Nuclear Medicine Imaging of Spine Injuries

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A.W.J.M. Glaudemans et al. (eds.), *Nuclear Medicine and Radiologic Imaging in Sports Injuries*, DOI 10.1007/978-3-662-46491-5_12

Abstract

Modern sports activities are associated with a high incidence of spine pain. Generally, the injuries seen are classified to their time of onset or specific injuries related to the vulnerable skeletal locations. Spinal fracture is fortunately very rare for incidences that are associated in contact sports activities. Prevention of spinal injuries and early diagnosis are the first priorities since delayed diagnosis may cause structural instability and early osteoarthritis or abnormal bony maturity. When plain radiographs of a patient with persistent symptoms reveal negative findings, a bone scan with single-photon emission computed tomography, computerised tomography scan or magnetic resonance imaging scan can be performed. Nuclear medicine imaging techniques, encompassing the visualisation and characterisation of biological processes at the molecular and cellular level, are useful techniques in localising the site of spinal injuries which are inconspicuous on the structural conventional imaging techniques.

Abbreviations

CT	Computed tomography
Ga (GS)	Gallium-67
GS	Gallium scan
HMPAO	Hexamethylpropyleneamine oxime
i.e.	That is
In	Indium-111
LBP	Low back pain
MDP	Methyl diphosphonate
MIP	Multiple image projection
MRI	Magnetic resonance imaging
SAP	Superior articular process
SPECT	Single-photon emission computed tomography
Tc	Technecium-99
WBC	White blood cells

12.1 Introduction

Nuclear medicine imaging techniques encompass the visualisation and characterisation of biological processes at the molecular and cellular level in vivo and in vitro. The bone structure is strong. Therefore injuries commonly occur in the ligamentous and muscular structures because they are the weaker points. Modern sports activities predispose a high incidence of spine pain. For instance, lower back pain (LBP) occurs in up to 50 % of elite athletes. Generally, the injuries seen in involving the spine are acute stress injuries, overuse injuries, or immature skeletal-related stresses. Fortunately acute spinal fractures relatively rarely occur. They occur most

frequently in contact sports such as rugby, American football, and high-velocity sports such as skiing and motor sports. Prevention and early diagnosis of spinal injuries are a first priority as the delayed diagnosis may cause structural instability and early osteoarthritis or abnormal bony maturity. Whenever an athlete sustains an injury with suspicion of a spinal fracture, they should be immobilised and transferred to a hospital for an immediate evaluation. Bone and ligamentous injury are evaluated with CT and MRI to assess fracture stability.

MRI is recommended as the primary imaging modality for investigation of athletes presenting with back or radicular pain. When bony injury is suspected, radiography technique or targeted CT should be obtained to help localise the injury and grade its severity. Bone scintigraphy is used when the primary diagnostic imaging measures fail to identify the site of injury in symptomatic individuals. In particular nuclear medicine techniques, i.e. gamma camera or single-photon emission tomography (SPECT) exploiting molecular probes (technetium-99) being tagged to a particular radionuclide (MDP) (Subramanian 1996), are useful tools in providing information on the targeted inflammatory or active sites of new bone formation or resorption for which visualisation are imperceptible on the MRI or CT. The sensitivity of bone scanning with SPECT is hampered by the lack of anatomical details (Bellah et al. 1991). However, integrated SPECT/CT has increased the interest in nuclear medicine of orthopaedic surgeons and sports medicine specialists, especially in diagnostics and management of sports-related injuries. SPECT in combination with CT enables a direct correlation of functional information and anatomical information, leading to a better diagnostic accuracy in scintigraphic evaluation. SPECT/CT therefore represents a clinically relevant component of the diagnostic process in patients with non-oncological orthopaedic conditions referred for bone scintigraphy (Even-Sapir et al. 2007; Scharf 2009). This chapter addresses the importance of the nuclear imaging tool and in particular the SPECT/CT in evaluating causes of pain among athletes with spine-related injuries.

12.2 Acute Injury (Muscle Contusions and Sprains and Stress Fractures)

Acute injuries include the full spectrum of ligament, tendon, and muscle injuries and acute fractures. The most common problem among athletes is self-limiting pain caused by muscle contusions and sprains (Table 12.1). Acute pain is most intense 24–48 h after injury. It is often associated with spasm that, after a couple of days, may be localised to a so-called trigger point. Therefore, imaging tools that comprise metabolic information are useful in determining the origin of pain in this group of patients, since plain radiography may fail to show non-displaced fractures.

Traditionally, three-phase bone scintigraphy is commonly exploited in the evaluation of athletes with traumatic pain. The high-contrast resolution of bone scan allows early detection of acute spine trauma when imaging is performed within 6–72 h following the onset of symptoms.

Table 12.1 Common classification of spine injuries by onset of symptoms

Acute injury	Overuse injury
Muscle contusion	Fatigue fracture
Ligament sprain	Spondylosis
Joint sprain	Spondylolisthesis

