Six major and seven minor diagnostic criteria have been developed by the Japanese Investigation Committee for osteonecrosis of the femoral head (ONFH). We have carried out a multicentre study to clarify these.

We studied prospectively 277 hips in 222 patients, from six hospitals, who had ONFH and other hip pathology and from whom histological material was available. We identified five criteria with high specificity: 1) collapse of the femoral head without narrowing of the joint space or acetabular abnormality on radiographs, including the crescent sign; 2) demarcating sclerosis in the femoral head without narrowing or acetabular abnormality; 3) a ‘cold-in-hot’ appearance on the bone scan; 4) a low-intensity band on T1-weighted images (band pattern); and 5) evidence of trabecular and marrow necrosis on histological examination. With any combination of two of these criteria, the sensitivity and specificity of the diagnosis were 91% and 99%, respectively.

The diagnosis of non-traumatic osteonecrosis of the femoral head (ONFH) is made by reference to the medical and social history including symptoms, signs, imaging and histological examination. To clarify the definition of ONFH, in 1986 the Japanese Investigation Committee (JIC) devised diagnostic criteria which were then revised in 1990 when MRI was added (Table I). We have performed a multicentre study to examine the sensitivity and specificity of these.

Patients and Methods

Between 1990 and 1995 we studied 277 hips in 222 patients, from six hospitals, who had ONFH and other hip pathology and from whom the histological findings were available. Detailed information was obtained regarding previous trauma, occupational or recreational diving, alcohol intake, and steroid administration. We excluded patients with traumatic osteonecrosis secondary to fractures of the femoral neck, dislocation of the hip, slipped capital femoral epiphysis, postirradiation osteonecrosis, Perthes’ disease, and ONFH secondary to Caisson disease, sickle-cell disease or Gaucher’s disease. Anteroposterior (AP) and lateral radiographs, bone scanning and MRI were undertaken. T1-weighted images were obtained by a spin-echo technique.

The histological findings of the femoral head at replacement arthroplasty were available in 267 hips. In the remaining ten, a core biopsy was performed under general anaesthesia with an 8 mm diameter trephine. These included five patients with ONFH in the preradiological stage (ARCO stage 1), four with transient osteoporosis, and one with hyperparathyroidism and a renal allograft. In the two other cases with stage-1 ONFH, core specimens were obtained and the femoral heads were later removed when the condition had progressed and prosthetic replacement performed. The core specimens including articular cartilage were obtained from the subtrochanteric area of the upper part of the femoral head under radiological control. MRI was performed after core biopsy to ensure that the core tract had reached the area with abnormal intensity. All of the histological specimens were fixed in neutrally buffered 10% formalin, decalcified, embedded in paraffin wax, sectioned to a thickness of 5 µm, and stained with haematoxylin and eosin. Histological diagnosis of ONFH was...
made when there was evidence of trabecular and marrow necrosis (‘necrotic’ zone) adjacent to viable bone and marrow (‘viable’ zone) with an intervening zone of repair (‘reparative’ zone) on the same section. Partial disappearance of the trabecular nuclei alone was not considered as osteonecrosis because empty osteocyte lacunae with normal bone marrow could be due to ageing and are sometimes observed in the eburnated bone adjacent to the articular surface in osteoarthritis.

Table I lists the six major and seven minor criteria which were recorded for each hip. On plain radiographs, depression of the femoral head is defined as a step in its outline. The crescent sign is defined as a subchondral radiolucency and the ‘cold-in-hot’ appearance on a bone scan as a photopenic region surrounded by an area of increased accumulation of radioisotope. Other abnormal findings on a bone scan are included as minor criteria. A low-intensity band on T1-weighted images (band pattern) separating the normal fat intensity area is a major criterion even when a peripheral portion of the head surrounded by a low-intensity band shows low intensity secondary to collapse. Low-intensity lines such as an epiphyseal scar or primary compression trabeculae are excluded from the band pattern.

Oral steroid administration is considered, but not an intra-articular injection. Regular alcohol intake of more than 320 g/week is considered as abuse.

There were 122 hips in 92 patients with ONFH available for study, 54 men with a mean age of 44 years (18 to 73) and 38 women with a mean age of 44 years (21 to 77). According to the ARCO staging system, 18 hips were in stage 1 (radiologically normal), four in stage 2 (radiologically abnormal with no crescent sign, flattening, or collapse of the femoral head), 81 in stage 3 (crescent sign, flattening or collapse of the femoral head), and 19 in stage 4 (degenerative change). Sixteen of the 81 hips in stage 3 had a radiological crescent sign without flattening or depression of the femoral head (stage 3A) and the remaining 65 showed collapse of the head (stage 3B). In 74 hips ONFH was related to usage of corticosteroids, in 30 to alcohol and in 18 it was idiopathic.

