

## The Role of SPECT in the evaluation of skeletal trauma

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Single photon emission computed tomography (SPECT) has, in the last decade, established a critical role in routine diagnosis. Skeletal scintigraphy exemplifies the impact in improving detection of lesions by delineation of their site and size. The advantage of minimizing the superimposed radioactivity from overlying and underlying structures is typified by the readiness with which avascular necrosis of the femoral head can be identified by removal of the surrounding hyperaemia which masks the classical photopaenia. However, the ability to achieve an accurate image at a plane at a prescribed depth is most characteristically shown by the study of a vertebra, a bone of irregular contour and subject to a variety of pathological disorders at different sites within it. The various focal abnormalities resulting from these can be localized exactly, readily distinguishing, for example, those in the body from those in the natural arch. In particular, the alterations resulting from trauma, such as pars interarticularis stress fracture, are readily seen. Consequently SPECT has an indispensable role in the investigation and management of low back pain. However, the ability of SPECT to delineate abnormal accumulation has provided a new approach to the evaluation of knee pain, especially when acute such as that resulting from athletic injury, since the identification of the presence or absence of focal abnormalities can be critical to patient management. The frequency of these various disorders in which SPECT is so useful explains why the procedure has become such a routine high-volume examination in so many departments.

**Key words:** single photon emission computed tomography (SPECT), skeletal scintigraphy, trauma

CONTINUING EXPANSION of experience with skeletal scintigraphy has identified that its role now extends far beyond the initial major indication, the evaluation of malignancy, and led to its use in the investigation of a wide range of benign disorders. Foremost amongst these applications has perhaps been the assessment of trauma, particularly that associated with athletic injuries. This reflects the frequency of such problems and the ready availability and inexpensive nature of skeletal scintigraphy. In general, a higher degree of diagnostic accuracy can be achieved but in various situations, difficulties are encountered, the solution to which exemplify the advantages of

single photon emission computed tomography (SPECT). The most fundamental of these is its ability to remove the activity from overlying and underlying tissues which otherwise would obscure the image at the depth of interest. This is perhaps typified by the removal of the hyperaemia often lying over the avascular head of femur and the contribution of activity below, arising from the acetabulum. However, more importantly, this feasibility of achieving an accurate image of a body section at a prescribed depth is critical in being able to separate bony structures which are overlapping in planar images. Such overlap, of course, is inevitable in viewing a vertebra in which the body is superimposed on the posterior elements in which a variety of lesions can occur in different sites, many being small in size. As a consequence, lesional contrast is improved, permitting not only improved detection but also, by display of slices in transaxial, coronal and sagittal projections, a perception of 3-dimensional anatomy which

Based on an invited lecture at the 32nd Annual Scientific Meeting of the Japanese Society of Nuclear Medicine, Yokohama, October 1992.

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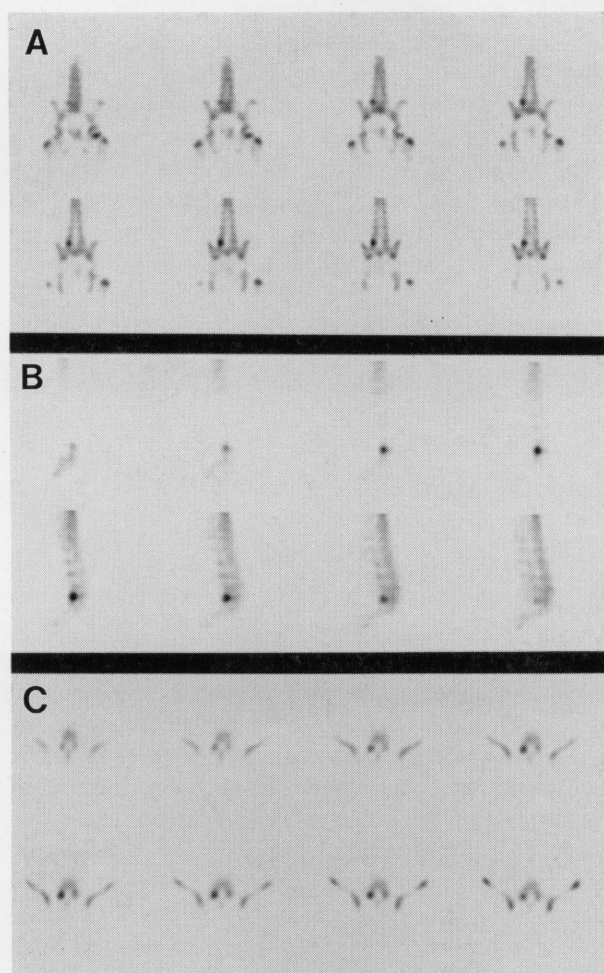
improves localization and more exact delineation of the size of the lesion. Interpretation usually requires review of this spatial information in all three planes but in some instances that provided in one plane may be of particular value. Thus, in SPECT examinations of the knee, the greatest information may well be obtained from the transaxial images since this plane is, of course, at right angles to the anteroposterior projection of the planar images and only achievable by SPECT.