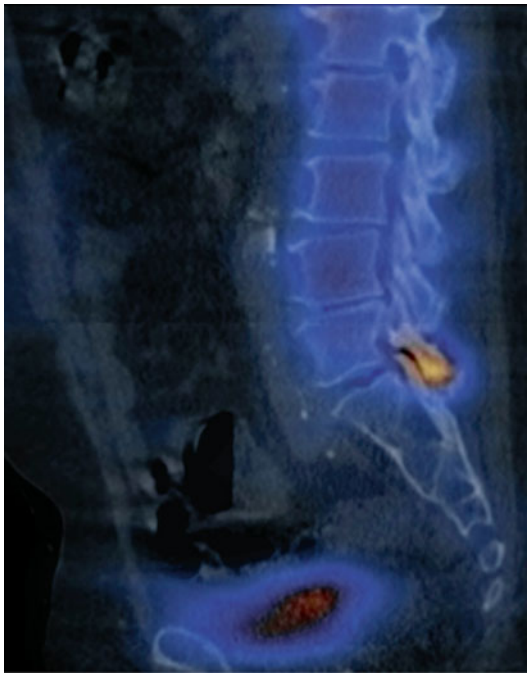

Fig. 12.1 L5 pars fracture. A 66-year-old female with lower back pain. MIP ^{99m}Tc-MDP SPECT/CT image shows the location of the metabolic activity indicating an acute stress reaction of the pars interarticularis without an obvious fracture

SPECT/CT in particular can complement the management of sports-related stress injuries when structural imaging methods, i.e. radiography or computed tomography failed to yield adequate information on their sites and nature of the attributed abnormalities.

Bone stress injuries account for about 10 % of general sports medicine practice (Anshu 2010; Traughber and Havlina 1991). Lower extremity bones are most commonly affected (70–95 %) followed by the spine.

Bone scintigraphy with SPECT/CT has high diagnostic accuracy in localising acute stress reactions and stress fractures involving the posterior elements of the spine (Fig. 12.1). SPECT/CT images confirm a fracture by high metabolic activity at the site of injury and the absence of osteoblastic or osteolytic pathology connote active degenerative osteoarthrosis.

Stress fractures will show a focal abnormal uptake corresponding to the fracture defect seen on the computed tomography (CT) of the fused SPECT/CT. Focal uptake in the pars or pedicle of the lumbar spine, without any morphological abnormality, is consistent with a stress reaction (pre-fracture phase) and ascertains the reason for back pain in an athlete (Anshu 2010).

12.3 Overuse-Related Injuries

Overuse injuries of the spine are more subtle and usually occur over time in a repetitive manner as a result of micro-trauma to the tendons, bones, and joints. "High-risk" overuse injuries render a long period of recovery with significant loss of time from sports participation. These include certain stress fractures, physeal stress injuries, spondylosis, spondylolisthesis, and sacroiliac joint injury/inflammation (Table 12.1).

12.3.1 Fatigue Fracture

Fatigue fractures are also related to the chronic repetitive stress applied to healthy bone (Southam et al. 2010). An example of this is the fatigue fracture of the sacral spine (Fig. 12.2). A vertical concentration of cycling overloading in the sacral bone combined with impaired shock absorption due to associated muscle fatigue has been postulated as a potential mechanism in regard to sacral fatigue fracture pathogenesis (McFarland et al. 1996). High-intensity training or rapid changes in training system are common predisposing factors (Major et al. 2000). Leg length discrepancy, footwear more than 6 months old, poor training surface, nutritional deficiencies, and the female athlete triad have also been implicated as risk factors, among others (Major et al. 2000; McFarland et al. 1996).

This type of fracture causes often an unsuspected and undiagnosed local limb pain in athletes. To ensure early diagnosis when an effective selective treatment is required, bone scintigraphy with SPECT/CT will be a useful tool especially in recognising high bone turnover as signalled by increased MDP metabolic activity.

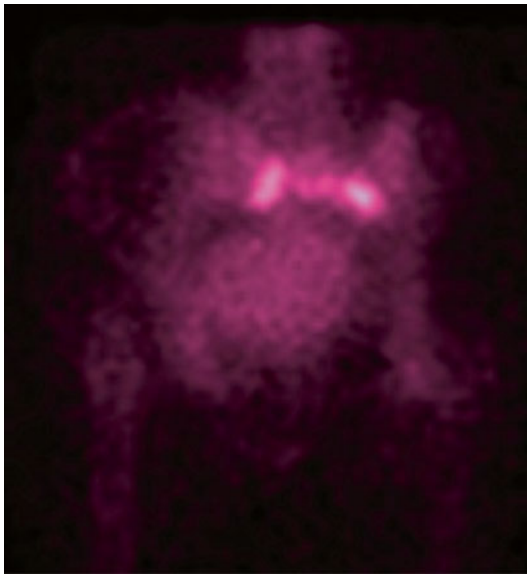

Fig. 12.2 A 62-year-old female with a fatigue fracture of the ala sacrum. Coronal ^{99m}Tc-MDP SPECT/CT image reveals an "H"-shape configuration sign

12.3.2 Spondylosis

Spondylosis is an age-related chronic process defined as the development of vertebral osteophytes, succeeded by osteochondrosis related to disc disease with disc space narrowing and secondary osteoarthritis of the facet joints. Premature spondylotic changes are likely to affect athletes with a history of vigorous load-bearing body stress activities. The more advanced stages of the process may produce a wide range of symptoms related to neuronal conflict of osteophytes or disc protrusion and facet osteoarthritis including pain. The degenerative disc changes include desiccation of the nucleus pulposus, loss of annulus fibrosus elasticity, and narrowing of the disc space with or without disc bulging or protrusion with or without annulus fibrosus rupture. Spondylosis is most often non-symptomatic. Not infrequently, however, these patients will have very few neck symptoms and will present with referred pain patterns: occipital headaches and pain in the shoulder, suboccipital and intrascapular areas, and anterior chest wall.

