The use of nuclear medicine techniques in the emergency department

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Abstract

Nuclear medicine techniques have received little attention in the practice of emergency medicine, yet radionuclide imaging can provide valuable and unique information in the management of acutely ill patients. In this review, emphasis is placed on the role of these techniques in patients with bone injuries, non-traumatic bone pain and in those with pleuritic chest pain. New developments such as single photon emission computed tomography (SPECT) in myocardial infarction are outlined and older techniques such as scrotal scintigraphy are reviewed. Radionuclide techniques are discussed in a clinical context and in relation to alternative imaging modalities or strategies that may be available to the emergency medicine physician. Aspects of a 24 hour nuclear medicine service are considered.

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Emergency medicine is a rapidly developing medical specialty. The fast pace of modern life and the high prevalence of accidents have greatly contributed to an increased workload. This has also led to the expansion and development of the services provided by the emergency department (ED). As a result, imaging techniques are increasingly requested as part of the assessment of patients attending the ED. Plain radiographic techniques are excellent in providing the emergency clinician with important morphological information but nuclear medicine procedures can be used to provide important functional and physiological information about a variety of disease states. The hallmarks of radionuclide techniques are uniqueness of information provided, ease of use, non-invasiveness, simplicity, and rapidity of performance. These have obvious advantages in emergency medicine. In general, nuclear medicine studies involve the use of a radioactive source, usually technetium (^{99m}Tc), which has a short half life (six hours). This is often bound to an agent that has a specific affinity for an organ or organ system. For example, ^{99m}Tc -methylene diphosphonate (MDP) binds to bone while ^{99m}Tc -iminodiacetic acid (IDA) is taken up and excreted by the hepatocytes, and labelled macroaggregates of human serum albumin (^{99m}Tc -MAA) are trapped in the terminal pulmonary arterioles due to their relatively large size. Administration is most often intravenous, but may be via any route according to the applica-

tion. Once the radiopharmaceutical reaches the required site, the patient is placed next to a gammacamera to detect the radiation emitted, usually γ radiation, as the radionuclide decays. A visual image of the radionuclide activity is thus obtained giving functional and anatomical information.

The purpose of this paper is to highlight to emergency physicians the potential of nuclear medicine techniques to evaluate acutely ill patients. We recognise that all of the applications discussed here may not be available in every centre. Indeed some radionuclide investigations may only occasionally be requested by the ED physician. We believe however that a sound knowledge of nuclear medicine techniques and their application in the ED is essential for appropriate patient management and referral.

Skeletal system

The technique of radionuclide bone scintigraphy is performed by the intravenous injection of ^{99m}Tc -MDP, which is taken up by actively remodelling bone. Imaging is usually performed at least two hours after injection (late or static phase). A two phase or three phase examination may be useful in specific circumstances in which case dynamic images are taken during first pass (less than two minutes) and blood pool (2-3 minutes) phases in addition to the late phase. In the ED, bone scintigraphy has a role in the assessment of patients presenting with bone trauma or with non-traumatic bone pain.

Bone trauma

Conventional radiography is the principal method of investigation in patients with suspected acute skeletal trauma. Usually the diagnosis of fracture is straightforward, however normal anatomical variants can mimic fracture and the presence of old trauma may make interpretation difficult. Furthermore, common fractures particularly scaphoid, pelvic and femoral neck fractures are not always clearly visible on plain films or can be obscured by overlying bowel gas.¹ The high sensitivity of bone scintigraphy in fracture detection is attributable to the affinity of the radiolabelled tracer for sites of active bone turnover and healing.² It can be used when the diagnosis of a fracture is in doubt on clinical and/or radiographic grounds. Scaphoid injuries are difficult to diagnose clinically with only 15% of patients with clinically suspected fracture having a true scaphoid fracture.³ A common diagnostic problem in the ED is encountered in the patient with clinically suspected scaphoid fracture and a negative initial radiograph. The

