ADDITIONAL DIAGNOSTIC TECHNIQUES

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A comprehensive clinical history and physical examination of an individual whose prospective employment might involve the risk of osteonecrosis should include assessment of any disease in his background known to have an association with avascular necrosis. If routine roentgenograms are positive or questionable with respect to articular involvement, or if an employee later becomes symptomatic even though his X-ray films reveal no evidence of osteonecrosis, appropriate medical consultation is suggested. Additional diagnostic techniques may then be recommended, as follows.

LABORATORY TESTS

When laboratory tests are indicated, the patient is usually hospitalized. These procedures may include: a complete blood count, urinalysis, sedimentation rate, multiphasic chemistry panel, rheumatoid-arthritis agglutination test, lupus erythematosus preparation, serum uric-acid determination, serum hemoglobin electrophoresis, liver-function panel (including bromsulphalein retention, serum alkaline phosphatase, and SGOT), liver biopsy, serum amylase, serum lipase, chemical fractionation of lipids (including serum cholesterol, triglycerides, and phospholipids), four-hour glucose-tolerance test, platelet count, prothrombin time, and partial thromboplastin time.

When nontraumatic fat embolism is suspected, additional blood and urine tests are performed. Methods currently used for the detection of lipiduria (Peltier, 1965) may not be sufficiently sensitive to detect low-grade traumatic or nontraumatic fat embolism (Fig. 1). Fat is not a normal constituent of urine (Beams, 1956), nor do fat globules appear in the urine in experimental hyperlipidemia (Scuderi, 1939). A simple qualitative ether-extraction method has been developed (Jones, 1972) that is specific, provided caution is taken to avoid false-positive results due to nonembolic fat in the urine. Since the presence of cellular elements — oval fat bodies, fatty casts, fatty epithelial cells, and fatty degenerating leukocytes (sudanophils) — or of fat-containing fungi (*Candida albicans*) invalidates the results, microscopic examination of urinary sediment is essential in all cases. Fat contamination of the glassware or solutions used in the test by soaps or oily lubricants must be avoided. Similarly, paraffin containers are not to be used for collecting specimens.

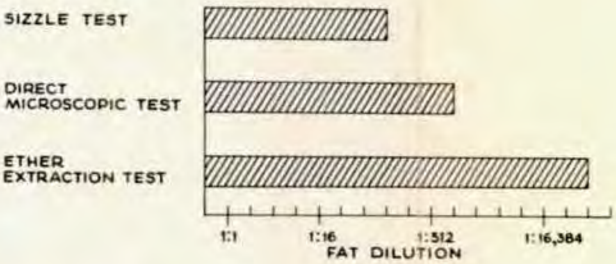

FIG. 1. Comparative sensitivity of tests for urine-fat determinations.

A simple test, in which plasma is stained for fat, has recently been developed (Nice, 1972) and may also be useful in the diagnosis of nontraumatic fat embolism. The most definitive means of diagnosing systemic fat embolism *in vivo* is by performing fat stains of percutaneous renal biopsy specimens.

When rheumatoid arthritis, gouty arthritis, septic arthritis (pyarthrosis), or osteomyelitis is suspected, a diagnostic arthrocentesis with synovianalysis is performed. It includes appropriate cultures, polarized light examination for uric-acid crystals, and determination of a rheumatoid factor.

SPECIALIZED RADIOLOGIC TECHNIQUES

Tomography

Tomography is performed when routine roentgenograms appear normal or questionable (Fig. 2). Tomograms performed of early juxta-articular lesions, before there is any evidence of gross architectural distortion or articular incongruity, often show cone-shaped lesions. The apex of the