These properties of SPECT obviously can provide improved diagnostic accuracy in the investigation of particular areas of the body, many of which are susceptible to trauma resulting from direct injury, stress or surgery and in the assessment of the sequelae which may result from any of these aetiologies. There are now, therefore, clear indications for the

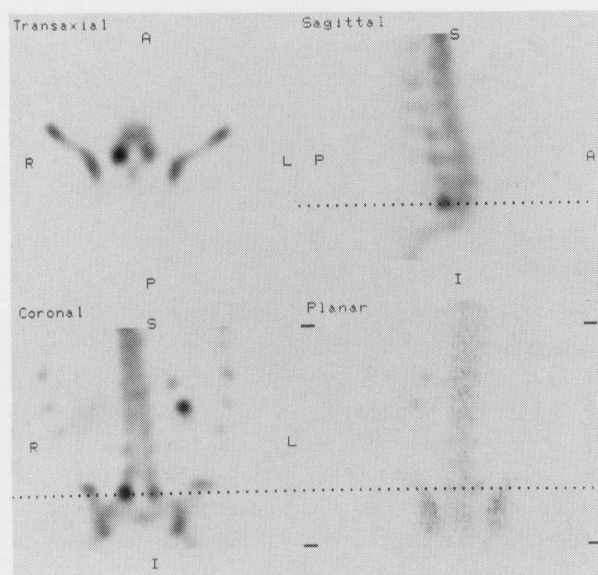
use of the procedure if optimal identification of such lesions is to be achieved.

## THE SPINE

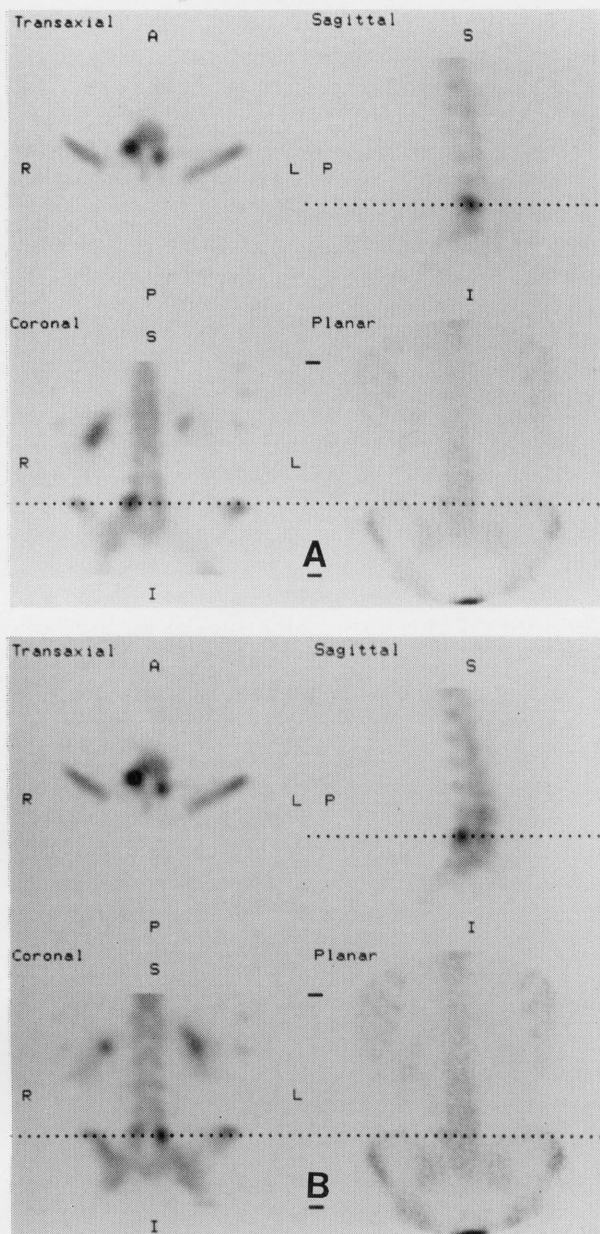
SPECT has certainly found its greatest popularity in the investigation of the lumbar spine. This very clearly reflects the frequency of the complaint of low back pain and the numerous aetiologies which can be responsible. Many of these are often readily demonstrable by planar scintigraphy. However, frequently, despite the predilection of many of such lesions for particular sites in the vertebra, the findings are non-specific since it is difficult to ascertain the precise location because of the overlapping of the various components of the vertebra when viewed in a standard posterior projection. Even oblique views may not elucidate the site of an abnormality. However, the use of SPECT readily allows the demonstration of each anatomical plane in the sequential sections. Thus, it is not only very easy to assess any alterations in the body of the vertebra but the pedicles, laminae and spinous process are all identifiable separately (Figs. 1-2). The value of the procedure, particularly its superiority not only over planar imaging but standard radiology, has been demon-



**Fig. 1** Serial sections, commencing top left, obtained with emission tomography in 3 planes, (A. Coronal; B. Sagittal; C. Transaxial) in a patient with a stress fracture in the pars interarticularis on the right. These permit visualization of the individual vertebral bodies, spinal canal, pedicles and spinous processes with clear delineation of the increased accumulation in the fracture site in the involved vertebra.

