

Detection of Femoral Head Avascular Necrosis in Adults by SPECT*

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Twenty-one adult patients with the clinical diagnosis of avascular necrosis (AVN) of the femoral head were examined with radionuclide angiography, planar bone scintigraphy, and single photon emission computed tomography (SPECT). A final diagnosis of AVN was established for 15 symptomatic patients with a total of 20 involved hips. SPECT and planar bone scintigraphy were considered positive for AVN only if a photopenic bony defect could be identified. Using SPECT bone scintigraphy, 12 of 15 symptomatic patients and 17 of 20 involved hips (sensitivity of 0.85) were correctly identified, whereas with planar imaging only eight of 15 patients and 11 of 20 involved hips were detected. There were no false-positive diagnoses on SPECT or planar bone scintigraphy. In addition, hyperemia in the region of the proximal femoral metaphysis was demonstrated in six of 20 involved hips. It is concluded that by identifying a photopenic defect that is not evident on planar views, SPECT can contribute to the diagnosis of AVN of the femoral head. In addition, metaphyseal hyperemia appears to be a promising new scintigraphic sign of AVN worthy of further investigation.

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A photon deficient defect in the femoral head frequently is the earliest scintigraphic evidence of avascular necrosis (AVN) of the adult hip. Bone scintigraphy may demonstrate absent or decreased femoral head activity before any radiographic changes are present (1-14), and even the serendipitous scintigraphic finding of femoral head AVN before the onset of symptoms has been reported (3,15). Subsequently, over a period of weeks to months, increased scintigraphic activity appears in the femoral metaphysis and in the bone adjacent to the articular surfaces of the involved hip. This progression of findings is probably due to hyperemia with ingrowth of osteoblasts upward from the metaphysis as well as the development of osteoarthritis in the joint (2,3,9). Eventually, the zone of increased scintigraphic activity advancing from the metaphysis into the femoral head may merge with the increased activity about the hip joint and totally obliterate the original photon deficient defect initially seen in the femoral head (2,3,9,10,12,14). As long as the photon deficient

defect can still be imaged, the scintigraphic diagnosis of AVN can be made with confidence. However, once the photon deficient defect has been obliterated or obscured, it may be difficult to distinguish AVN from osteoarthritis, fracture, inflammatory arthritis, or other causes for increased bony repair (9,10,12,16).

Because the posterior margin of the acetabulum extends downward behind the femoral head, a photon deficient defect within the femoral head may be obscured on anterior view planar images by increased scintigraphic activity originating in the underlying acetabulum. However, using single photon emission computed tomography (SPECT), it is possible to separate underlying and overlying distributions of activity into sequential tomographic images. For this reason, SPECT imaging should improve detection of any photon deficient zone within the femoral head. Therefore, to determine the diagnostic efficacy of SPECT bone scintigraphy, we examined a series of adult patients referred to our laboratory with the clinical diagnosis of AVN of the femoral head.

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MATERIALS AND METHODS

Twenty-one adult patients with the clinical diagnosis of AVN of the femoral head were examined with plain

film radiography, radionuclide angiography, planar scintigraphy, and technically optimal SPECT bone scintigraphy. An additional five referred patients were excluded from the study because of imaging artifacts created by rapid bladder filling during SPECT acquisition. Ages ranged from 19 to 74 yr (mean of 40 yr) with 12 males and nine females included in the series. These patients had suffered from hip pain for as little as 1 day or as much as 18 mo (mean of 5 mo). While all 21 patients underwent bone scintigraphy to confirm the clinical diagnosis of AVN, recognized risk factors for AVN were identified in only 16 cases: renal transplantation with steroid therapy (six), high dose steroid therapy without transplantation (four), alcoholism (four), fracture-dislocation (one), and radiation therapy (one). For 15 patients with 20 involved hips a final diagnosis of femoral head AVN was established either by histologic examination following total hip replacement (nine hips) or by subsequent appearance and progression of radiographic changes previously established as diagnostic of AVN (11 hips) (18-20). Two patients with traumatic injuries (stress fracture of the femoral neck and osteochondral fracture-dislocation of the femoral head) also were encountered in the series. The four remaining patients, who were radiographically normal and did not complain of hip pain 3 mo later, were thought to have no significant bone pathology.