In certain circumstances, bone scintigraphy with SPECT/CT may have a complementary role to plain radiography and CT in isolating the site of increased bone turnover as signalled by marked uptake of MDP (Fig. 12.3). Spondylolysis has been reported to be the most common cause of lower back pain seen in a sports medicine clinic (Stasinopoulos 2004). It remains the major cause of spondylolisthesis and spine instability. AP and standing lateral lumbar radiographs are supplemented by oblique views. On oblique views the defect is seen as the so-called fracture in the "neck of the Scotty dog". Collier et al. and others reported that SPECT is more sensitive than planar bone scintigraphy in the identification of symptomatic sites in spondylolysis (Collier et al. 1985). SPECT improves the detection of spondylolysis compared to planar bone scintigraphy (Bellah et al. 1991).

For spondylolysis or stress fracture in athletes, bone scintigraphy with SPECT/CT was found more sensitive than lumbar MRI; this is related to the non-visualisation of the pars interarticularis on MRI examinations performed for disc disease (Masci et al. 2006). A SPECT/CT bone scan is also recommended for those cases in which a pars defect is suspected on plain radiographs. It may help to determine if a pars defect seen on X-ray is "hot" and therefore likely to be a cause for the pain. Most frequently, spondylolysis is associated with repetitive microtrauma, occurring in the adolescent during spinal growth. An increased incidence of spondylolysis is seen in adolescent athletes who practice sports with repetitive and excessive hyperextension such as gymnastics, diving, ballet, and soccer (d'Hemecourt et al. 2000, 2002).

12.3.3 Spondylolisthesis

Spondylolisthesis is a spinal condition in which all or a part of a vertebra has slipped forward on another (Fig. 12.4). There are several types of spondylolisthesis, but the most common in sports are stress fractures in the isthmus or pars interarticularis (Seimon 1983). The most common clinical manifestation of

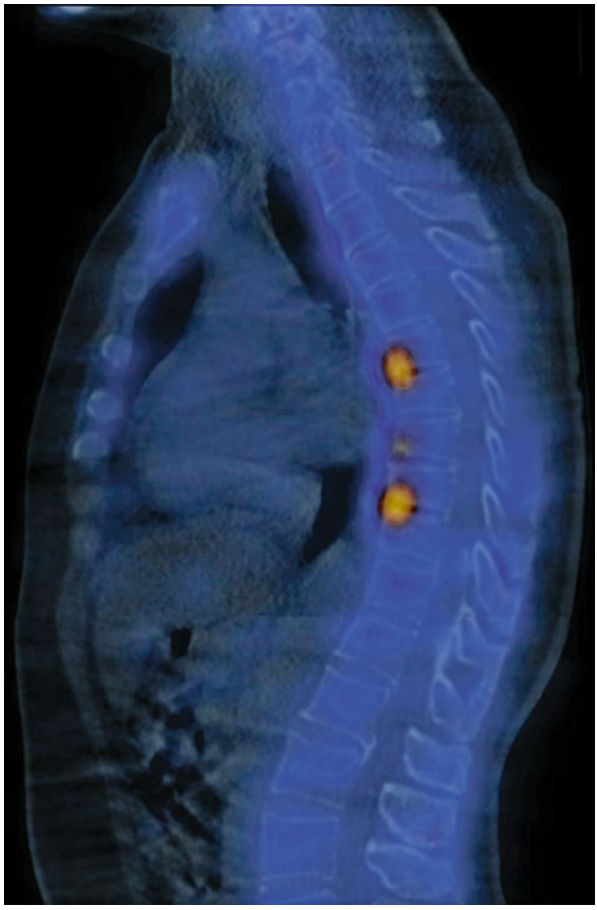

Fig. 12.3 A 29-year-old female with back pain. MIP ^{99m}Tc-MDP SPECT/CT shows increased metabolic activity in the disc plates of the lower thoracic spine with T9 and C10 anterior wedging denoting chronic spondylosis

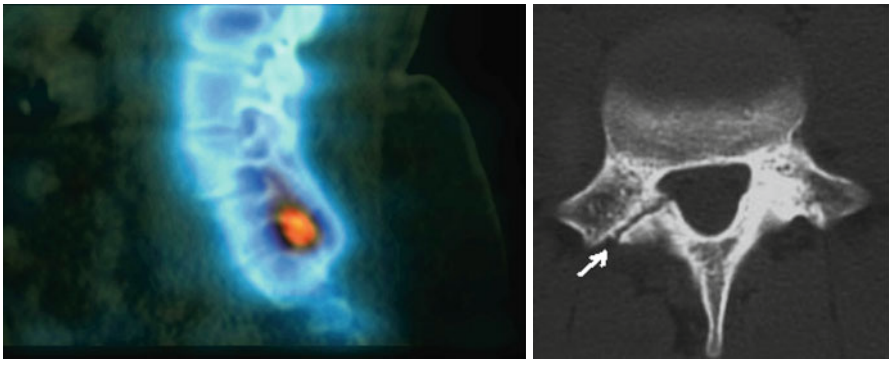

Fig. 12.4 A 46-year-old male with L4–L5 pars interarticularis defect. MIP ^{99m}Tc-MDP SPECT/CT shows increased metabolic activity at the site of a L4–L5 interarticularis fracture resulting in anterolisthesis of L3 on L4 vertebra. The axial CT image confirms presence of the fracture involving the right pars interarticularis (*arrowed*)