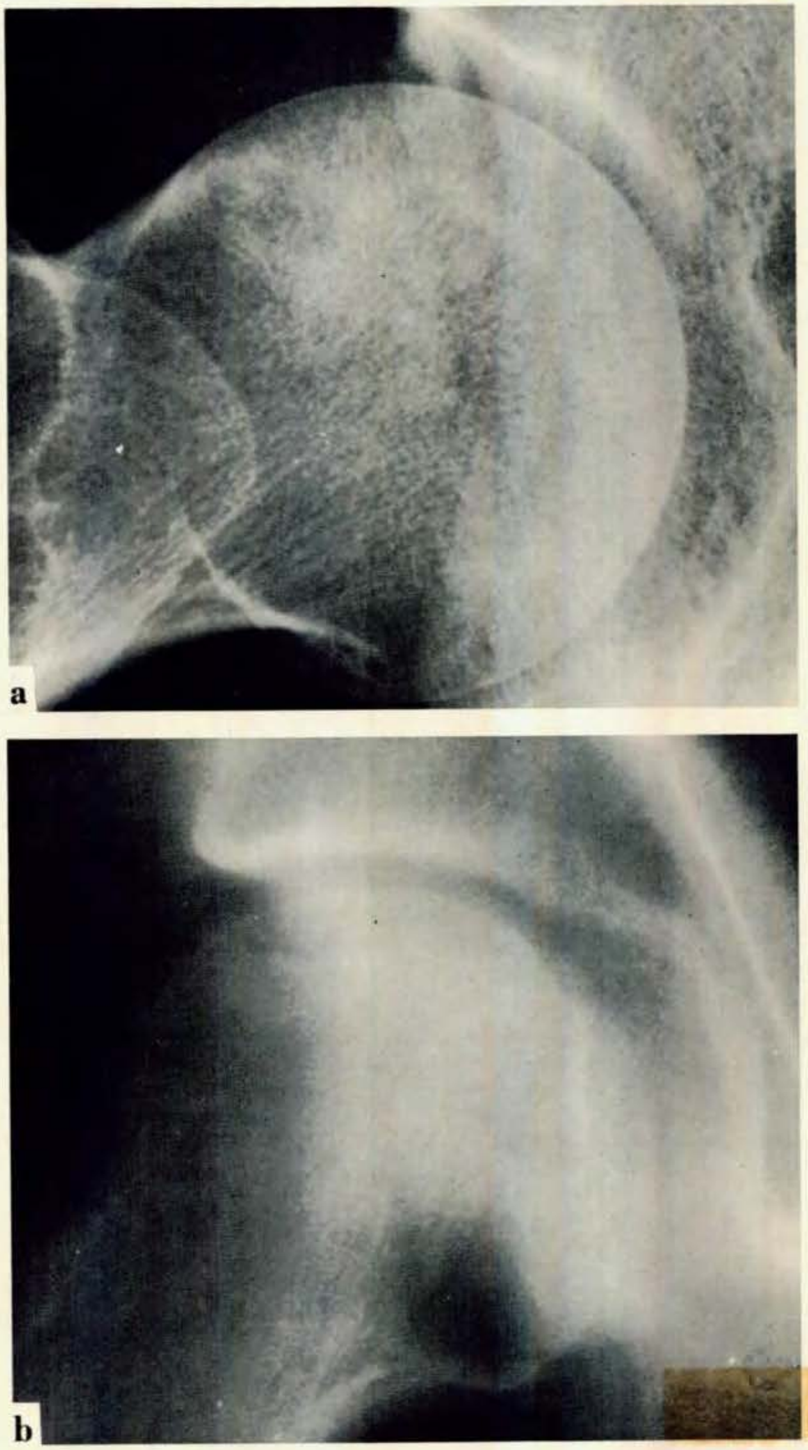

FIG. 2. R femoral head of patient who developed Type I decompression sickness near end of 600- and 650-ft dives. (*a*) Lateral roentgenogram 3½ yr later shows diffuse area of central rarefaction surrounded by patchy sclerosis involving anterior portion of head and extending from region of obliterated epiphyseal line to subchondral region. (*b*) These findings were confirmed on A-P tomogram, which reveals obvious subchondral irregular radiolucency and sclerosis without evidence of segmental collapse.

wedge is usually near the center of the obliterated epiphyseal line with the base of the lesion underlying the articular cartilage. In addition, areas of diffuse or marginal sclerosis or spotty rarefaction are often noted.

Positioning patients for tomography of the humeral head to avoid glenoid superimposition requires a 45° anterior oblique projection. To lift the angle of the acromion away from the humeral head, and to avoid superimposition of the coracoid process, the X-ray tube is tilted 15° inferior, with the humerus in full internal and external rotation. The full external rotatory view in the anterior-inferior-oblique projection (Inman-Temple-Jones) reveals lesions within the central third of the humeral head. Classic "snowcap" lesions of the humeral head are likewise revealed by tomograms in this projection.

Radionuclide Bone Scanning

When routine roentgenograms and tomograms still have not resolved the diagnosis, radioactive sodium fluoride (^{18}F) or technetium polyphosphate (^{99m}Tc) bone scans are performed to assess the vascularity of the femoral and humeral heads and the knees. Incorporation of ^{18}F into bone appears to depend on the exchange of fluoride ions with hydroxyl ions, not only at the surfaces but also within the interior of the hydroxyapatite crystals. Initial distribution of ^{18}F within bone is dependent on the blood-perfusion rate.