Radionuclide angiography performed following the bolus i.v. injection of 25 mCi (925 MBq) of technetium-99m medronate consisted of eight sequential, 5-sec, anterior view images of the hips followed immediately by a 500,000-count blood-pool image. Three hours later, 500,000-count anterior view bone scintigrams of the hips were obtained using a large field-of-view gamma camera equipped with a high-resolution collimator. SPECT examinations were performed with a rotating gamma-camera device* equipped with a low-energy, general-purpose collimator. All data were acquired and processed as 64 X 64 matrices. Sixty-four projections over 360° were acquired for 20 sec per projection. Following uniformity correction and a nine-point smooth for each projection, 6-mm-thick transaxial, coronal, and sagittal tomograms were reconstructed using filtered back projection with a ramp filter. While it was of value to have all three tomographic planes simultaneously available at the time of interpretation, photopenic defects in the femoral head were seen to best advantage on the coronal tomograms. A log map was used when photographing SPECT images on transparencies. Radiographic evaluation consisted of AP views obtained both in a neutral position and with abduction and external rotation. In questionable cases, 3 to 1 magnification radiographs were obtained using a technique described elsewhere (17). When both planar and SPECT bone scintigraphy failed to demonstrate a photon deficient defect in a symptomatic hip, 100,000

count 2 or 4 mm pinhole collimator views were obtained.

Radionuclide angiography, planar bone scintigraphy, and SPECT were evaluated independently without benefit of clinical or radiographic correlation. Radionuclide angiography was scored for oligemia over the femoral head and hyperemia in the region of the proximal femoral metaphysis. Four adult patients without hip pain undergoing bone scintigraphy for other indications previously were examined to establish the appearance of the normal hip on SPECT bone imaging. SPECT and planar bone scintigraphy were considered to be positive for AVN only if a photopenic defect could be identified in the femoral head. On high-resolution collimator planar images, a photopenic defect within the femoral head typically demonstrated less activity than the central portion of the ipsilateral sacroiliac joint. On coronal SPECT bone images, a photopenic femoral head typically demonstrated less activity than the ipsilateral femoral neck. However, in addition to intensity of femoral head activity, size, and configuration of a potential abnormality were considered before a femoral head was classified as showing a photopenic defect. Furthermore, increased activity throughout the femoral head was not considered to be diagnostic of AVN.

Radiographs were evaluated for AVN without knowledge of the clinical or scintigraphic findings by a skeletal radiologist (GFC) using previously described criteria (18-20). In addition, to simplify the radiographic findings for subsequent analysis, all hips with radiographic abnormalities were classified as showing femoral head flattening, subchondral fracture ("crescent" sign), and/or osteoarthritic changes.

RESULTS

When a photopenic defect was used as the diagnostic criterion for AVN, SPECT correctly identified both 17 of 20 involved hips (sensitivity 0.85) and 12 of 15 patients suffering hip pain due to AVN (sensitivity 0.80). As shown in Table 1, the results of SPECT were better than the 0.55 sensitivity (chi-square test with $p < 0.05$) and 0.53 sensitivity of planar scintigraphy for identifying involved hips and patients, respectively. For example, Fig. 1 shows a photopenic defect in the left

TABLE 1
Diagnostic Sensitivity for AVN of Adult Femoral Head

Item	Symptomatic patients	Involved hips
SPECT scintigraphy	0.80	0.85
Planar scintigraphy	0.53	0.55
Abnormal radiographs	0.67	0.55
"Crescent" sign	0.33	0.30