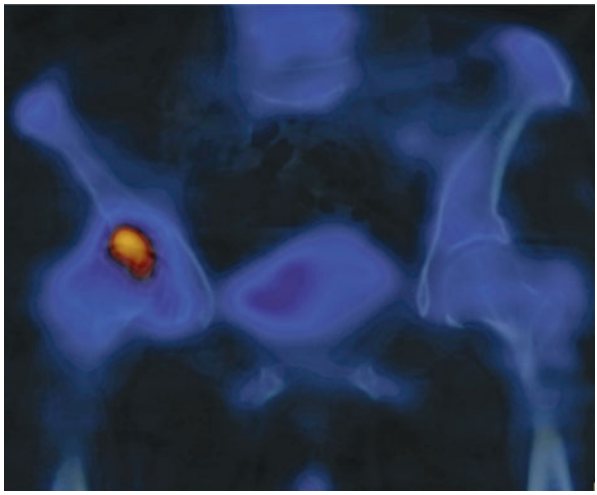

Fig. 12.5 A 44-year-old female with right lower lumbar pain. MIP ^{99m}Tc-MDP SPECT/CT shows increased metabolic uptake of the right hip joint representing osteoarthritis as a cause of referred pain to the lower lumbar region

spondylolisthesis is lower back pain. Although the cause of this type of back pain in the adult has been studied extensively, its origin is still unclear. Bone scintigraphy with SPECT/CT has a role when the acuity of a pars defect is in question and it can be documented within 3 months after the injury; if the defect is longer existing, the scan will become negative.

12.4 Specific Spine Injuries

12.4.1 Acute and Chronic Lumbago

Pain in the lower back in athletes can be caused by a variety of conditions including musculo-ligamentous, osteoarticular, and neurologic disorders. It is a common source of pain in athletes, leading to significant time missed and disability (Petering Ryan and Charles 2011). Undifferentiated lower back pain in the general population is a well-established indication for planar bone scintigraphy (Bombardieri et al. 2006; Kanmaz et al. 1998). SPECT/CT imaging is useful for anatomic and functional evaluation of benign and malignant spine bone diseases, particularly for evaluation of chronic back pain (Schillaci 2005). Mechanical lower back pain accounts for up to 97 % of lower back pain diagnoses in the general population (Kalichman and Hunter 2007; Deyo and Weinstein 2001). A clinical examination of mechanical lower back pain is non-specific and is not able to discriminate vascular, infectious, inflammatory, and neoplastic aetiologies. Lumbar facet joint capsules are richly innervated with autonomic nerve fibres and may become a potential source of pain (Willard 1997). Lower back pain getting worse when sitting may indicate a

Table 12.2 Pain and the potential attributes

Symptoms	Causes
Acute and chronic local pain	Direct trauma, spondylolisthesis, sacral insufficiency fracture, facet joint osteoarthritis
Sciatica	Disc prolapse
Referred pain (Fig. 12.5)	Osteoarthritis of knee or hip joint

herniated lumbar disc. Pain with acute onset may suggest a herniated disc or a muscle strain, as opposed to a more gradual onset of pain, which fits more with osteoarthritis, spinal stenosis, or spondylolisthesis (Table 12.2).

Sports persons who continue to complain of lower back pain for more than 6 weeks should have plain radiographs including oblique views (Logroscino et al. 2001). The vast majority of patients with predominantly lower back pain will have normal plain radiographs. In these patients with suspected clinically bone abnormality, bone scintigraphy with SPECT/CT may be considered as a second-line imaging test (Table 12.3).

The major goal of bone scintigraphy is to establish whether the patient's pain is related to an active bony process. Gates and McDonald argued that a normal bone scan effectively excludes a bony-based lesion (Gates and Mc Donald 1999). When bone pathology is present, nuclear scintigraphy has a proven role in the identification of a number of conditions including facet joint disease or instability, sacroiliac disease, pseudoarthrosis, fracture, and post-operative infection (Table 12.4). In particular, bone scans have the potential to detect active bone remodelling, whereas corresponding radiographs may be normal or document past structural change in the joint (Okamoto 1995). For instance, the sacral insufficiency fracture represents a repetitive, prolonged muscular action on the bone that has not accommodated itself to the action, resulting in stress fractures. The use of SPECT in addition to CT helps determine the cause of lower back pain (Fig. 12.6).

The use of SPECT in bone scanning has improved the sensitivity and location capacity of these lesions by 20–50 % when compared to planar bone scan (Even-Sapir 2005) as is shown in Table 12.3.

Ghormley first coined the concept "facet joint syndrome" in 1933 when discussing alternate sources of lower back pain (Ghormley 1933). Lumbar spine facet joint pain may affect many patients with chronic lower back pain, with a wide estimation between 5 and 90 % (Cohen and Raja 2007). A small study using a computer algorithm to fuse the SPECT and CT data demonstrated an improved ability over SPECT alone in differentiating activity between L4/L5 and L5/S1 facet joints (McDonald 2007).

12.4.2 Cervicalgia and Cervicobrachialgia

Cervical spine strains and sprains frequently occur as a result of a whiplash injury, which often occurs as the result of motor vehicle accidents, falls, sports-related accidents, or other traumatic events that cause a sudden jerk of the head and neck

Table 12.3 Differential diagnosis of lower back pain and diagnostic imaging tools that may be indicated

Evaluation	Back sprain	Disc prolapse	Spinal stenosis	Spondylolisthesis	Spondyloarthropathy	Infection	Tumour	Metabolic
Predominant pain	Back	Leg	Back/leg	Back	Back	Back	Back	Back
Radiography		+	+	+	+	+/–	+/–	+
CT		+	+			+	+	
MRI	+	+	+	+	+	+	+	+
Bone scan with SPECT					+	+	+	+
Bone scan with SPECT/CT	+	+	+	+	+	+	+	+

Table 12.4 Indications of bone scintigraphy with SPECT/CT in spine-related trauma

Negative CT or radiographic results
Focal neurologic deficit
Immunosuppression, diabetes mellitus
Significant cumulative traumata
Duration more than 6 weeks

