in the RBI as a concave arc of significantly increased radioactive uptake from the lower femoral head or the femoral head and neck to the necrotic zone.

In MRI Type I FHN, the blood supply to the femoral head necrosis area is disrupted, the bone metabolism is stopped and there is no reparative granulation tissue entering the necrosis area to repair and generate new bone. This process leads to areas with decreased radioactive uptake in the RBI, which is the RBI finding of early FHN [15]. Among the 23 hips with Type I FHN, the femoral head necrotic areas of 19 hips (82.6%) showed areas with decreased radioactive uptake in the RBI. The areas with a decreased radioactive uptake in the RBI consisting of the necrotic areas, combined with the arc- or ring-shaped areas with increased radioactive uptake, consisting of the ‘line-like sign’ zone, forms the ‘hands-holding-a-white-ball sign’ or the ‘doughnut sign’. The occurrence rates of these 2 signs in MRI Type I FHN were 47.8% and 30.4%, respectively. The necrotic areas of 4 hips were so small that the slight changes in radioactive uptake caused by necrosis could not be distinguished by RBI with low spatial resolution, and the RBI manifestation was normal or showed limited increased radioactive uptake due to the effects of the increased radioactive uptake in the ‘line-like sign’ zone.

In Type II FHN, the reparative granulation tissue enters the necrotic area and results in osteogenesis. The extent of the increased radioactive uptake in the necrotic area revealed by RBI differs according to the extent of the osteogenesis in the granulation tissue. When a low level of osteogenesis occurs in the necrotic area, areas of decreased radioactive uptake or slightly increased radioactive uptake in the necrotic area can still be revealed by RBI, and the extent of the increased radioactive uptake in the
necrotic area is lower than in the 'line-like sign' zone, which has increased radioactive uptake. In RBI, the areas with decreased radioactive uptake or slightly increased radioactive uptake in the necrotic areas and the arc- or ring-shaped areas with increased radioactive uptake in the 'line-like sign' zone together form the 'hands-holding-a-white-ball sign', the 'hands-holding-a-black-ball sign' and the 'doughnut sign'. When high levels of osteogenesis occur in the necrotic area, there is not much difference in the osteogenic and metabolic activity levels between the necrotic area and the 'line-like sign' zone. The two areas also had similar levels of increased radioactive uptake and cannot be distinguished in an RBI with low spatial resolution and contrast resolution, leading to the sign of diffusely increased uptake. The occurrence rates of the 'hands-holding-a-white-ball sign', the 'hands-holding-a-black-ball sign', the 'doughnut sign' and the sign of diffusely increased uptake in MRI Type II FHN were 10.8%, 18.9%, 18.9% and 43.2%, respectively. Additionally, 91.7% of hips with Type III FHN showed diffusely increased uptake in RBI.

We believe that the 'hands-holding-a-white-ball sign', the 'hands-holding-a-black-ball sign' and the 'doughnut sign', which consisted of the areas of decreased or slightly increased radioactive uptake in femoral head necrosis and the areas of significantly increased uptake surrounding the necrotic area, are also consistent with the pathological basis of femoral head necrosis and can be used as the specific signs for the RBI diagnosis of FHN. Moreover, in the present study, the total occurrence rate of the 'hands-holding-a-white-ball sign', the 'hands-holding-a-black-ball sign' and the 'doughnut sign' in FHN was as high as 51.4%, which can compensate for the previously low diagnostic rate when only using the specific 'doughnut sign' for the RBI diagnosis of FHN (in this study, the occurrence rate of this sign was only 19.4%).

When FHN lesions are relatively small (the lesions in this study were all less than 2.0 cm) or when osteogenic activity is weak, RBI often yields false negative results due to the overlapping anterior and posterior structures, lower spatial resolution or weakly increased radioactive uptake, thus causing missed diagnoses of FHN [15,16]. In our group, there were 2 hips with MRI Type I FHN and 1 hip with MRI Type II FHN that were missed by RBI. When the FHN lesion is small, the different levels of increased radioactive uptake in the necrotic area and its surrounding area cannot be distinguished in the low spatial resolution RBI and is called limited increased radioactive uptake. There were 2 hips in MRI Type I and 2 in Type II that showed similar RBI findings as discussed above, which were difficult to distinguish from the limited increased radioactive uptake caused by other bone lesions. In addition, the diffusely increased uptake in the FHN femoral head and neck as revealed by RBI is similar to the increased radioactive uptake in the femoral head caused by other diseases, such as bone marrow edema syndrome of the hip, synovitis and hip degeneration [17], making it difficult to rely solely on RBI to obtain a differential diagnosis.