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shortfalls of plain radiography are initial false negative results,⁴ low interobserver agreement ($\kappa < 40\%$),⁵ and delays in diagnosis³ with possible resultant disability.⁶ The result is that there is a general tendency to overtreat suspected scaphoid injuries. In most centres, the current practice is to review all suspected scaphoid fractures with initial negative radiography at 14 days after injury and to obtain further plain films in the patients with persistent clinical signs. If the second radiograph is negative then bone scintigraphy rather than repeated radiography is often the investigation of choice. Using this approach, in one study 75% of the patients with true scaphoid fractures had the diagnosis made by bone scintigraphy as the radiographs remained negative at the time of reassessment.³ Radionuclide bone scanning has been shown to have up to 100% sensitivity and 98% specificity for scaphoid fractures compared with only 64% for plain radiography.⁷ High sensitivity is sometimes achieved at the expense of lower specificity because of false positive results from bone bruising or reflex sympathetic dystrophy. Magnetic resonance imaging (MRI) of the scaphoid is rapidly evolving as an effective second line investigation of suspected scaphoid fractures.⁸⁻¹⁰ Some recent studies have shown MRI to have greater sensitivity and specificity than scintigraphy.^{8,9} However, the cost of MRI is greater and the facility is generally not as easily accessible. At the present time, the widespread availability of scintigraphy and ease of access to it means it is currently the imaging modality most often used in this setting.

Accurate detection of occult hip fractures is important medically and economically in the ED. Bone scintigraphy provides accurate information about the presence of proximal femoral fracture when radiographs are negative and clinical suspicion is high. In contrast with previous suggestions, femoral fractures can be detected with radionuclide bone imaging as soon as patients present¹¹ thus avoiding unnecessary waiting until 72 hours after the injury as was traditionally proposed. In occult proximal femoral fractures the sensitivity and NPV of scintigraphy was 98% and 99% respectively in 145 patients with normal or equivocal plain films.¹¹ False positive results, for example due to fractures of the greater trochanter simulating femoral neck fractures, have led to the use of additional imaging techniques. MRI where available has also been suggested as the procedure of choice for the diagnosis of occult femoral fractures if the suspicion of multiple trauma is low. Both computed tomography (CT) and MRI can aid in the planning of the surgical approach. Bone scanning however has the additional advantage of being able to establish other diagnoses in 41% of patients¹¹ by providing a view of the entire skeleton as well as being able to detect hip fractures with high sensitivity.

Occult fractures can be difficult to diagnose in the paediatric population particularly if an infant cannot easily articulate his symptoms or when the child presents with a limp. Greenstick fractures and fractures of the small bones of the

Figure 1 Whole body bone scan showing multiple occult bilateral rib fractures (arrowed). The linear alignment is typical of fractures.

feet may be difficult to see on plain films and may require scintigraphic diagnosis. Bone scanning is generally used in the child with a limp when other investigations are negative.¹²

Skeletal scintigraphy has an advantage in being able to routinely assess the entire skeleton without exposure to additional radiation or incurring additional expense (fig 1).

This advantage is used in the evaluation of suspected physical abuse. Multiple fractures at different stages of healing may be visualised in non-accidental injury.¹³ The sites and the mechanism of injury can be demonstrated. It must be emphasised that difficulties can arise in distinguishing increased uptake at the normal growth plate from abnormal activity as a result of injury. Documentation of injuries must be carried out in conjunction with plain radiographs as bone scintigraphy is not sensitive in the diagnosis of skull fractures, while radiography is even less sensitive for epiphyseal plate injuries.¹²

Non-traumatic bone pain

Stress fractures (fatigue fractures) are most commonly seen in athletes, dancers and military recruits and are attributable to continued mechanical trauma that causes bone resorption in excess of bone remodelling. The most common location is in the tibia. Femoral neck stress fractures can be especially difficult to detect. Early stress fractures are frequently associated with normal radiological findings, with radiographic sensitivity being as low as 15% initially and 50% at follow up.¹⁴ Furthermore, radiographs can be negative for up to four months.¹⁵ Early diagnosis is important, as the causative activity must be restricted in

Figure 2 Bilateral shin splints (medial tibial stress syndrome) in a young marathon runner showing the typical pattern of uptake in the tibial cortex.

order to avoid a full thickness break.¹⁶ The gold standard for diagnosis is the triple phase technetium bone scan. The sensitivity of scintigraphy approaches 100% as only a handful of false negative scans have been reported.¹⁴ Scintigraphic grading of stress fractures can be used to assist in prescribing the appropriate duration of rest.¹² A proposed imaging algorithm for suspected stress fracture¹⁴ recommends initial plain radiography followed by triple phase radionuclide bone scanning if this is negative. The combination of bone scan findings and radiological findings allows the correct diagnosis to be made in 90% of cases.¹⁷ MRI is advocated as a problem solving modality, and CT should be reserved to delineate a fracture in a high risk location (for example, tarsal navicular) or when the fracture line is not seen at MRI.