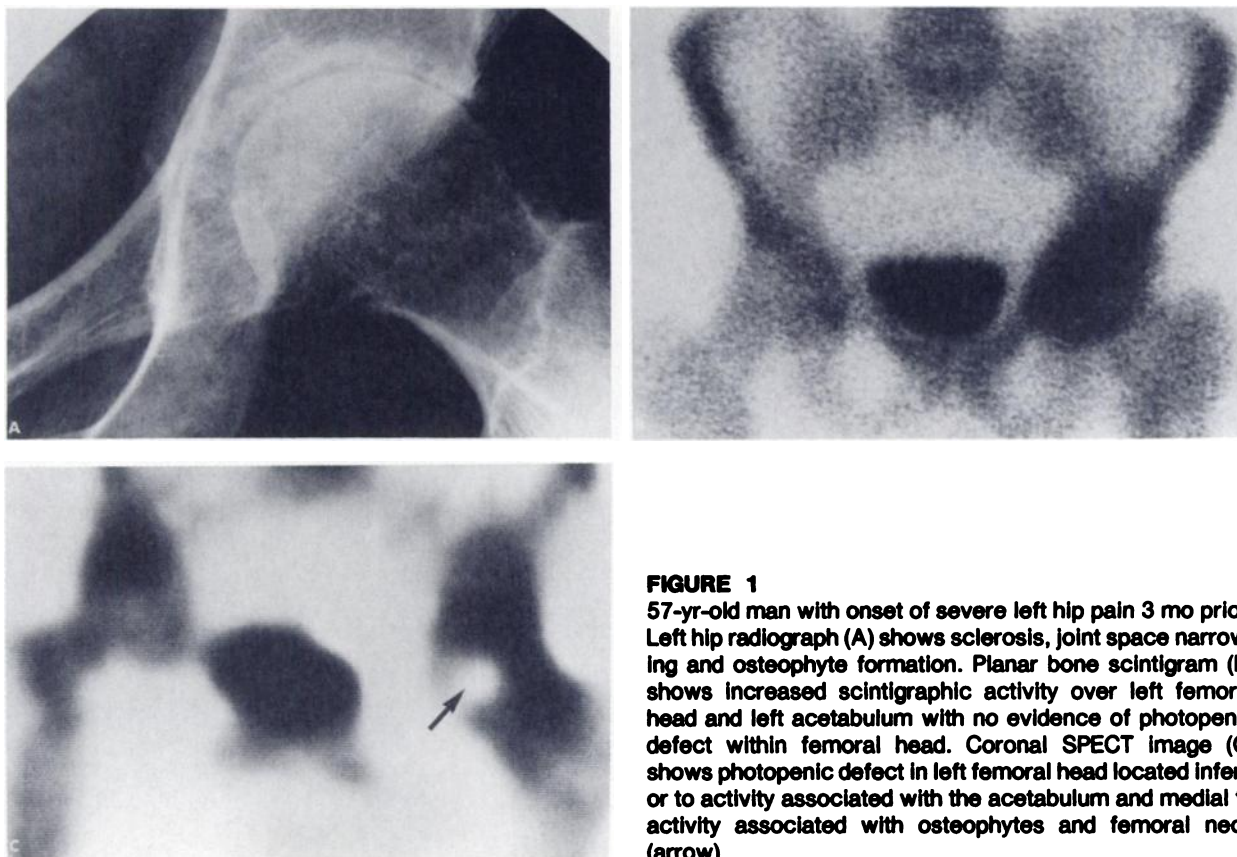


FIGURE 1
 57-yr-old man with onset of severe left hip pain 3 mo prior. Left hip radiograph (A) shows sclerosis, joint space narrowing and osteophyte formation. Planar bone scintigram (B) shows increased scintigraphic activity over left femoral head and left acetabulum with no evidence of photopenic defect within femoral head. Coronal SPECT image (C) shows photopenic defect in left femoral head located inferior to activity associated with the acetabulum and medial to activity associated with osteophytes and femoral neck (arrow)

femoral head seen only with SPECT. This 57-yr-old male had suffered minimal left hip pain for many years with the onset of severe left hip pain 3 mo prior. Radiographs at the time of bone scintigraphy showed sclerosis, joint space narrowing, and osteophyte formation. However, a subchondral fracture was evident only on a follow-up radiograph 1 mo later. Figure 2 shows the radiographs and bone scintigrams of a 52-yr-old woman treated with prednisone for chronic active hepatitis for whom histologic proof of AVN is available. At the time of scintigraphy the patient had been bothered by left hip pain for 4 mo. Radiographs show left femoral head flattening and sclerosis. The anterior view planar bone scintigram shows increased activity over the acetabulum and proximal left femur without convincing evidence of a photon deficient defect in the left femoral head. For the right hip the planar image shows prominence of activity involving the base of the femoral head and/or the subcapital portion of the femoral neck without a photopenic defect in the right femoral head. SPECT images and histogram analysis through both hips clearly demonstrate a photon deficient defect within the left femoral head. In addition, a photon deficient defect is seen within the asymptomatic and radiographically normal right femoral head. One month later, despite limited weight-bearing, the patient developed right hip pain. Radiographs at that time showed a new

subchondral fracture in the right femoral head. Because of increasingly severe hip pain the patient eventually underwent bilateral total hip replacements. AVN was found in both resected femoral heads.