This study demonstrated that FHN in different MRI types has diverse RBI manifestations, and the 'hands-holding-a-black-ball sign' and the sign of diffusely increased uptake are only found in MRI Type II and III FHN but not in MRI Type I. The 'hands-holding-a-white-ball sign' and the 'doughnut sign' are only observed in MRI Type I or II but not in MRI Type III. The corresponding statistical analysis results showed that the 'hands-holding-a-white-ball sign' often suggests that the FHN is in MRI Type I, and the emergence of the sign of diffusely increased radioactive uptake suggests that the FHN has entered MRI Type II or III.
Abbreviations

RBI: radionuclide bone imaging; FHN: femoral head necrosis; MRI: magnetic resonance imaging; $^{99m}$Tc-MDP: 99m-tc methylene diphosphonate; SPECT: single-photon emission computed tomography

Declarations

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Availability of data and materials

The dataset supporting the conclusions of this article is included within the article. Data and materials during the current study are available from the corresponding author on reasonable request.

Authors’ contributions

Lei Ding and Zhenhua Gao participated in design of the study, collected the patients’ data, and drafted the manuscript. Xianbiao Xie, Gang Huang and Liangcai Wu processed the figures, helped draft the manuscript, and performed critical revision of the manuscript. Quanfei Meng and Junqiang Yin conceived and designed the study, supervised the project. All authors read and approved the final version of the manuscript.

Ethics approval and consent to participate

Current study was approved by the Institutional Ethics Committee of The First Affiliated Hospital of Sun Yat-Sen University and need for signed informed consent was waived.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.
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Tables

Table 1. Clinical Characteristics of 42 patients with FHN

| Characteristics         | No. of patients |
|-------------------------|-----------------|
| **Age**                 |                 |
| Mean                    | 42 years        |
| Range                   | 22–62 years     |
| **Sex**                 |                 |
| Men                     | 26              |
| Women                   | 16              |
| **Hip involved**        |                 |
| Left                    | 5               |
| Right                   | 7               |
| Both                    | 30              |
| **Etiology**            |                 |
| High-dose corticosteroids | 24          |
| Long-term abuse of alcohol | 18         |

Table 2. MRI types and the corresponding pathological findings for 13 hips with FHN
| MRI type   | MRI findings                                                                 | Pathological findings                                                                 |
|-----------|------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Type I, 2 hips | The shape of the necrotic femoral head was normal, and the surrounding area of the 'line-like zone' showed a pure fat-like signal. | The surrounding areas of the 'line-like zone' showed bone trabecula and bone marrow necrosis with no granulation tissue. |
| Type II, 4 hips | The shape of the necrotic femoral head was normal, and the surrounding area of the 'line-like zone' showed a fat and granulation-like mixed signal. | The surrounding area of the 'line-like zone' showed bone trabecula, bone marrow necrosis and a small amount of granulation tissue and new bone. |
| Type III, 7 hips | The necrotic femoral head collapsed.                                         | The surrounding area of the 'line-like zone' showed bone trabecula, bone marrow necrosis and a large amount of granulation tissue and new bone. |

Table 3. RBI findings for 72 hips with various MRI types of FHN

| MRI type   | Hands-holding-a-white-ball sign | Hands-holding-a-black-ball sign | Doughnut sign | Diffusely increased uptake | Limited increased radioactive uptake | Limited decreased radioactive uptake | Negative |
|-----------|---------------------------------|---------------------------------|---------------|---------------------------|-------------------------------------|--------------------------------------|----------|
| Type I, 23 hips | 11                             | 0                               | 7             | 0                         | 2                                   | 1                                    | 2        |
| Type II, 37 hips | 4                              | 7                               | 7             | 16                        | 2                                   | 0                                    | 1        |
| Type III, 12 hips | 0                              | 1                               | 0             | 11                        | 0                                   | 0                                    | 0        |
| Total      | 15                             | 8                               | 14            | 27                        | 4                                   | 1                                    | 3        |

Conclusions

In conclusion, based on the MRI findings and the pathological observations of FHN, this study performed MRI staging classification for FHN. We then analyzed the RBI manifestations of the different MRI types of FHN and observed that in addition to the 'doughnut sign' that was previously used to diagnose FHN, the 'hands-holding-a-white-ball sign' and 'hands-holding-a-black-ball sign' can also be used as specific signs for the RBI diagnosis of FHN. This study also showed that the occurrence rates of different RBI signs in the FHN of different MRI types are also different, and different RBI signs might suggest that the FHN is in different MRI types.