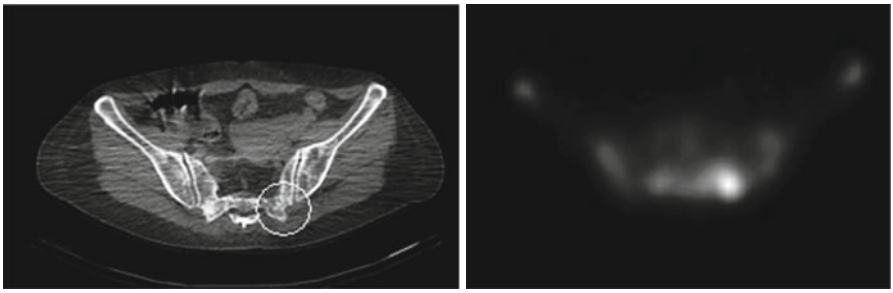

Fig. 12.6 A veteran female athlete with left pelvic pain. There is an old insufficiency fracture seen involving the left ala sacrum (*round white marker*) on the axial CT image. MIP ^{99m}Tc-MDP SPECT image shows slightly increased metabolic activity at the fracture site

(Rodrigo and Leonardo Oliveira 2006). The intensity of athletic competition has led to a large number of injuries that result in neck (cervicalgia) or upper limb pain (cervicobrachialgia), a situation made worse by the heavy backpacks among school-going adolescents and young athletes. Most injuries are a result of muscle strain or physical therapy. In older patients predominant arm pain (brachialgia) is related to mechanical pressure and inflammation of the involved nerve roots which is likely attributed to bone proliferation related to degeneration.

In many conditions, such as suspected infection or suspected acute osteoporotic crush fracture, MRI is the investigation of choice. CT is highly accurate for assessment of bone lesions such as suspected tumours or pars interarticularis defects. Bone scintigraphy with SPECT/CT is useful in distinguishing between abnormalities that are caused by fractures of the pars and other focal areas of increased activity that include facet joint osteoarthritis (Elster 1989).

Bone scintigraphy is also indicated to exclude spinal metastases, when there is a known primary tumour or a suspected pars interarticularis fracture for which changes may be difficult to see on plain radiographs, particularly in young patients with subtle stress fractures (Table 12.5). The majority of patients with non-specific cervicalgia show improvement of symptoms within 12 months. In this group there is value in identifying those in whom the cause is active facet arthropathy, since a corticosteroid injection to the culprit joints can hasten their symptomatic recovery (Fig. 12.7). SPECT/CT imaging is the ideal investigation in this group, given the additive information derived from the combination of functional and structural changes obtained.

Table 12.5 Differential diagnosis of cervicalgia and the diagnostic imaging tools that may be indicated

Evaluation	Neck strain	Degenerative disc disease	Myelopathy	Spondyloarthropathy	Tumour	Metabolic	Infection
Predominant pain	Neck	Neck	Neck	Neck	Neck	Neck	Neck
Radiography		+	+/–	+	+/–	+	+/–
CT		+	+		+		
MRI	+	+	+	+	+	+	+
Bone scan with SPECT				+	+	+/–	+
Bone scan with SPECT/CT	+	+	+	+	+	+	+

Fig. 12.7 A 59-year-old-female with neck pain. MIP ^{99m}Tc-MDP SPECT/CT shows increased metabolic activity of the C7–T1 apophyseal joint – cervical discogenic spondylosis

12.4.3 Intervertebral Disc Injuries and Radiculopathy

Because of excessive weight bearing and stress, athletes sometimes damage an intervertebral disc. A herniated intervertebral disc is defined as the displacement of nucleus pulposus through the torn fibres of the annulus fibrosus. Most disc herniations occur during the third and fourth decades of life while the nucleus pulposus is still gelatinous. The two most common levels are L4–L5 and L5–S1. Not everyone with a disc herniation has significant discomfort.

A large herniation in a capacious canal may not be clinically significant since there is no compression of the neural elements, while a minor protrusion in a small canal may be crippling since there is not enough room to accommodate both the disc and the nerve root. The major interest of nuclear imaging in disc herniation is to enhance the identification of a vital associated cause, i.e. compression vertebral fractures or primary

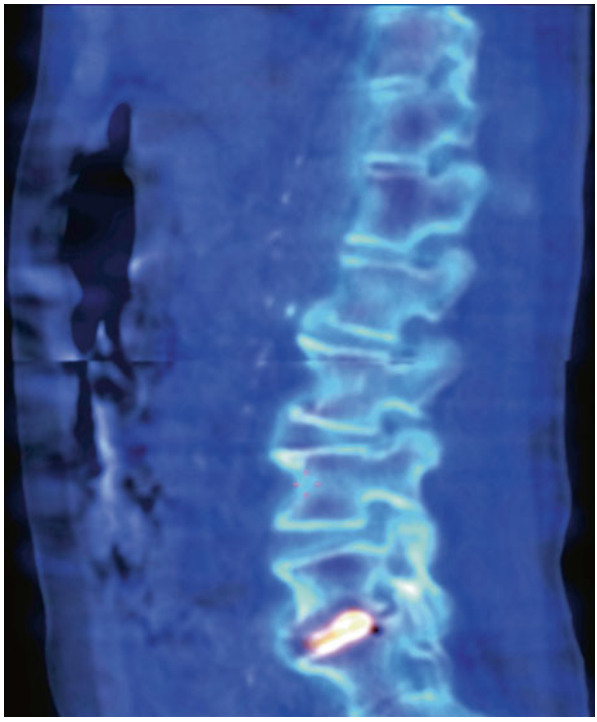

Fig. 12.8 A 37-year-old male with acute lower back pain and sciatica following a mishap in sports activity. MIP ^{99m}Tc-MDP SPECT/CT shows a severely prolapsed L4–L5 disc with increased metabolic activity denoting discitis