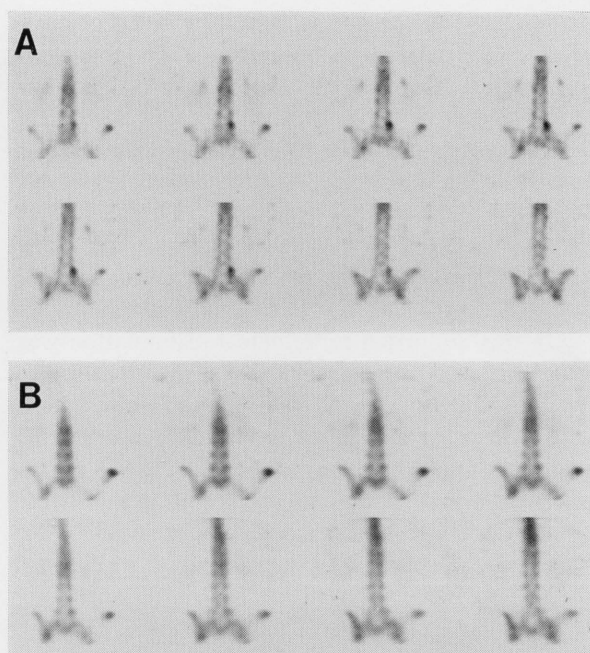


**Fig. 2** By selection of the appropriate sections from each plane, those which demonstrate the abnormality most clearly are presented adjacent to each other, permitting simultaneous comparison and allowing precise assessment of size and site of the pars fracture. (Top left, transaxial; top right, sagittal; bottom left, coronal; bottom right, planar view. The dotted line indicates the level relevant to the appropriate plane displayed). It is also possible to identify the mild accumulation, much less well delineated than the fracture site, in the contralateral pars indicating the commonly observed reaction to the altered spinal mechanics.



**Fig. 3** The exact localization which can be achieved with SPECT is demonstrated by the identification at different planes in a patient in whom the same vertebra is the site both of a pars interarticularis stress fracture on the right (A) and osteochondritis in the articular facet on the left (B).

strated in many series. Ryan et al.<sup>1</sup> for example, studying 70 patients with low back pain, detected lesions with planar imaging in 36% and SPECT in 60%. Additional lesions were found in 39% of the patients with a positive planar scan. Of the lesions detected by SPECT alone, 63% were localised to the posterior element. X-ray detected 90% of the anterior lesions but only 40% of posterior lesions. In a recent extensive study by Kanmaz et al.<sup>2</sup> of 1390 adult patients with chronic low back pain, abnormal studies



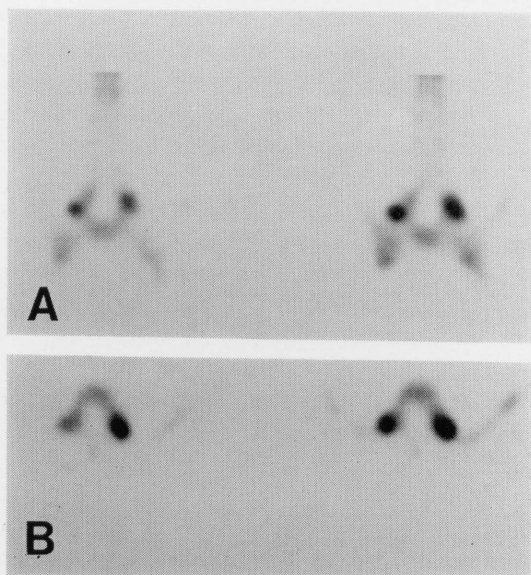
**Fig. 4** The response to appropriate management in a 12 year old cricketer who suffered a stress fracture of the pars interarticularis of L5 (A), is readily demonstrated by the marked reduction in the focal osteoblastic activity in the sequential study (B) undertaken 6 months later.

were encountered in 1006. Within the lumbo-sacral spine, 44% of the abnormalities were equally well seen on planar and SPECT, 24% better seen on SPECT but 31% were only seen using SPECT. Within the lumbar spine, 36% of abnormalities were located within the vertebral bodies but it was possible to identify 53.8% lay in the laminar or pedicles, 8.7% in the spinous processes and 1.3% in the transverse processes, clearly demonstrating the feasibility of exact localization (Fig. 3). The improved sensitivity confirmed by SPECT was elegantly demonstrated by Gates<sup>3</sup> in a study of 100 patients with low back pain, 23 of whom had abnormalities seen only on SPECT. However, by grading the intensity of the alteration noted in the abnormal planar scans, it was evident that this improved accuracy with SPECT lay in its ability to identify quite readily those lesions with the minimal change in planar imaging, 39 (81%) of 48 such lesions being easily detected by SPECT.