The control group consisted of 155 hips in 139 patients. Of these 126 were women with a mean age of 57 years (20 to 81) and 13 were men with a mean age of 47 years (21 to 63). The aetiology was osteoarthritis (OA) in 109 hips, rheumatoid arthritis (RA) in 18, rapidly destructive arthroplasty of the hip (RDA) in 12, transient osteoporosis in four, pigmented villonodular synovitis in two, spondyloepiphyseal dysplasia in two, dialysis arthropathy in two, metastatic bone disease in two, primary bone tumour in one, ankylosing spondylitis in one, hyperparathyroidism with renal allograft in one and mixed connective tissue disease in one.

Based on the final histological diagnosis, the sensitivity and specificity of a number of clinical and radiological tests were calculated as in Figure 1. The sensitivity and specificity of a group of tests were considered in an attempt to identify those most appropriate for clinical application.

**Results**

The sensitivity and specificity of each criterion are shown in Table II. In the major criteria, the sensitivity of the crescent sign was low (27%) and the sensitivities of the other imaging tests were moderate (53% to 69%). By
contrast, the specificities of radiography, bone scanning and MRI were very high (96% to 100%). Three cases of RDA showed a false-positive result with depression of the femoral head without narrowing of the joint space or acetabular abnormality. One bone tumour, a chondroblastoma, had a false-positive result for the demarcating sclerosis without narrowing of the joint space or acetabular abnormality. Two cases of RDA presented with a false-positive crescent sign. Four of OA, one of RDA and one of chondroblastoma had a false-positive ‘cold-in-hot’ sign on the bone scan. Histologically, all the seven core biopsy specimens of stage-1 ONFH had trabecular and marrow necrosis (‘necrotic’ zone) adjacent to viable bone and marrow (‘viable’ zone) with an intervening zone of repair (‘reparative’ zone) on the same section. All the four core specimens in transient osteoporosis showed bone-marrow oedema but the nuclei of the trabeculae did not disappear. Trabecular and marrow necrosis which was separated from the viable area of bone was seen in RDA, but was not identified as osteonecrosis because it was assumed to be secondary to mechanical fragmentation.

Of the minor criteria, depression of the femoral head with narrowing of the joint space and radiolucency or sclerosis without narrowing or acetabular abnormality had a relatively high specificity (89% and 94%, respectively) but very low sensitivity (17% and 21%, respectively). The specificity of flattening of the upper area of the femoral head on radiographs, ‘cold or hot’ on bone scans, homogeneous or inhomogeneous low intensity without the band pattern on T1-weighted images and hip pain were low (0% to 10%). The history of steroid use or alcohol abuse showed high sensitivity (88%) and specificity (89%).

When ONFH is diagnosed with four or more positive minor criteria including at least one radiological feature, the sensitivity was 100% but the specificity was only 2% (Table III). With one positive major criterion, the specificity increased to 94%. With two positive major criteria, the specificity further increased to 97% but the sensitivity

![Diagram showing the sensitivity and specificity of the diagnostic tests: a, true-positive; b, false-positive; c, false-negative; and d, true-negative.](image)

### Table II. Sensitivity and specificity of each diagnostic criterion

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Number of hips</th>
<th>True-positive</th>
<th>False-negative</th>
<th>False-positive</th>
<th>True-negative</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Radiological</td>
<td>Depression of the femoral head</td>
<td>65</td>
<td>57</td>
<td>3</td>
<td>152</td>
<td>53</td>
<td>98</td>
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<td></td>
<td>Demarcating sclerosis in the femoral head</td>
<td>70</td>
<td>52</td>
<td>1</td>
<td>154</td>
<td>57</td>
<td>99</td>
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<tr>
<td></td>
<td>Crescent sign (subchondral fracture line)</td>
<td>33</td>
<td>89</td>
<td>2</td>
<td>153</td>
<td>27</td>
<td>99</td>
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<tr>
<td>Bone scan</td>
<td>Cold in hot</td>
<td>85</td>
<td>37</td>
<td>6</td>
<td>149</td>
<td>70</td>
<td>96</td>
</tr>
<tr>
<td>MRI</td>
<td>Low intensity band on T1-weighted images</td>
<td>67</td>
<td>55</td>
<td>0</td>
<td>155</td>
<td>55</td>
<td>100</td>
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<tr>
<td>Histology</td>
<td>Trabecular and marrow necrosis</td>
<td>122</td>
<td>0</td>
<td>0</td>
<td>155</td>
<td>100</td>
<td>100</td>
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<tr>
<td><strong>Minor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiological</td>
<td>Depression of the femoral head with narrowing of the joint space</td>
<td>21</td>
<td>101</td>
<td>17</td>
<td>138</td>
<td>17</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Cystic radiolucency or mottled sclerosis without acetabular abnormality or narrowing of the joint space</td>
<td>26</td>
<td>96</td>
<td>10</td>
<td>145</td>
<td>21</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>Flattening of the superior portion of the femoral head</td>
<td>73</td>
<td>49</td>
<td>139</td>
<td>16</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>Bone scan</td>
<td>Cold or hot</td>
<td>36</td>
<td>86</td>
<td>149</td>
<td>6</td>
<td>30</td>
<td>4</td>
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<tr>
<td>MRI</td>
<td>Homogeneous or inhomogeneous low intensity without the band pattern on T1-weighted images</td>
<td>54</td>
<td>68</td>
<td>153</td>
<td>2</td>
<td>44</td>
<td>1</td>
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<tr>
<td>Symptom</td>
<td>Hip pain with weight-bearing</td>
<td>105</td>
<td>17</td>
<td>155</td>
<td>0</td>
<td>86</td>
<td>0</td>
</tr>
<tr>
<td>History</td>
<td>Corticosteroid usage or alcohol abuse</td>
<td>107</td>
<td>15</td>
<td>17</td>
<td>138</td>
<td>88</td>
<td>89</td>
</tr>
</tbody>
</table>
decreased to 91%. With three or more positive major criteria, the specificity became 100% but the sensitivity further decreased (79% to 4%).