For six hips with a photopenic defect evident on SPECT but not planar bone scintigrams, the duration of symptoms ranged from 1 to 18 mo. Neither duration of symptoms nor radiographic findings distinguished these six false-negative planar bone scintigrams from the 11 other instances of confirmed AVN in which both planar and SPECT bone scintigraphy correctly identified a photopenic defect.

For this series there were no false-positive diagnoses of AVN on either planar or SPECT bone scintigraphy (specificity 1.00). In particular, AVN was correctly excluded for four symptomatic patients without significant bone pathology, one patient with femoral neck stress fracture, one patient with osteochondral fracture-dislocation of the femoral head, and in the contralateral hip of ten patients eventually shown to have only unilateral femoral head AVN. Furthermore, in a pilot study of four asymptomatic patients undertaken to establish the normal appearance of SPECT images, neither SPECT nor planar bone scintigraphy identified photopenic defects in the femoral head. Nonetheless, imaging of a greater number of normal asymptomatic individuals in addition to imaging of patients suffering

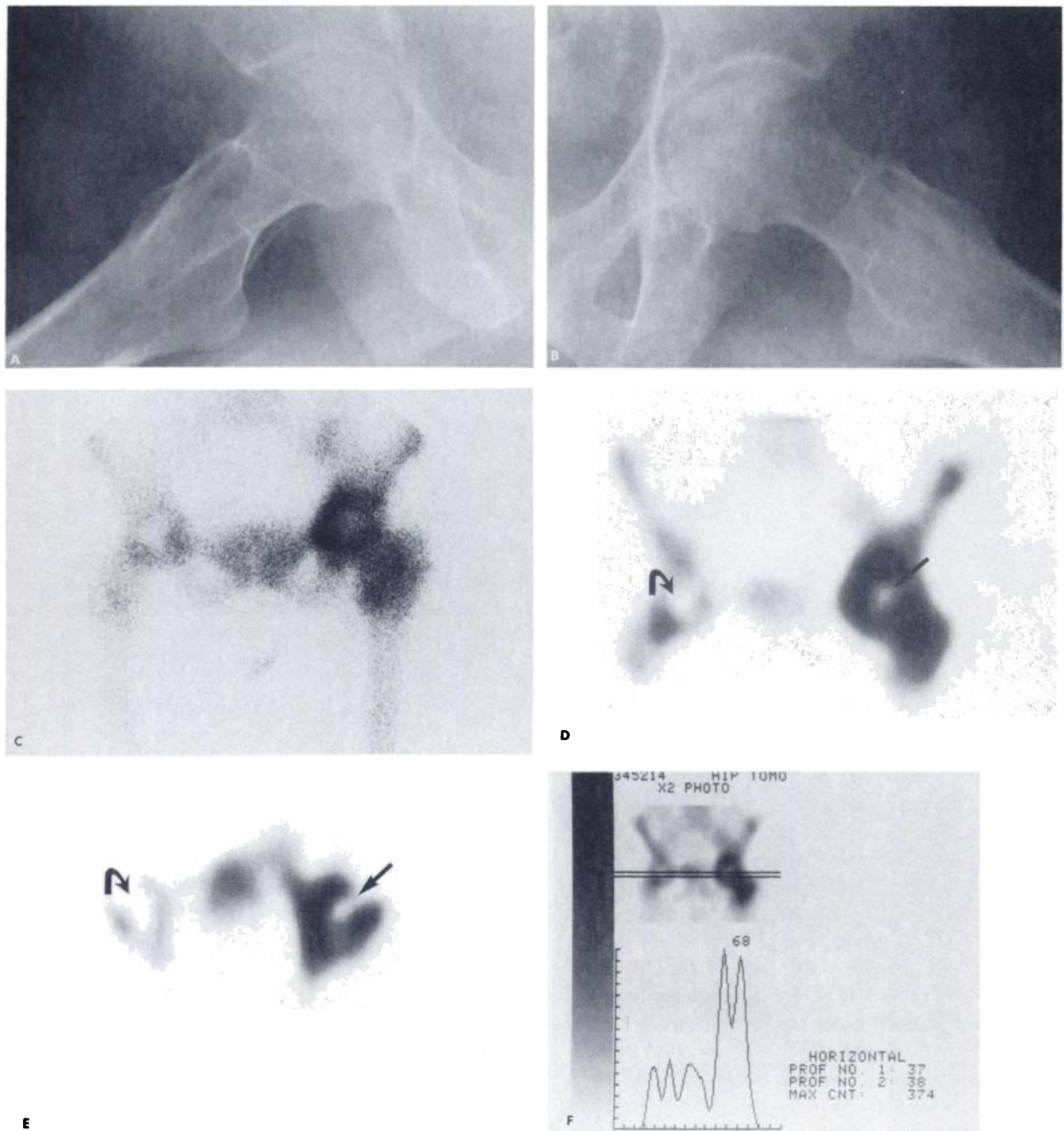


FIGURE 2

52-yr-old woman treated with prednisone for chronic active hepatitis had experienced left hip pain for 4 mo. Normal right hip radiograph (A). Left hip radiograph (B) shows sclerosis and flattening of femoral head. Anterior view planar bone scintigram (C) shows increased activity over acetabulum and proximal left femur without convincing evidence of photon deficient defect in left femoral head. Coronal (D) and transaxial (E) SPECT bone scintigrams through both hips clearly demonstrate central photon deficient defect surrounded by increased activity within left femoral head (straight arrow). In addition, photon deficient defect is seen within asymptomatic right femoral head (curved arrow). Histogram analysis (F) confirms photon deficient defects within both femoral heads

hip pain from a wide variety of bone and soft-tissue pathologies is needed before the specificity of SPECT bone scintigraphy for avascular necrosis of the femoral head can be conclusively demonstrated.

There were no instances in this adult population in

which pinhole planar views demonstrated a photon deficient defect that SPECT bone scintigraphy failed to detect. For example, Fig. 3 shows high resolution collimator, pinhole collimator, and SPECT bone scintigrams for a 62-yr-old man with a 4-mo history of right