The major clinical application for this sensitivity in providing such precise localization again reflects the ability of skeletal scintigraphy to demonstrate the physiological activity of a skeletal lesion. This emerges most vividly from a study by Collier et al.<sup>4</sup> who studied 19 patients with a radiological evidence of spondylolysis and/or spondylolthesis. The importance of this particular investigation was not merely that SPECT had a sensitivity of 85% com-



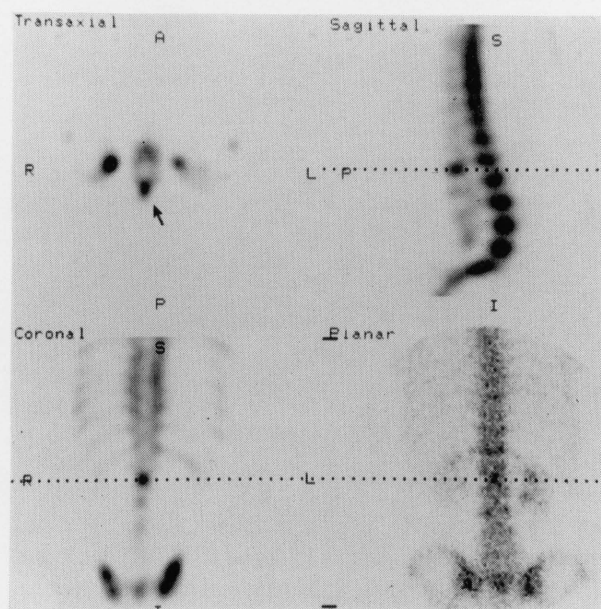
pared to 62% for planar scintigraphy but that positive studies occurred in only the 13 patients with pain. Similarly Bellah et al. (1991) undertook lumbar SPECT studies in 162 young athletes with low back pain, the symptoms being referable to the posterior elements, in most instances suspected to be the result of stress in the pars interarticularis as the result of athletic injury. In 71 patients lesions were identified with SPECT whereas the planar study was positive in only 32. In 25 of the individuals in whom the SPECT was abnormal radiological examination was normal. It was suggested that such discordance between radionuclide and radiological examination could well be of assistance in deciding whether or not surgery might be required. Further, it was postulated that serial examinations might demonstrate resolution of the scintigraphic abnormalities. We certainly have found that a sequential study at 6 months can indeed identify a return to normality and confirm satisfactory management (Fig. 4). Intense accumulation reflecting the osteoblastic response to bone remodelling following surgical trauma is of course to be expected with only very gradual reduction as healing is achieved. Nevertheless abnormal persistence of such uptake is clearly of significance. Characteristically it will occur in pseudoarthrosis, a complication of lumbar fusion operations (Fig. 5) Accordingly Slizofski et al.<sup>5</sup> studied 26 patients who had undergone lumbar spinal fusion more than 6 months previously. Fifteen who were symptomatic focal accumulation compatible with pseudoarthrosis was visualised, more readily with SPECT than planar imaging. Six of the 11 asymptomatic patients had focal areas of increased activity.



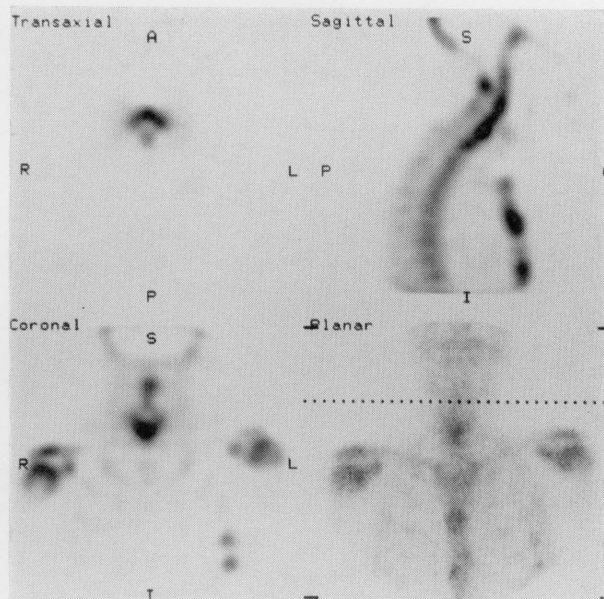
**Fig. 5** Persistence of abnormal focal increased activity within the bony mass 15 months following spinal fusion identifies pseudoarthrosis, as the cause of persistent pain.

It was suggested that this might reflect painless pseudoarthrosis but the possibility obviously exists that a longer period is required before the abnormal uptake becomes significantly reduced. Serial bone scans would obviously show decreasing intensity over a period. More recently attention was drawn by workers from the same centre, Onsel et al.,<sup>6</sup> to the care that must be taken in evaluation of increased sacroiliac joint uptake visualised with SPECT. Such uptake was demonstrable in 43 (6%) of 753 patients. It certainly was relevant that 14 of the 43 patients had undergone prior lumbar laminectomy and/or spinal fusion. This concluded that such increased sacroiliac joint uptake is usually the result of altered spinal mechanics. Nevertheless it must be remembered that SPECT does provide a very sensitive method for identifying pathology in the sacroiliac joint.