Shin splints or medial tibial stress syndrome is a syndrome of pain and tenderness localised to the medial border of the tibia that is attributable to periostitis of the soleus muscle tendon complex with tearing of Sharpey's fibres between the muscle insertion and bone. It is important to distinguish it from a stress fracture, as the recommended period of rest is much less for shin splints. In many cases the diagnosis can be made clinically, but the characteristic bone scan appearances of linear, superficial uptake on the posteromedial tibial cortex is useful in equivocal cases¹⁸ (fig 2). Stress fractures show a more focal or fusiform uptake in the static phase and increased activity in the arterial and blood pool images.

Radionuclide imaging is particularly useful in specific anatomical sites such as in the pelvis, where findings obtained with other imaging modalities can be subtle. Sacral insufficiency fractures are common in the elderly osteoporotic population and are difficult to visualise on plain films because of overlying bowel gas and osteopenia. The bone scan has been shown to be the most sensitive imaging technique in detecting occult sacral insufficiency fractures (fig 3) in postmenopausal women.¹⁹ MRI is extremely sensitive for the

Figure 3 Characteristic H shaped appearance of sacral insufficiency fractures on an MDP-^{99m}Tc bone scan.

detection of associated marrow oedema but may not demonstrate the fracture lines.²⁰ The classic scintigraphic finding of increased uptake in the body of the sacrum and one or more alae is highly specific.^{21 22}

The investigation of osteomyelitis should start with plain radiography, however it is well known that radiographs are often normal in early infection. A three phase bone scan is the investigation of choice in suspected osteomyelitis as increased tracer activity is seen during the blood pool phase and on static images.²³ Bone scintigraphy is usually positive within three days of the onset of symptoms but may be abnormal within 24 hours.²⁴ The findings must be interpreted with the radiographic changes. It has been shown to have 94% sensitivity and 95% specificity for the diagnosis of acute osteomyelitis when plain films demonstrate no other evidence of bony remodelling.²⁵ Should the bone scan prove non-specific, ⁶⁷gallium or ¹¹¹indium labelled leucocyte imaging is usually helpful to exclude infection.^{26 27} For osteomyelitis, MRI gives results similar to those of the three phase bone scan²⁵ but is considerably more expensive. It can be used to determine the extent of infection.²⁸

Technetium bone scanning may also be used in evaluating patients with arthritis to determine the extent of disease, rule out joint sepsis, judge efficacy of treatment and evaluate progression.^{29 30} Nuclear medicine studies can sometimes confirm the diagnosis. For example, the pattern of osteoarthritis can be distinguished from rheumatoid arthritis and a distinction between arthropathy and muscular trauma or infection can be made. The monitoring of treatment, selection of injection site and assessment of disease activity is also aided by bone scintigraphy.

Cardiovascular system

One of the commonest problems encountered in the ED is the evaluation of a patient with chest pain. Clinical features and ECG findings available at the time of presentation have a low sensitivity (18%–65%), and a low specificity (69%).³¹ In many cases the ECG findings do

not influence the decision to admit the patient with chest pain.³² Fear of inappropriate discharge, reported in of 3% to 10% of patients,^{31, 33} has led to an unnecessarily high number of admissions to coronary care units.³⁴ Up to a half of patients admitted are eventually found to have non-cardiac chest pain.^{35, 36} A faster, more definitive diagnosis of myocardial infarction in the ED could avoid unnecessary admission and may prevent missed diagnosis.