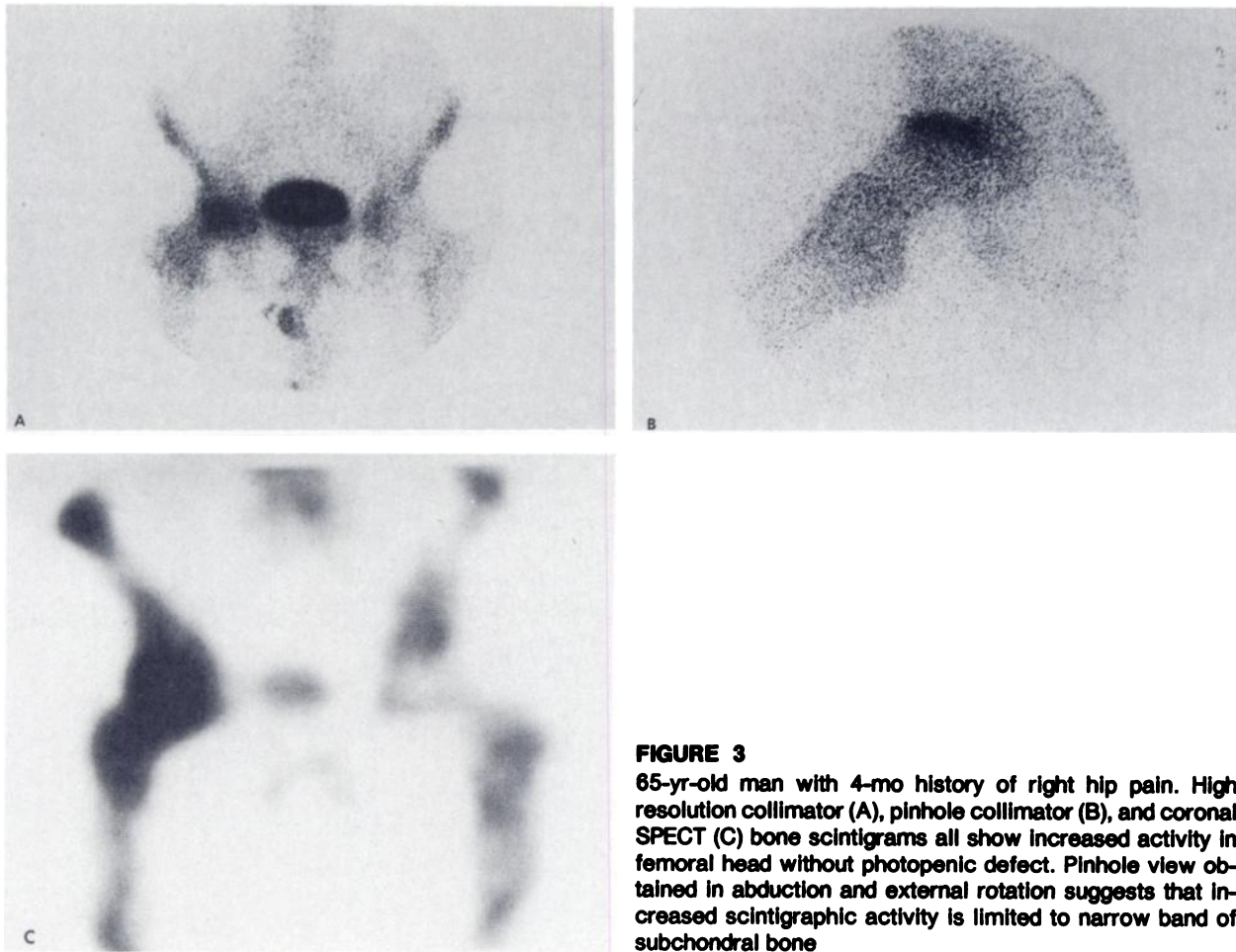


FIGURE 3

65-yr-old man with 4-mo history of right hip pain. High resolution collimator (A), pinhole collimator (B), and coronal SPECT (C) bone scintigrams all show increased activity in femoral head without photopenic defect. Pinhole view obtained in abduction and external rotation suggests that increased scintigraphic activity is limited to narrow band of subchondral bone

hip pain. Radiographs at the time of scintigraphy were normal. All bone scintigrams show increased activity in the femoral head without a photopenic defect. The pinhole view obtained in abduction and external rotation suggests that the increased scintigraphic activity is limited to a narrow band of subchondral bone without the deeper bony involvement often seen with AVN of the femoral head. Subsequently, because of severe pain, the patient underwent total hip replacement with confirmation of AVN in the resected right femoral head.

When used to examine the 20 hips with confirmed AVN, radionuclide angiography and blood-pool imaging never demonstrated oligemia over the femoral head. However, for six out of 20 hips with AVN, hyperemia was demonstrated in the region of the proximal femoral metaphysis (sensitivity 0.30). For example, Fig. 4 shows radionuclide angiography along with both planar and SPECT bone scintigraphy for a 26-yr-old woman with a 1 mo history of right hip pain. On both the 5-sec per image flow study and the blood-pool image, hyperemia is seen in the region of the right femoral metaphysis. This is located slightly below and lateral to the expected location for hyperemia associated with intra-