While SPECT obviously can be of value in siting any lesion, particularly a solitary one (Fig. 6), anywhere in the vertebral column, we have actually found it of less value in the cervical and thoracic spine. Standard planar scintigraphy usually permits ready identification of sites of arthritic change responsible for pain in the neck. It is probable that it also could have a role in the evaluation of continuing symptomatology following surgery in the cervical spine. On occasion, however, we have found a surprising extent of abnormal accumulation, such as that associated with whiplash injury resulting from motor vehicle accidents (Fig. 7). Boyko et al.<sup>7</sup> did study 30



**Fig. 6** A mild and poorly delineated area of increased uptake identified with planar imaging is clearly identified with SPECT as the intense osteoblastic activity resulting from a fracture of the spinous process of L1.

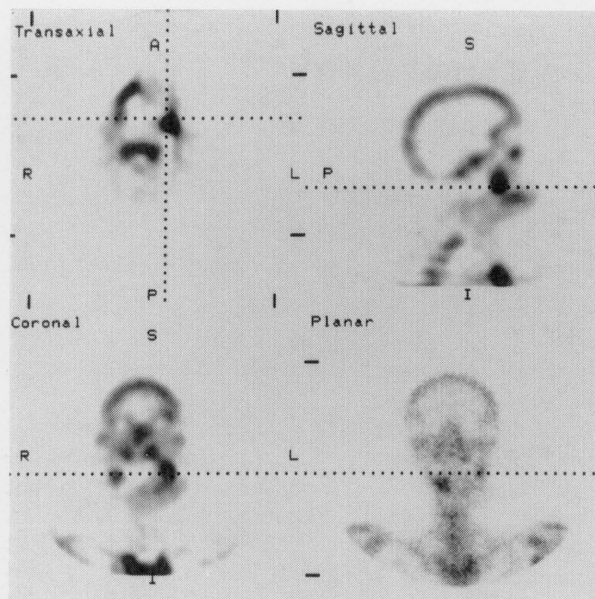


**Fig. 7** SPECT permits the identification of the extensive abnormal accumulation in the cervical spine following "whiplash" injury resulting from a motor vehicle accident. In the sagittal view, the sternal fractures are also readily visualised.

patients with cervical spine trauma in the lateral articular pillar compression deformity on X-ray, concluding that a normal SPECT study negated the diagnosis of a recent fracture. However, most of the investigations were performed within 72 hours of the injury.

### THE SKULL

The value of SPECT in achieving greater identification of regions in the skull than planar views, has been well established. De Roo,<sup>8</sup> for example, showed that 20% of 131 abnormalities in 69 patients were only demonstrable with SPECT. This improved sensitivity was particularly apparent in relation to regions at the base of the skull, 7 of 17 skull base lesions only being demonstrable with SPECT. Similarly, in an investigation of 39 patients with nasopharyngeal carcinoma involving the skull base, Wang et al.<sup>9</sup> reported that not only did 4 patients have abnormal SPECT scans with normal planar images but that in an additional 18 the extent and localization of lesions were markedly improved with SPECT. The variety of skull disorders which can be more readily identified with SPECT were illustrated by Israel et al.<sup>10</sup> However they, like most others, have not identified the procedure as being of great assistance in identifying traumatic lesions of the skull. Nevertheless, a number of authors have found it to be of considerable assistance in the evaluation of the surgical trauma associated with mandibular bone



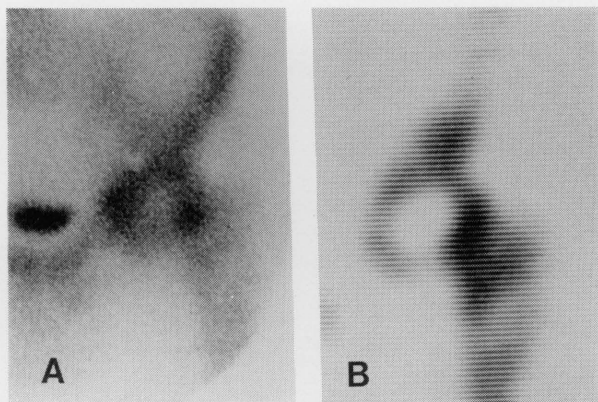
**Fig. 8** The total void of activity in a mandibular bone graft indicates non-viability with much greater clarity than planar views, because of the elimination of the associated soft tissue hyperaemia.

grafts. It has proved useful in ascertaining the presence or absence of complication infection which can be difficult to assess in view of the activity in the soft tissues adjacent to the graft. However, it has been particularly applicable to ascertaining the viability of microvascularised bone grafts in the mandible (Fig. 8). Moskowitz and Lukash,<sup>11</sup> in particular, emphasised the role in this regard, not only because of the difficulties arising from "shine through" of bone structures from the opposite site, but since it was possible to identify that uptake in bone was uniform through the entire graft and not only on the surface, the so-called "creeping substitution".