Inability to demonstrate increased uptake in a lesion indicates delayed revascularization. Incomplete revascularization and repair in the subchondral region of the femoral or humeral head probably account for late structural collapse. Radionuclide scanning is therefore likely to be a more reliable method of estimating circulation to bone than radiographs are, since positive scans are often obtained before distinct X-ray changes appear. The most effective bone-scanning agent for osteonecrosis is probably ^{18}F, since it decays rapidly (its physical half-life is 1.87 hours), which permits scanning with a minimal radiation dose to the patient. In addition, rapid clearance from plasma, rapid urinary excretion, and high specificity for active bone deposition combine to produce excellent contrast between lesion and normal bone. The scanning time is 90 minutes, with a parenteral dose of 30 to 60 millirads for bone scanning.

Another bone-scanning agent is strontium-85 (^{85}Sr). But its physical half-life is long — 65 days — and its turnover rate in bone, slow, resulting in long scanning times. Radioactive strontium (^{87m}Sr), like radioactive fluoride (^{18}F), subjects the patient to minimal irradiation, thereby permitting studies of nonmalignant conditions. But ^{87m}Sr is expensive and has 95% retention during the first few hours, which results in relatively high background radiation. Radioactive calcium (^{47}Ca) has not proven effective in the scanning-image evaluation of osteonecrosis. Recently ^{99m}Tc has been found to provide very satisfactory skeletal imaging of early lesions; it is, furthermore, less expensive and more available than ^{18}F.

SPECIAL SURGICAL PROCEDURES

When routine roentgenograms, tomograms, or radionuclide scans reveal juxta-articular lesions without evidence of articular incongruity, whether the patient is symptomatic or not, certain diagnostic procedures may be performed through a small lateral thigh incision, usually with spinal anesthesia and with biplane roentgenographic localization.

Radioactive Phosphorus (^{32}P) Uptake Study

This technique is adapted from Boyd and Calandruccio (1963) and involves radioactive phosphorus (^{32}P), which emits beta rays. It is a bone-seeking isotope, with a half-life of 14.3 days and a soft-tissue penetration of 7 mm.

Approximately 90 minutes prior to surgery, 500 microcuries of a buffered solution of ^{32}P are administered intravenously. Under biplane roentgenographic control, a calibrated localization pin is drilled into the area of the lesion in a femoral (or humeral) head and is replaced by a surgical scintillation detector probe (Fig. 3*a*).

The probe has a cesium iodide crystal that is sensitive to beta emission, and its handle encloses a photomultiplier tube and preamplifier. The probe is lightweight, cold-sterilized, and more sensitive than the Geiger-Müller instrument, and it can be used with any standard rate meter. The recorded radiation is derived from bone immediately surrounding the probe tip.

The uptake of ^{32}P in a femoral-head lesion (Fig. 3*b*) is recorded, and the probe is then withdrawn to the trochanteric region (Fig. 3*c*) where an uptake is recorded for comparison. A trochanter-to-head (T H) ratio is calculated, expressing uptake by the lesion in comparison with uptake by a segment of bone with an unimpaired blood supply.

If circulation to the lesion is interrupted, there is little uptake for at least two hours following the injection of ^{32}P, while there will be sufficient uptake in the trochanteric region for comparative purposes. Predictions of viability derived from

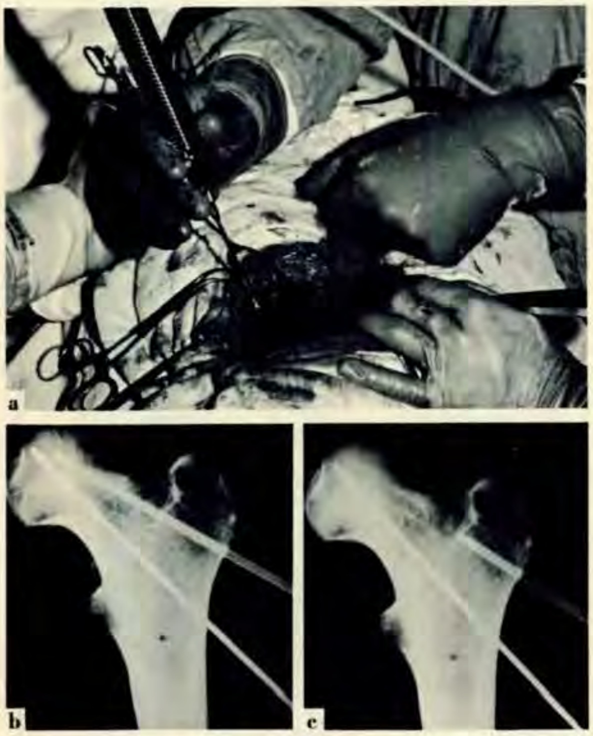

FIG. 3. (*a*) Scintillation probe being introduced into femoral head through predrilled hole in lateral cortex. (*b*) Sensitive cesium iodide tip of scintillation probe is localized in dry specimen of proximal femur, indicating usual location for femoral-head determinations. (*c*) Comparative location of probe for trochanteric ^{32}P uptake readings.