disc diseases. In this regard, bone scan is helpful to establish the age of compression fractures (Gates 1998) Bone scan is used if MRI is not available or non-specific. MRI was found helpful in determining which fractures were acute (Park et al. 2013). Indeed particularly challenging in patients with sports injuries is the discrimination of active and old injury or anatomical abnormalities. The information of planar bone scintigraphy may be helpful in managing patients with pain and disability, but nowadays accurate localisation of the involving fractures by means of SPECT/CT is critical because of the advent of vertebroplasty and kyphoplasty (Maynard et al. 2000). The role of SPECT/CT in personalising the treatment for specific pain-related injury attributable to sports are of paramount importance as to avert unnecessary long wasting rehabilitative therapy. In a retrospective study, Maynard et al. (2000) found that increased activity on a bone scan strongly predicted a positive clinical response (i.e. relief of pain) to percutaneous vertebroplasty in osteoporotic vertebral compression fractures.

Although the bone scan can be used to age fractures or stress injuries, only SPECT/CT depicts details of complicated combinations of old and new injuries especially in patients with crippling pain (Fig. 12.8). In a study by Auerbach et al. (2008), negative findings on bone scintigraphy with SPECT were found 100 % predictive of mechanical back pain for children with less than 6 weeks of symptoms regardless of radiological examination finding. Bone scintigraphy with SPECT is a good diagnostic option for early presentation of lower back pain in children (Auerbach et al. 2008).

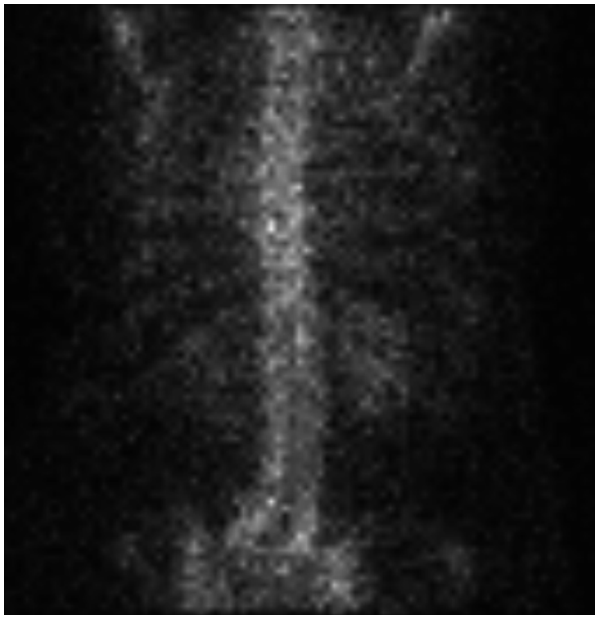

Fig. 12.9 A 28-year-old female with idiopathic scoliosis with pain. MIP ^{99m}Tc-MDP SPECT shows no notable increased metabolic activity to suggest a leading cause for the scoliotic pain

Table 12.6 Common causes of scoliosis and scoliotic spine position

Causes of scoliosis	Aetiology
Primary	Idiopathic
	Congenital
	Scheuermann's disease
Secondary	Tumour, i.e. osteoid osteoma, neurofibromatosis
	Neuromuscular condition, i.e. cerebral palsy
	Degenerative spine disease in elderly
	Infection
Secondary not spine related	Muscle contusion, bowel obstruction, renal stone

12.4.4 Scoliosis

Scoliosis refers to abnormal curvature of the spine, with a lateral component of >10°. Most commonly, scoliosis is idiopathic. Idiopathic scoliosis is classified according to the age of onset with three major groups described: infantile, juvenile, or adolescent (Fig. 12.9). The cause of scoliosis can either be primary or secondary (Table 12.6). Primary causes include congenital defects due to abnormal vertebral segmentation. Traditional imaging tools, i.e. plain radiographs or CT, may be inaccurate in determining the cause of scoliosis. This is important when scoliotic spine position is non-idiopathic and related to problems listed in Table 12.5. In one study, 30 % of children with idiopathic scoliosis had back pain (Ramirez et al. 1997).

Scoliosis may be evident in young athletes, with a prevalence of 2–24 % (Dickson 1999). The highest rates are observed among dancers, gymnasts, and swimmers. The

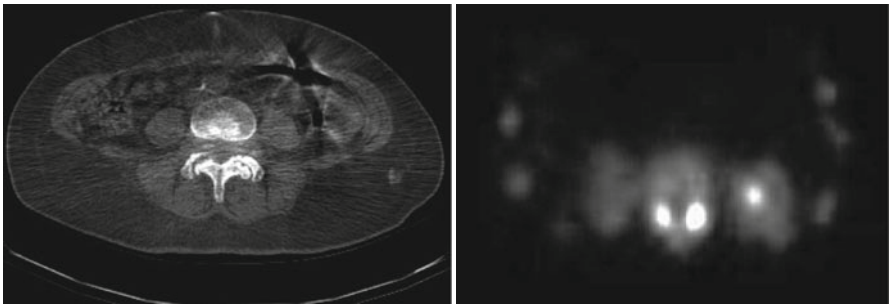

Fig. 12.10 A 57-year-old male with facet joint arthrosis and the resulting scoliosis. Axial CT (*left*) and the correlated MDP SPECT (*right*) image showing facet joint degeneration with increased metabolic uptake

scoliosis may be due in part to loosening of the joints, delay in the onset of puberty (which can lead to weakened bones), and stresses on the growing spine. There have also been isolated reports of a higher risk for scoliosis in young athletes who engage vigorously in sports that put an uneven load on the spine. These include figure skating, dance, tennis, skiing, and javelin throwing, among other sports. In most cases, the scoliosis is minor, and everyday sports do not lead to scoliosis. Exercise has many benefits for people both young and old and may even help patients with scoliosis.