### THE PELVIS

In view of the major clinical importance of ascertaining the vascular status of the femoral head following fracture, many authors have reported on their experience using SPECT to assess avascular necrosis of the femoral head. Difficulties can be encountered with planar imaging in view of the surrounding hyperaemia in the early stages and subsequently, as healing progresses, the ring of activity reflecting bone healing surrounding the persistent photon-deficient centre (Fig. 9). Thus, Collier et al.<sup>12</sup> found a sensitivity of 85% for SPECT in the investigation of 20 hips involved by avascular necrosis, compared with a sensitivity of 55% for both planar scintigraphy and for radiography. However, artefacts caused by activity in the bladder are frequently encountered



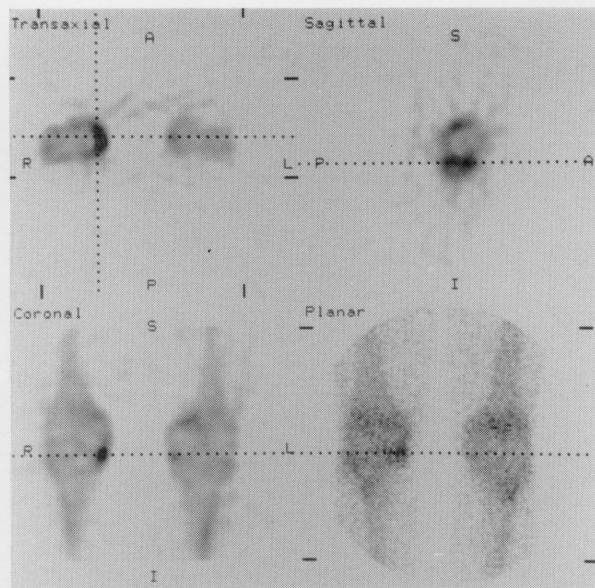


**Fig. 9** The planar views (A) in a patient with a fractured neck of femur do identify the fracture site and the secondary osteoarthritis in the acetabulum but merely raise suspicion of photopaenia in the femoral head which might indicate avascular necrosis. With SPECT (B), the absence of accumulation in the femoral head diagnostic of avascular necrosis is clear-cut, the fracture site also being more readily visualised.

during the acquisition of a pelvis SPECT study. A number of techniques have been advocated in order to reduce the effect of such artefacts although none has gained universal acceptance. Certainly, in children with Perthes' disease, we continue to find that the use of the pinhole collimator provides markedly superior images of the avascular head. However, Gruen et al.<sup>13</sup> found that in adults, SPECT revealed 8 patients with alterations in the femoral head indicative of avascular necrosis whereas only 5 of these abnormalities were seen on pinhole images. In addition, 6 of 8 patients with abnormal pinhole images had normal SPECT studies. Since the "bladder artefact" does to a considerable extent reflect the change in radioactivity due to the increasing urine in the bladder throughout the study, improved studies are probable with the shorter time required with studies with multi-headed cameras, quite apart from the higher resolution achievable. Thus, for example, Lee et al.<sup>14</sup> utilising triple-head high resolution SPECT, found that the sensitivity in detecting femoral head avascular necrosis in this way was 97% compared to 82% for planar studies, higher than previously reported using single-headed SPECT.

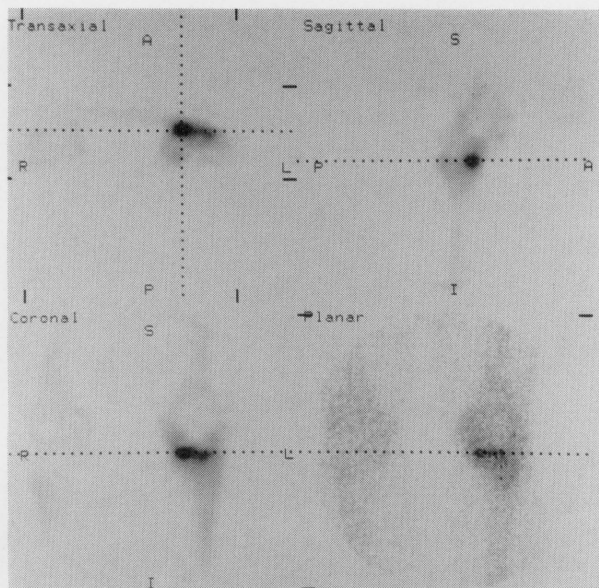
### THE KNEE

In view of the overlapping anatomical features of the knee, it is not surprising that SPECT has been found of considerable use in localizing abnormal osteoblastic activity in and around the knee. Collier et al.<sup>15</sup> for example, in the investigation of chronic knee pain found SPECT to be the most sensitive for evaluating the extent of osteoarthritis. We have,