T/H ratios of less than 3/1 and of nonviability from readings of 6/1 or more are approximately 90% accurate. Certain modifications of this method were made after examination of 28 patients with intertrochanteric or femoral-neck fractures in an attempt to predict posttraumatic avascular necrosis of the femoral head (Jones and Bovill, 1972).

Well-demarcated, wedge-shaped subchondral lesions surrounded by a substantial zone of marginal sclerosis show no significant radioactivity within the subchondral region (T/H ratio exceeds 6/1). On the other hand, there is often indirect evidence of hypervascularity immediately subjacent to the sclerotic margin (T/H ratio, 1/1.5), suggesting that the revascularization process has not been successful in penetrating the lesion's fibrous avascular boundary.

Differential Oximetry and Intramedullary Pressure Determinations

Probe oximeters have been used without success in measuring differential oxygen tensions between a lesion and the greater trochanter (Woodhouse, 1962). Currently a simpler method is used, whereby a cannula and obturator are inserted into the lesion within the femoral (or humeral) head; heparinized blood specimens are obtained from the affected region and the greater trochanter. The patient breathes alternately room air and 100% O_2 by mask, and comparable specimens of blood are obtained from the trochanteric region. If the lesion has sufficient vascularity, O_2 tension of the aspirated blood will ordinarily increase significantly with 100% O_2 inspiration. Often, however, attempted aspiration of the lesion results in a "dry tap."

Next, the obturator is reintroduced and a simple three-way stop-cock and spinal-fluid manometer are added to the cannula. The intramedullary blood pressure in the lesion itself is not important. But the presence or absence of fluctuations in manometric pressure caused by arterial pulse pressure is significant. The absence of manometric fluctuations within the lesion, and their presence in the trochanteric region, are considered confirmatory evidence of avascularity (Miles, 1959).

Intraosseous Phlebography

Since veins and arteries follow a close and essentially parallel course in the femoral head, neck, and joint capsule, venography provides indirect information regarding the arterial blood supply of the femoral head.

Intraosseous phlebography (venography) is more reliable than arteriography for detecting osteonecrosis (Rook, 1953). Veins, even small retinacular branches, can be detected roentgenographically more clearly than the corresponding arteries. Veins are more fragile than arteries; and if a typical venous pattern is present, it is likely that the corresponding arterial tree is also present.

The affected hip is placed in neutral or external rotation to minimize intra-articular pressure (Soto-Hall and Johnson, 1964). It is quite important that the injection cannula not penetrate the articular cartilage of the femoral head. Approximately 5 cc of 50% Hypaque is introduced in about 15 seconds, and A-P roentgenograms are taken during and following the injection (Hulth, 1958; Hulth and Johansson, 1962).

The iodized contrast medium is injected directly into the femoral-head lesion rather than into the trochanteric region (Arlet, 1971). Eberle (1971) doubted the possibility of making reliable predictions on circulatory conditions in the femoral head and neck by means of intratrochanteric phlebography, since drainage from these areas cannot be observed with this technique. The flow of venous blood from an osteonecrotic lesion is invariably reduced or completely arrested, and often greater pressure than usual is necessary to inject the contrast medium. Frequently no venous drainage from the lesion is detected at all, and the contrast material pools within the cancellous bone. Or, if there is a subchondral fracture extending through the necrotic lesion and cartilage, the contrast material pools within the joint itself.

Positive phlebograms are those in which veins arising from the femoral head are immediately filled with contrast medium. In positive circumflex venograms, the retinacular, medial and lateral circumflex, femoral, and external iliac veins are filled. In positive ligamentum-teres venograms, the foveal vein as well as the acetabular, obturator, and internal iliac veins are filled. In certain instances both these systems are filled simultaneously (Fig. 4*a*).

Negative phlebograms are those in which no veins are visible and the contrast medium has flowed into the joint space or remains in the cancellous bone of the head and neck. Venous stasis is associated with femoral-head necrosis. In most cases of nontraumatic necrosis the phlebogram is negative, with a typical trabecular (intramedullary) drainage pattern, inasmuch as the contrast medium flows through the medullary sinus of the femoral neck and trochanteric region. Serial phlebograms demonstrate delayed drainage of the contrast medium with persistent pooling within the femoral head, neck, and proximal shaft (Fig. 4*b*).