Figures
A 52-year-old male with osteonecrosis of the right femoral head (MRI Type I). Axial T2WI shows the 'line-like sign' (arrows) and its surrounding area (arrowhead) and peripheral area (Fig. 1a). View of the interface corresponding to 'line-like sign' zone on MRI (arrows) between the necrosis (arrowhead) and normal area of the femoral head specimen removed (Fig. 1b). The coronal fat-suppressed T2WI shows that the right femoral head has a normal shape, and the 'line-like sign' surrounding area (arrowhead) has a pure fat signal accompanied by a diffuse hyperintense signal (arrows) in the peripheral area (Fig. 1c). The pathology of the 'line-like sign' surrounding area reveals bone trabecula necrosis and interruption, and the fat cells in the marrow cavity have undergone necrosis and fused into fat sacs (arrow) (Fig. 1d). The medial area of the 'line-like sign' zone shows fractured bone trabecula and fibrous granulation tissue (arrows) in pathology (Fig. 1e), and the lateral area of the 'line-like sign' zone shows fractured bone
trabecula and new bone (arrows) (Fig. 1f). The peripheral area of the 'line-like sign' zone shows bone marrow edema in pathology (Fig. 1g). The RBI finding of the right femoral head shows the 'hands (arrows)-holding-a-white-ball (arrowhead) sign' (Fig. 1h).

Figure 2

A 55-year-old male with bilateral osteonecrosis of the femoral head (MRI Type II). Axial T2WI of the right femoral head shows the 'line-like sign' (arrows) and its surrounding area (arrowhead) and peripheral area (Fig. 2a). View of the interface corresponding to 'line-like sign' zone on MRI (arrows) between the necrosis (arrowhead) and normal area of the femoral head specimen removed (Fig. 2b). The coronal T1WI (Fig. 2c) and coronal fat-suppressed T2WI (Fig. 2d) show that the right femoral head has a normal shape, and the 'line-like sign' surrounding area (arrowhead) (arrow) has a mixed signal of fat and granulation. The pathology of the 'line-like sign' surrounding area reveals bone trabecula and bone marrow necrosis (arrowheads) with small amounts of new granulation tissue (arrows) (Fig. 2e). The RBI finding of the right femoral head is the 'hands (arrow)-holding-a-black-ball (arrowhead) sign' (Fig. 2f).
A 37-year-old female with bilateral osteonecrosis of the femoral head; the osteonecrosis of the right femoral head was MRI Type III. The coronal T1WI shows the collapsed right femoral head, and the ‘line-like sign’ (arrows) surrounding area (arrowhead) has a mixed signal of fat and granulation tissue that is accompanied by a diffuse hypointense signal in the bone marrow of the peripheral area (Fig. 3a). The RBI finding shows diffusely increased uptake (arrows) in the right femoral head and neck (Fig. 3b).

A 38-year-old male with bilateral osteonecrosis of the femoral head (MRI Type I). The coronal fat-suppressed T2WI reveals that the bilateral femoral heads are of a normal shape, and the ‘line-like sign’ (arrows) surrounding area (arrowhead) has a pure fat hypointense signal that is accompanied by a diffuse hyperintense signal in the bone marrow of the peripheral area (Fig.4a). The RBI finding of the bilateral femoral heads is the ‘hands-holding-a-white-ball sign’ (Fig. 4b).
Figure 5

A 52-year-old male with bilateral osteonecrosis of the femoral head (MRI Type I). The coronal T1WI reveals that the bilateral femoral heads are of a normal shape, and the ‘line-like sign’ (arrows) surrounding area (arrowhead) has a pure fat hyperintense signal (Fig. 5a). The RBI finding of the bilateral femoral heads is the ‘doughnut sign’ (arrows) (Fig. 5b).

Figure 6

A 35-year-old female with osteonecrosis of the left femoral head (MRI Type II). The coronal fat-suppressed T2WI shows that the left femoral head is of a normal shape, and the ‘line-like sign’ (arrows) surrounding area (arrowhead) has a mixed signal of fat and granulation tissue that is accompanied by a patchy, slightly hypointense signal in the bone marrow of the peripheral area (Fig. 6a). The RBI finding reveals a diffusely increased uptake (arrows) (Fig. 6b).
Figure 7

A 35-year-old male with bilateral osteonecrosis of the femoral head; the left femoral head is in MRI Type II. The coronal fat-suppressed T2WI shows that the left femoral head is of a normal shape, and the 'line-like sign' (arrows) surrounding area (arrowhead) has a mixed signal of fat and granulation tissue that is accompanied by a diffuse hyperintense signal in the bone marrow of the peripheral area (Fig. 7a). The RBI finding of the left femoral head shows the ‘doughnut sign’ (arrows) (Fig. 7b).