Acute painful scoliosis may indicate the presence of vertebral infection or a tumour such as osteoid osteoma. Bar-Shalom et al. evaluated the role of nuclear medicine by using ^{67}Ga (GS)- or ^{111}In-labelled white blood cells (WBC) and SPECT/CT in the diagnosis and localisation of infections. These techniques improved diagnosis, localisation, and definition of extent of disease (Bar-Shalom et al. 2006). In another study, an improved utility of the SPECT/CT using ^{99m}Tc-HMPAO-labelled leukocytes was shown in patients with suspected osteomyelitis by providing accurate anatomic localisation and precise definition of the extent of infection (Luca and Orazio 2006). Osteoid osteoma of the spine must be considered when backache is associated with muscle spasm and scoliosis. Bone scintigraphy with SPECT/CT provides information about the metabolic activity of the bone and surrounding tissue and for the evaluation of back pain in particular as an attribute to scoliosis (Fig. 12.10).

12.4.5 M. Scheuermann

The adolescent athlete may also suffer from lower back pain that is caused by growth-related problems such as scoliosis and Scheuermann's kyphosis. These problems may or may not be related to sports activity, but they can affect an athlete's ability to perform up to his or her standards. Juvenile kyphosis known as Scheuermann's disease has no clear aetiology. The prevalence of back pain in children and adolescents varies widely from 12 to 50 %. Jones et al. reported an average lifetime prevalence of back pain of 40.2 % in 500 children between 10 and 16 years of age (Jones et al. 2004). Back pain in children occurs less frequently than in adults. The incidence of back pain in adults with M. Scheuermann has been

Table 12.7 Radiological characteristics and diagnostic criteria for Scheuermann's disease

Radiological characteristics
Anterior vertebral body wedging
Endplate irregularity
Disc space narrowing
Schmorl's nodes
Diagnostic criteria
Hyperkyphosis 94°
Wedging 95° in three or more consecutive vertebral bodies
Irregular endplates
Disc space narrowing

estimated to be as high as 60–80 % (Kelsey and White 1980); the actual incidence of back pain in children, however, is unknown. Neurologic complications secondary to Scheuermann's disease are rare but have been reported (Bradford and Garica 1969).

Differentiation between Scheuermann's disease and postural kyphosis is facilitated by viewing the patient, in the forward flexed position, from the side. Patients with postural kyphosis have a smooth, rounded curve, which reverses on voluntary extension. A variant of type II lumbar Scheuermann's is known as "acute traumatic intraosseous disc herniation". This is characterised by a history of a traumatic event, i.e. a fall. These patients will experience severe pain after their injury and can pinpoint when their symptoms began (Bowles and King 2004).

No definitive aetiology has been identified; one accepted cause for Scheuermann's kyphosis is repeated or acute trauma of the immature spine, as is seen with adolescent athletes performing gymnastics (Hollingworth 1996). The typical deformity of Scheuermann's kyphosis involves a sharp, angular gibbus that does not correct on extension of the spine. Other radiological criteria for the diagnosis of Scheuermann's kyphosis include irregular upper and lower endplates with Schmorl's nodes, disc-height loss, and associated apophyseal ring fractures (Table 12.7).

Bone scintigraphy findings are generally not pathognomonic, appearing as subtle increases in isotope uptake at the sites involved by the disease (Holt et al. 1997). MRI may be helpful to rule out discitis if this is the concern. In addition, MRI will further evaluate Schmorl's nodes and disc prolapse beneath the vertebral apophyses (Khoury et al. 2006) (Fig. 12.11).

12.4.6 Spinal Stenosis and Intervertebral Disc Injuries

Cervical stenosis is prevalent in athletes and has been reported in a 2011 study published in the medical journal "Neurosurgical Focus". (Aaron et al. 2011) The condition is serious as it poses risks of developing more severe spinal conditions in the future.

These patients usually have symptoms secondary to mechanical pressure and inflammation of the nerve roots that originate in the back and extend down the leg. The aetiology of the mechanical pressure can be soft tissue-herniated disc, bone protrusions, or a combination of these two. The diagnosis of spinal stenosis usually can

Fig. 12.11 A 9-year-old girl with back pain. Sagittal T2-weighted MRI showing multi-levels of lumbar disc prolapses and Schmorl's nodules (*white arrows*) with abnormal paradiscal disc plate suggestive of atypical Scheuermann's disease (Image courtesy of the Lourdes Medical Centre)

be settled by plain X-ray which will demonstrate facet degeneration, disc degeneration, and decreased interpedicular and sagittal canal diameter (Greenberg 1997). The anteroposterior (AP) diameter of the normal adult male cervical canal has a mean value of 17–18 mm at vertebral levels C3–C5. The lower cervical canal measures 12–14 mm. Cervical stenosis is associated with an AP diameter of less than 10 mm, whereas diameters of 10–13 mm are relatively stenotic in the upper cervical region.