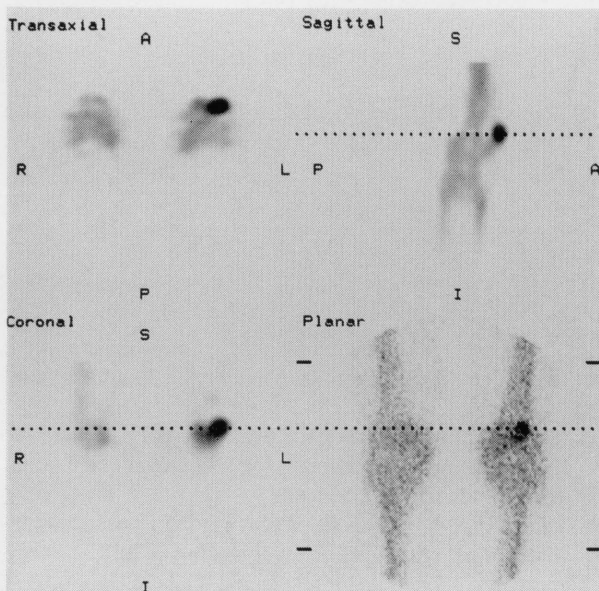


**Fig. 10** Whereas planar imaging merely identified a mild abnormality in the medial aspect of the right knee, SPECT identifies intense accumulation which, particularly in the transaxial view conforms to the outline of the medial meniscus and is characteristic of a meniscal tear.

however, found the procedure to be extremely valuable, and of increasing use in the assessment of patients with acute knee pain, most commonly those who have recently suffered acute athletic trauma. In the study of 52 such patients, Murray et al.<sup>16</sup> found that the planar images were equivalent to those obtained with SPECT in only 17 patients (33%). In 12 patients the planar was less diagnostic in that the uptake was much less than that obtained with SPECT whereas in the remaining 23, the accumulation in the region of the knee in the planar studies was too marked and diffuse to allow any localization of the uptake. SPECT, however, was particularly valuable in identifying the site and delineation of the extent of the damage when meniscal tears were the cause of the presenting pain, being correct in 31 patients (Fig. 10) Dye et al.<sup>17</sup> have confirmed the role of SPECT in this extremely common athletic injury and also found that it offers a guide to post-operative prognosis. At follow-up, 6 of 14 (43%) of patients with persistent abnormal studies developed over degenerative changes compared to only 1 of 20 (5%) of those with restoration of normal scintigraphic activity. The sensitivity in our series of 80% is certainly comparable to that encountered in many series using magnetic resonant imaging and indeed recently Miller<sup>18</sup> found an accuracy for MRI diagnosis of meniscal tears of only 75% and Kriegsman<sup>19</sup> found sensitivity of only 73.2% for meniscal tears and 63.3% for lateral tears. MRI, however, has a very high sensitivity for the detection of cruciate

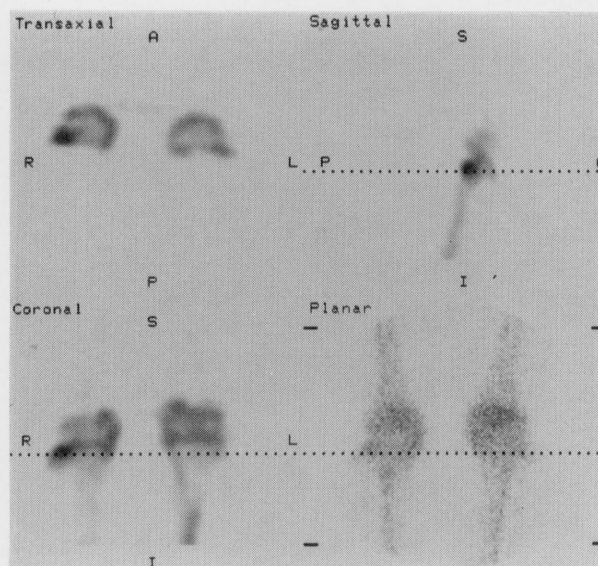


**Fig. 11** The localization provided by SPECT allows the identification of the focal abnormal uptake resulting from avulsion of the anterior cruciate ligament from its tibial attachment.

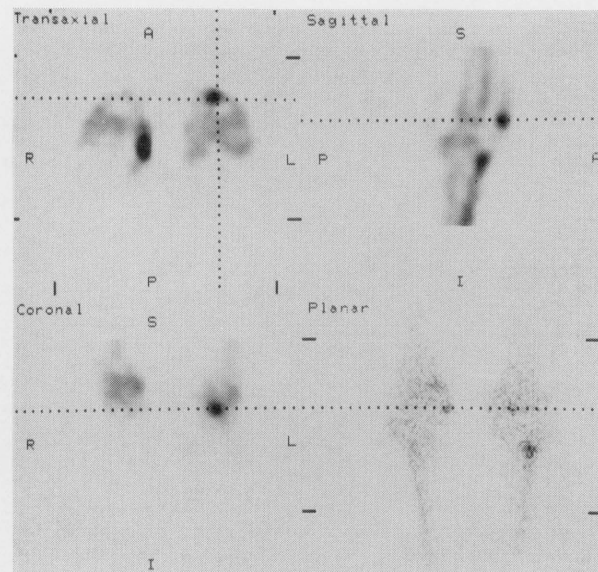


**Fig. 12** Whereas the planar views merely identified an alteration in radiopharmaceutical distribution in the region of the left knee, SPECT permits demonstration not only of bilateral bipartite patellae but the localization of the intense accumulation in the traumatised lateral fragment on the left, responsible for the knee pain.