A clinical decision concerning appropriate management can be difficult to reach in those patients with typical angina and a normal or equivocal ECG. Previous studies have demonstrated that resting thallium-201 myocardial perfusion imaging can be used to improve decision making in these patients.^{37, 38} ^{99m}Tc labelled sestamibi can also be injected intravenously and is taken up by the myocardium in proportion to myocardial blood flow. After injection, imaging is usually performed at 30–60 minutes but can be done at up to four hours and reflects myocardial perfusion at the time of injection. A dedicated single detector single photon emission computed tomography (SPECT) gammacamera may be located in the ED.³¹ Patients with abnormal or equivocal resting ^{99m}Tc-sestamibi SPECT images at the time of presentation in the ED have a high incidence of adverse cardiac events. Recent studies assessing patients with suspected myocardial infarction and non-diagnostic ECGs have shown that normal rest ^{99m}Tc-sestamibi SPECT imaging was associated with an excellent long term and short-term outcome.^{39–41} Negative predictive values as high as 94% to 100% have been reported for normal radionuclide studies performed in the ED.^{41–44} The decision not to admit patients following a normal study resulted in a 57% reduction in hospital admissions with substantial cost savings.⁴⁰ Thus the strategy of performing myocardial perfusion imaging in patients with anginal chest pain and a normal or non-diagnostic ECG while in the ED seems to be safe, accurate and cost effective. Furthermore, the technique of resting myocardial perfusion imaging is relatively easy to perform and results can be obtained without delay in a nuclear medicine department with a 24 hour on call service.

Respiratory system

Pulmonary embolism (PE) is commonly fatal yet it is a very difficult diagnosis to make. In a prospective study, 21% of patients presenting to the ED with pleuritic chest pain had PE demonstrated at angiography or necropsy.⁴⁵ Necropsy studies consistently show that most cases of fatal PE are unrecognised. Among patients who die from PE, the diagnosis is unsuspected in 70%.⁴⁶ This statistic has not changed in three decades.⁴⁷ Routine investigations such as chest radiograph, ECG and arterial blood gas measurements are seldom diagnostic.^{48, 49} A ventilation-perfusion (V/Q) study after intravenous injection of 74–150 MBq ^{99m}Tc-MAA (macroaggregates of human serum albumin) and inhalation of either ⁸¹Kr gas or ^{99m}Tc technegas is the standard investi-

gation in the evaluation of patients with suspected PE. The V/Q scan can be performed in any hospital equipped with a gammacamera, a source of radiopharmaceutical and suitably trained staff. In the PIOPEd study,⁵⁰ isotope lung scanning had a sensitivity of 98% but a specificity of only 10% for detecting PE. Combining clinical pre-test probabilities and VQ results is helpful in predicting the presence of embolism. A normal perfusion scan (14% of studies) and low clinical suspicion virtually rules out significant PE (prevalence of 4%). A study showing multiple segmental perfusion defects associated with normal ventilation and high clinical suspicion can confirm the diagnosis of PE (prevalence of PE is 96%).⁵⁰ Unfortunately a large group of patients (40% to 60%) have an intermediate or low probability V/Q study yielding an indeterminate result (prevalence of PE is 10% to 40%). These patients often need a further test such as pulmonary angiography, leg vein ultrasound or spiral CT. Increasingly, contrast enhanced spiral CT of the pulmonary arteries is advocated as the first line of investigation of PE in patients with abnormalities on plain chest radiography, in those with underlying lung disease or patients on intensive care, as scintigraphic interpretation may be difficult in these patients. In a recent multicentric European trial (ESTI-PEP),⁵¹ sensitivity was 88% and specificity 94% for spiral CT to subsegmental artery level. The widespread availability, low cost and lower radiation dose of V/Q scanning makes it preferable in the assessment of pleuritic chest pain in young patients and in those without abnormalities on the chest radiograph. Magnetic resonance angiography using intravenous gadolinium has shown promise in demonstrating the pulmonary arteries but it is generally considered to be a research modality in the diagnosis of acute PE at present. The gold standard investigation for PE is still conventional pulmonary angiography although this was available in only one third of UK hospitals in 1991.⁵²

Scrotal pain

Acute scrotal pain is a surgical emergency for which some surgeons prefer to perform exploratory scrotal surgery without any preoperative imaging, in order to maximise testicular salvage. It is crucial that imaging studies should not cause undue delay in treatment when they are performed to evaluate for testicular torsion. Scintigraphy can play an important part in excluding testicular torsion in questionable cases. The clinical presentation of torsion of the testes, torsion of the testicular appendages, testicular tumour and inflammatory disease may overlap and diagnosis can be difficult. ^{99m}Tc labelled pertechnetate is injected into a peripheral vein as a bolus with the patient in the supine position.⁵³ Testicular perfusion can be assessed immediately both by evaluation of flow to the testicles on dynamic images and by assessment of the static images. The non-perfused testicle of acute torsion (fig 4) can be differentiated from the hyperaemic tissue seen in epididymo-orchitis and other