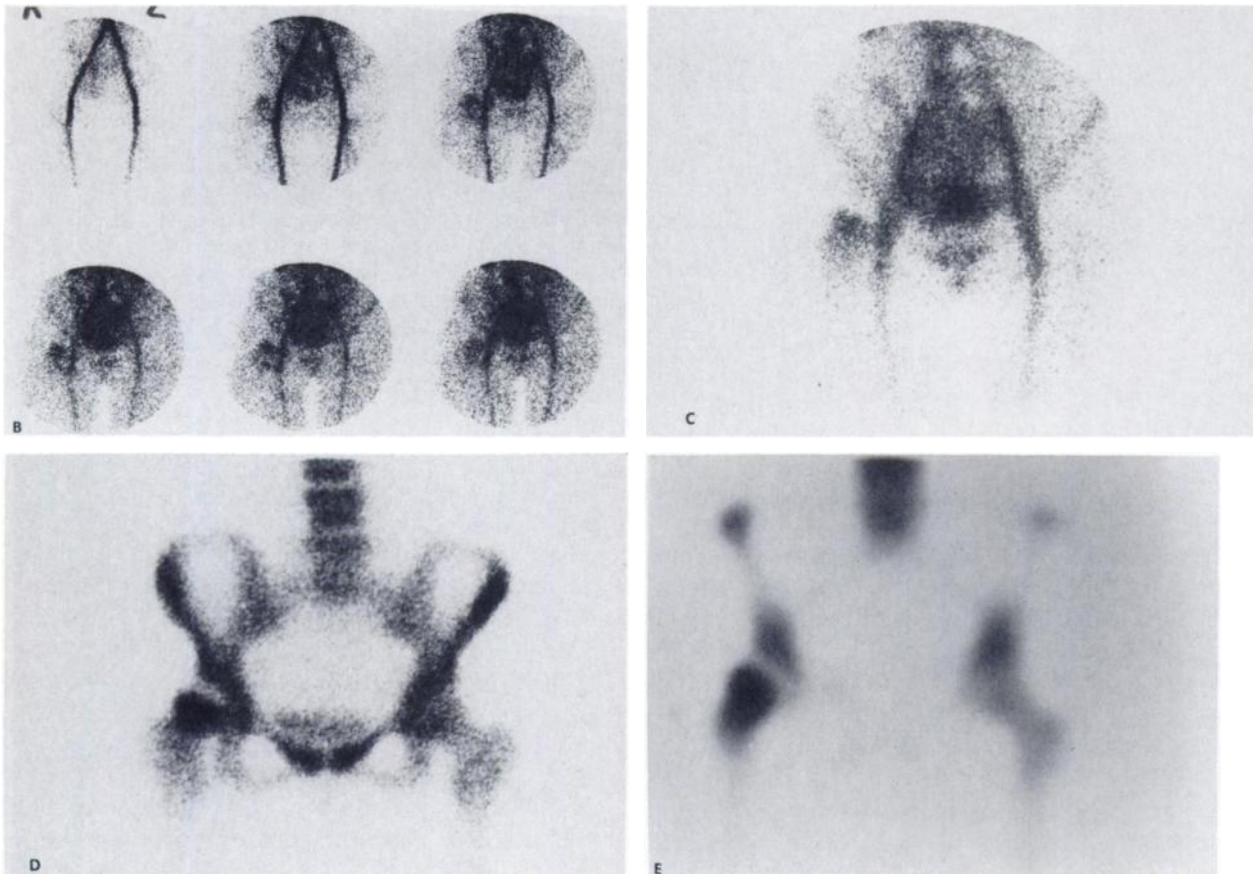
articular inflammation such as might be seen with septic arthritis. Both planar and SPECT bone scintigraphy show a photon deficient defect in the femoral head. This finding, which may represent collateral flow to the capsular arteries, was not present in the 20 femurs without AVN or trauma. However, for one case of femoral neck stress fracture and another instance of femoral head osteochondral fracture-dislocation, hyperemia was present at the hip. In addition, hyperemia over the proximal femoral metaphysis in association with AVN was present in one instance when both planar and SPECT bone scintigraphy were unable to identify a photopenic defect.

Of the 20 hips with AVN, 13 had radiographic abnormalities at the time of initial scintigraphy. As is shown in Fig. 5, a subchondral fracture—the most specific radiographic finding of early femoral head AVN—was present in only six instances. The other seven radiographically abnormal hips showed either flattening of the femoral head or osteoarthritic changes, findings generally not considered to be specific for AVN. Table 1 also shows the diagnostic sensitivity of radiographic examinations for AVN when either the highly specific “crescent” sign or any combination



FIGURE 4