ligament tears, whereas we encountered SPECT abnormality in only 5 of 10 patients with this injury, only being identified when the tear had resulted in avulsion of the tibial attachment (Fig. 11). However, our continuing experience has shown the very wide range of traumatic lesions in and around the knee which can very readily be identified with SPECT, so



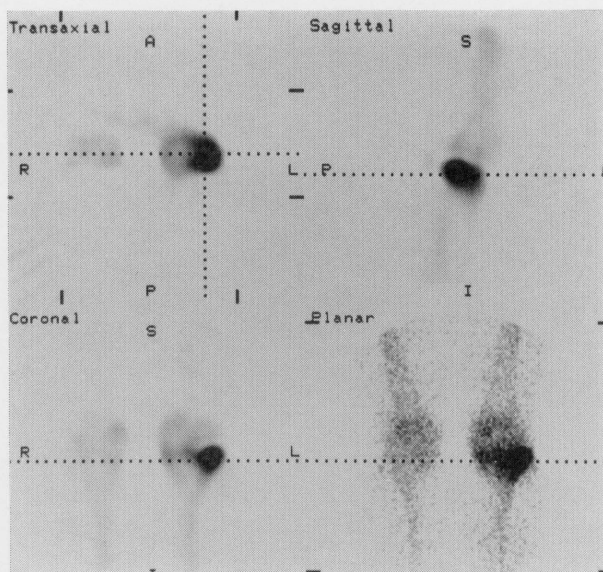
**Fig. 13** SPECT shows that there is increased accumulation in the right tibi-fibular joint, the result of traumatic arthritic reaction, and thus the cause of the presenting patello-femoral pain.



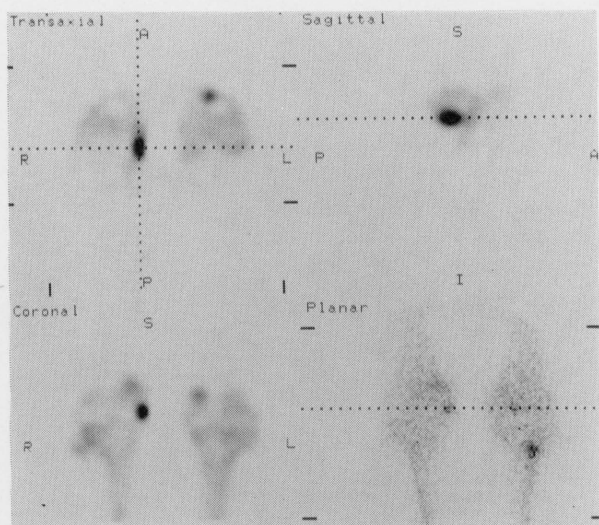
**Fig. 14** The changes of "basketball's knee", intense focal accumulation at the insertion of the patellar ligament on both the inferior patella and tibial tuberosity, are clearly demonstrated, particularly in the sagittal plane.

permitting a decision as to whether arthroscopy is indeed warranted or not. A typical advantage is the readily demonstrated abnormal uptake in a fragment of a bipartite patella, so indicating that the patellar pain is the result of trauma to this radiological abnormality (Fig. 12). Many other causes of pain can equally well be recognised varying from





**Fig. 15** Sub-chondral infraction is identified by the extensive and very intense accumulation involving the lateral tibial plateau, the extent being particularly obvious in the transaxial plane. Standard radiographs over a period of 3 months remained entirely normal.



**Fig. 16** An ill-defined abnormality in the right knee with planar imaging is clearly delineated as an intense focal area of osteoblastic activity with SPECT in the site characteristic of osteochondritis dissecans in the medial femoral condyle.

traumatic arthritis in the tibial-fibular joint (Fig. 13) to the range of focal uptake resulting from insertional stress, particularly of the patellar ligament associated with many sporting injuries (Fig. 14). The value of SPECT in showing focal bone repair following the avulsion of collateral ligaments was also illustrated by Marks et al.<sup>20</sup> However, the major importance of the study by these workers was their convincing demonstration of the role of SPECT in the diagnosis

of sub-chondral infraction (Fig. 15). In the investigation of 13 patients following acute traumatic haemarthrosis of the knee, none of 13 showed any abnormality either radiologically or on arthroscopy whereas both magnetic resonance imaging and SPECT were positive in all patients. They pointed out that the alterations do differ from those encountered in osteochondritis dissecans (Fig. 16). Studying this lesion in 15 patients, Brecht-Krauss<sup>21</sup> found a sensitivity with planar scintigraphy of 79% but actually 100% with SPECT.

## CONCLUSION

There is now extensive evidence that skeletal SPECT is invaluable in improving the diagnosis of a variety of bone and joint disorders in many parts of the body. When compared to conventional planar techniques, it certainly provides images with improved localization and clearcut assessment of the extent of the lesion. Since trauma so readily induces osteoblastic response and altered distribution of the bone-seeking radiopharmaceuticals, SPECT has a particular role in the early assessment of patients following injury.

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