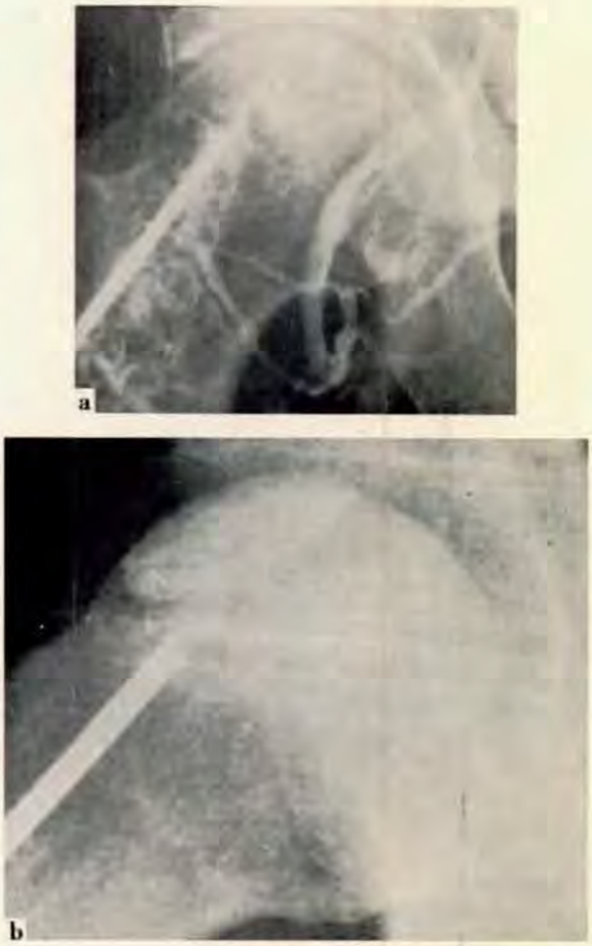

FIG. 4. (*a*) A-P view of R hip taken during intraosseous phlebography, revealing essentially normal immediate venous drainage from periphery of femoral head and neck. (*b*) X-ray film taken 15 min later suggesting residual contrast material (Hypaque) sequestered in avascular-appearing segment. (Jones, 1971. Illustration courtesy of publisher.)

Biopsy Drilling Procedure

Biopsy drilling should be performed to confirm a diagnosis of osteonecrosis if hemodynamic tests are abnormal (Arlet and Ficat, 1971). Early diagnosis is particularly important when necrotic lesions are unaccompanied by gross architectural distortion or articular incongruity, so that irreversible damage may possibly be avoided by using surgical procedures to revascularize the necrotic area.

Furthermore, it is important to biopsy atypical lesions bearing similarity to avascular necrosis, which may actually be a giant-cell tumor, cystic tuberculosis, pigmented villonodular synovitis, chondroblastoma, or calcified enchondroma.

Through a lateral thigh approach a Turkel trephine with obturator is positioned by biplane roentgenograms to the anterosuperior region of the femoral head (where most lesions of idiopathic necrosis are located). The surgeon introduces the trephine into the subchondral bone, advancing and rotating it while verifying its position radiologically (Fig. 5*a*). The biopsy specimen is removed and examined macroscopically. It is then fixed in formalin, decalcified with nitric acid, and embedded in paraffin. Sections are cut along the major axis and stained with hematoxylin-eosin. Occasionally larger biopsy cores are removed for pathological examination. In these instances high-resolution roentgenograms of the cores are obtained prior to sectioning and staining (Fig. 5*b*). The incision may be lengthened proximally and posteriorly to obtain specimens of the capsule and synovium for special additional studies.

FIG. 5. (*a*) A-P view of R hip of 51-year-old Caucasian male with idiopathic osteonecrosis, showing location of Turkel biopsy drilling trocar in subchondral bone of femoral head. (*b*) High-resolution roentgenogram of osseous cylinder (1 x 5 cm) obtained from femoral head by biopsy drilling. Arrow points to sclerotic (and necrotic) lesions.

SUMMARY

When a comprehensive clinical history and physical examination indicate possible idiopathic or nontraumatic osseous avascular necrosis, additional diagnostic tests are often recommended, including tomography and radionuclide bone scans. The suspected lesion may be confirmed by various tests, such as a differential radioactive phosphorus (^{32}P) uptake study, differential oximetry, intramedullary pressure determinations, intraosseous phlebography, and biopsy for tissue microscopy and microroentgenography.

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