Figure 4 ^{99m}Tc -pertechnetate study showing a photopenic defect (arrow) in the left testis diagnostic of testicular torsion.

inflammatory conditions. Scintigraphy has a sensitivity of 96% and a specificity of 98% with an overall accuracy of 96% as compared with clinical evaluation, which has 66% sensitivity, 96% specificity and 88% accuracy.⁵⁴ Neither power Doppler ultrasound nor colour Doppler has proved to be more useful than scintigraphy in diagnosing torsion. Because of its greater specificity (97% versus 77%), scintigraphy may help prevent unnecessary surgery when colour Doppler ultrasound shows equivocal flow.⁵⁵ Furthermore, ultrasound is an operator dependent technique and suffers from technical failures in up to 10% of cases when no colour signal can be obtained from either testis.⁵⁶ The exclusive use of colour Doppler sonography in the evaluation of testicular torsion is not recommended in prepubertal patients where radionuclide scintigraphy remains the imaging modality of choice.^{57–58} Delayed or missed torsion (more than 24 hours history) may demonstrate a hyperaemic rim on scintigraphy identical to that seen in a scrotal abscess, therefore interpretation in conjunction with the clinical findings is essential. Tumour, haematoma and hydrocoele may give rise to photopenic defects. Knowledge of patient history, physical examination and ultrasound findings may help to differentiate these conditions from torsion.⁵⁹ In general, scrotal scintigraphy is preferable in the investigation of acute (less than 24 hours) scrotal pain and is most useful in excluding torsion where there is a low pre-test probability of torsion. Immediate availability on a 24 hour basis is essential.

Other applications

Gastrointestinal bleeding an indication for an emergency ^{99m}Tc -sulphur (or albumin) colloid or ^{99m}Tc labelled red blood cells study to non-invasively detect intermittent haemorrhage with high sensitivity at low bleeding rates. Patients with fever of unknown cause being treated in the ED can be investigated for occult abscess formation using ^{67}Ga -citrate or ^{111}In labelled white cells.^{60–61}

Access to nuclear medicine services

Ideally a radionuclide service should be available to the ED seven days a week and studies should be reported without delay by an expert in nuclear medicine. Twenty four hour on call staff (nuclear medicine physician or radiologist, technician, radiopharmacist and nursing staff) and state of the art equipment including portable systems are required. Teleradiology systems allow flexibility and home reporting of out of hours examinations.⁶² Published data however reveal that only 29% of nuclear medicine departments in the UK offer an on call service. Limited financial resources and lack of available personnel seem to be the reason why centres willing to offer an on call service are unable to do so.⁶³ The cost implications of a round the clock nuclear medicine service⁶⁴ are probably not justified in all centres in the present financial climate, but such financial considerations must be viewed in the light of an increase in overall cost effectiveness. In the case of triaging of patients with chest pain (to exclude myocardial infarction, PE, etc) the prompt application of nuclear medicine techniques has been shown to affect patient outcome⁶⁴ and increase cost effectiveness.^{40–44} In other centres, on call services have been abandoned because of lack of demand.⁶³ We believe that the organised provision of emergency radionuclide services requires good departmental communication between the nuclear medicine and the ED in order to identify clinical demand and to guide the appropriate use of these valuable techniques in the emergency setting.

Conclusion

Nuclear medicine is an underused specialty and this is as true in the ED as in other branches of medicine. Clearly, the potential for the use of radionuclide methods in the ED is great. Vital functional information can be provided to supplement anatomical imaging studies. In some situations, the information derived from nuclear medicine imaging in the emergency setting is so unique that no other imaging modality can replace it.

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Contributors

B S McGlone researched the topic, discussed the ideas, compiled the images, updated the material and contributed to the writing and revisions of the paper. K K Balan initiated the project, researched the topic, discussed the ideas, provided the images, contributed to the writing of the paper, and edited the paper. B S McGlone and K K Balan are guarantors of this paper.

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