26-yr-old woman with 1-mo history of right hip pain. Right hip radiograph (A) shows subchondral fracture. Five-second per image flow study (B) and blood-pool image (C) show hyperemia in the region of the right femoral metaphysis. Photon deficient defect is seen in right femoral head on both planar (D) and coronal SPECT (E) bone scintigrams



of abnormal radiographic findings (“crescent” sign, femoral head flattening, and/or osteoarthritic changes) was present.

While patients were asked to void before SPECT data acquisition, rapid bladder filling still contributed to unsatisfactory examination for five patients who

were excluded from the series. For example, Fig. 6 shows unsatisfactory SPECT image obtained when the patient’s bladder filled rapidly during the time of SPECT acquisition. As the 64 sequential projections were acquired, activity within the bladder increased. On the SPECT image, broad rays project beyond the

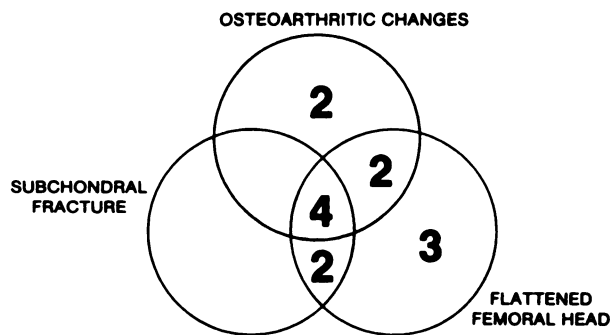


FIGURE 5
Distribution of abnormal radiographic findings for 13 of 20 hips with confirmed femoral head AVN. Remaining seven hips were normal radiographically at time of initial scintigraphy

bladder and in part obscure the femoral heads. When confronted with increasing activity in the bladder on the sequentially acquire 64 projections, the current reconstruction algorithm creates these artifacts. Bladder catheterization would eliminate this problem.