The sensitivity of each major criterion is shown in Table IV. The ‘cold-in-hot’ appearance on bone scans showed high sensitivity in stages 1 and 2 (72% and 75%, respectively) but it was most sensitive in stage 3A (81%). On the other hand, a low-intensity band on the T1-weighted images was most sensitive in stage 1 (100%). Stage-1 ONFH without the cold-in-hot sign showed ‘cold’ on bone scans in one (6%) and ‘normal’ in the remaining four (22%). Demarcating sclerosis in the femoral head was independent of other criteria but depression of the head and the crescent sign were dependent on each other, although 17 (14%) showed both signs simultaneously. When these two criteria were combined into one as ‘collapse of the femoral head’, the sensitivity increased to 65% while the specificity was still high (98%).

Criteria with more than 50% sensitivity and more than 95% specificity were chosen (Table V). Using these, the specificity of any sets of two positive new criteria was fulfilled two of the new criteria namely demarcating sclerosis and a cold-in-hot on bone scan. The specificity of two positive new criteria was 91% but it was 100% when cases of stage-4 ONFH were excluded.

### Discussion

Although many different techniques have been used in the early diagnosis of ONFH no single method has been shown to give an accurate diagnosis. It has been suggested that criteria for systemic lupus erythematosus and rheumatoid arthritis be included for more accurate diagnosis. It would also be beneficial for non-orthopaedic practising physicians since ONFH is often associated with other medical problems. The JIC diagnostic criteria are met, but the accuracy and efficacy of the criteria have to be clarified and simplified.

The specificity of the previous major criteria was high and appropriate for diagnosis but that of minor criteria was lower and of limited value.

Of the major criteria, the presence of the crescent sign is early evidence of collapse and depression of the femoral head occurs late. These should be combined into one. Differentiation of the findings on the bone scan into ‘cold in...
hot’ and ‘cold or hot’ and of MRI on T1-weighted images into ‘band pattern’ and ‘homogeneous or inhomogeneous pattern’, gave high specificity. The ‘double-line sign’ on T2-weighted images has been reported to be specific[11,12] but our study showed sufficient specificity of the band pattern on T1-weighted images. It also showed better sensitivity than the ‘cold-in-hot’ appearance in stage 1 (Table IV).

Although, theoretically, ONFH presents ‘cold’ on bone scans before ‘cold in hot’ appears,[34] only one case of stage-1 ONFH was judged to be ‘cold’. Since the judgement of ‘cold’ or ‘normal’ is qualitative and the resolution of bone scans is low, the sensitivity of bone scans for the detection of stage-1 ONFH is not as high as that of MRI.

Histological examination showed 100% of sensitivity and specificity in our study because the femoral heads were available for histology in most cases. Caution must be taken in the diagnosis of biopsy specimens since it may give both false-negative and false-positive results.

When the diagnostic criteria were simplified into the five (Table V), 99% of specificity was achieved with any two positive criteria. It is important to rule out bone tumours which may present similar features. Several types of dysplasia which have a thickened portion of cartilage and may have a similar appearance to ONFH on radiographs should also be differentiated. The sensitivity of two positive criteria was 91% but it was 100% when applied to ONFH in stages 1 to 3. It is not possible to detect stage-0 ONFH on T1-weighted images or in a bone scan. This requires further study although the period of stage 0 should not be as long as four weeks.[35,36]

Our findings have shown that there are five criteria which give the most effective diagnosis of ONFH (Table V). Definite ONFH was diagnosed by fulfilling any sets of two of the criteria with the exclusion of bone tumours and dysplasias.

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References