DISCUSSION

Most investigators using technetium-99m medronate or chemically similar radiopharmaceuticals report that avascular necrosis of the adult femoral head initially shows a photopenic defect (1-14). Increased scintigraphic activity over the acetabulum and in the proximal femoral metaphysis may be present at the time of initial scintigraphy or may develop over the course of weeks to months (2,3,9). Subsequently, the photopenic defect often is lost on planar scintigraphy amidst the ingrowth of osteoblasts upward into the adult femoral head and the increasingly severe osteoarthritic change in the joint (2,3,9,10,12,14). However, such osteoarthritic change in the posterior rim of the acetabulum—which overlies the upper and inner portion of the femoral head—may in part obscure a persistent photopenic defect. In addition, a thin peripheral rim of increased activity in the subchondral bone over the articular surfaces of the femoral head may obscure an underlying photopenic defect at the center of the femoral head. Strömqvist's published data suggests that for planar bone scintigraphy of a normal hip "less than half of the emission ascribed to the femoral head is derived from the femoral head itself" (21), and late in the case of AVN increased uptake adjacent to the avascular femoral head undoubtedly reduces the target-to-back-

ground ratio even further. However, by removing overlying and underlying activity from the tomographic plane containing the femoral head, SPECT bone scintigraphy improves image contrast and thereby facilitates detection of photopenic defects.

Using SPECT bone scintigraphy, a photopenic defect was found for 12 of 15 symptomatic patients and 17 of 20 hips with AVN, whereas with planar imaging only eight of 15 patients and 11 of 20 hips demonstrated this finding. The persistence for as much as 18 mo of these photon deficient defects distinguishes our results with SPECT from most previous reports which were based on a variety of planar scintigraphic techniques (1-3,16,21-24). However, this persistence of photopenic defects in the femoral head is consistent with the incomplete femoral head revascularization reported in the histologic study of AVN by Inoue and Ono (25). In studying 40 adult femoral heads involved with AVN, they found that, "the characteristic histopathological changes of recurrent necrosis were present in 83%. Recurrent necrosis occurred widely after revascularization had progressed as far as the subchondral zone." These same authors go on to conclude that once AVN has occurred, the adult femoral head may be subjected to repeated episodes of infarction.

The possibility of hyperemia in the region of the proximal femoral metaphysis and adjacent soft tissues in conjunction with AVN has not been stressed in the nuclear medicine literature. However, based on the findings of x-ray angiography, Theron reported that collateral vascular perfusion to the femoral head can form in adult AVN (26). Following occlusion of the capsular arteries early in AVN, a variable degree of collateralization occurs from vessels perfusing the femoral metaphysis and the acetabulum. It is tempting to speculate that when rich collateral flow is established from the medial circumflex artery or other vessels near the metaphysis, a metaphyseal hyperemia characteristic of AVN may be demonstrated by radionuclide angiography. Because such collaterals may not form, the finding is not present in every case of femoral head AVN, and other causes for metaphyseal hyperemia such as a localized form of the reflex sympathetic dystrophy syndrome (27) might account for this finding. Metaphyseal hyperemia does appear, however, to be a promising new scintigraphic sign of AVN worthy of further investigation. The location of hyperemia in the proximal femoral metaphysis rather than the hip joint should aid in distinguishing AVN from septic arthritis or other inflammatory intra-articular processes.

We conclude that when a photopenic defect is used as the scintigraphic criterion for AVN, SPECT bone scintigraphy is more sensitive than either planar imaging or



FIGURE 6
Transaxial SPECT image through femoral heads which was obtained when patient's bladder filled rapidly during the time of SPECT acquisition. Broad rays project beyond bladder and in part obscure femoral heads

radiography. This is true not only when the patient first complains of hip pain but also when symptoms have been present for as long as 18 mo. By identifying a photopenic defect that is not evident on planar views, SPECT can contribute to the accurate diagnosis of AVN of the femoral head. It is hoped that in those instances when AVN is present but a photopenic defect is not detected that the newly described sign of AVN-induced metaphyseal hyperemia will aid in establishing the correct diagnosis.

FOOTNOTE

* 400T, General Electric Medical Systems Group, Milwaukee, WI.

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