The thoracic spinal canal varies from 12 to 14 mm in diameter in the adult. Primary central thoracic spinal stenosis is rare. Occasionally, hypertrophy or ossification of the posterior longitudinal ligament results in central canal stenosis. Lateral thoracic stenosis may result from hypertrophy of facet joints with occasional synovial cyst encroachment. The diameter of the normal lumbar spinal canal varies from 15 to 27 mm. Lumbar stenosis results from a spinal canal diameter of less than 12 mm in some patients; a diameter of 10 mm is definitely stenotic.

Table 12.8 Spinal stenosis and the related anatomy of the surrounding structures compromise

Posterior compartment	Lateral recess	Pars region	Intervertebral foramen
Contents	Lumbar nerve root	Dorsal root ganglia Ventral motor root	Spinal nerve
Potential cause	Hypertrophic facet joints (SAP)	Osteophytes under the pars	Hypertrophic facet joints (SAP)
Affected nerve root	Same as the vertebrae (L3 SAP involve L3 roots)	Same as the vertebrae (L3 pars involve L3 roots)	One level up from the vertebrae (L4 SAP or L3–L4 disc involve L3 roots)

Note: *SAP* superior articular facet

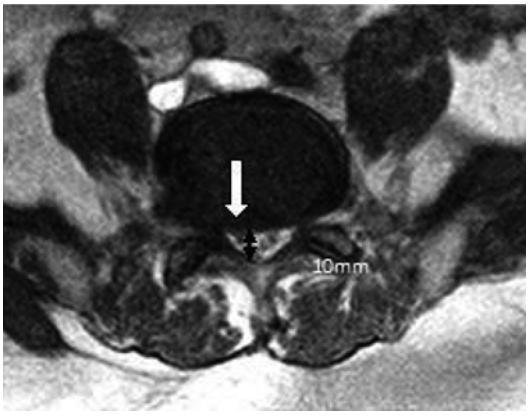

Fig. 12.12 A 46-year-old male with sciatica. Axial T2-weighted MRI at L4–L5 level showing stenotic spinal column caused by a diffuse disc bulge (*white arrow*) with adjoining exiting neural foramina impingement. The remaining spinal canal diameter (*double-sided arrow*) being 10 mm (Image courtesy of the Lourdes Medical Centre)

Pain and neurologic deficits are related to the degree of stenosis which compromise the respective nerve root at the respective lumbar levels (Table 12.8).

Spinal MRI is the most universally suitable technique for the diagnosis of spinal stenosis (Fig. 12.12). SPECT bone scintigraphy is sensitive to diseases that actively affect bone pathophysiology, but spatial resolution is limited (Fig. 12.13).

12.4.7 Vertebral Body Fractures

Vertebral fractures of the thoracic and lumbar spine are usually associated with major trauma and can cause spinal cord damage that result in neural deficits. Major causes of these fractures include trauma related to motor vehicle accidents or sports. Thoracolumbar fractures are more common in older children and adolescents, while cervical fractures are more common in younger children. In athletes, acute fractures of the thoracolumbar spine are rare (Curtis and d'Hemecourt 2007). Thoracolumbar pain is a frequent complaint of many athletes, but the cause is often uncertain. Compression fractures of the spine are rarely seen in athletics and are not always recognised as a potential cause of the symptoms (Vicki et al. 1995).

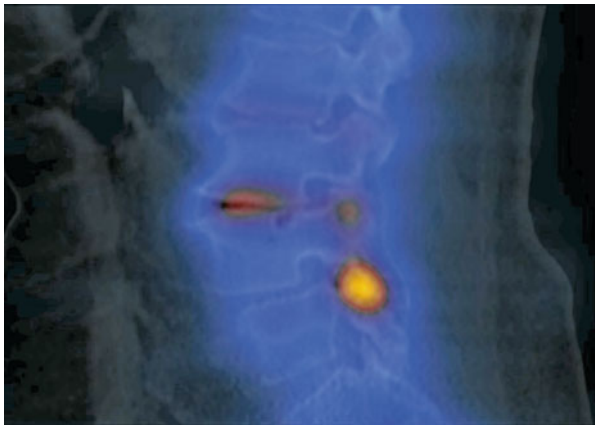

Fig. 12.13 A 37-year-old female with spinal stenosis secondary to spondylolisthesis. MIP ^{99m}Tc-MDP SPECT/CT shows increased metabolic activity involving the L4–L5 pars interarticularis fracture

Radiographs are useful to assess the degree of compression of the vertebral body. Compression of less than 25 % indicates stability, with a single anterior column involvement. CT is the major imaging tool to stage traumatic spine fractures. MRI is often used, but cannot be performed in some patients and is non-specific in others. With CT or MRI, compression fracture can be distinguished from severe degenerative disease, both of which show increased uptake on bone scintigraphy.

Bone scintigraphy with SPECT/CT in patients with acute back pain and a history of compression fractures is helpful in locating the acute injury site (Fig. 12.14). Furthermore, SPECT/CT allows discrimination of the osteonecrotic core from nearby hyperactivity due to viable bone if the primary cause of concern was an infection or malignancy. In this regard, MRI is not able to visualise bone destruction, but proved helpful to detect soft tissue involvement (Dore et al. 2009).

Thoracolumbar compression fractures of less than 25 %, without neurologic symptoms, are not associated with posterior instability. Posterior instability, however, becomes a concern as the compression approaches 50 % (Keane 1987). Collins et al. demonstrated that bone scintigraphy with SPECT/CT provides additional information compared to SPECT alone in up to 62.5 % of cases of perioperative evaluation of vertebral compression fractures, resulting in significant changes in the final assessment (Collins et al. 2004; Punit et al 2013).

12.4.8 Ankylosis Spondylitis

Ankylosing spondylitis, also known as Bechterew's disease, is a chronic inflammatory seronegative type disease of the axial skeleton. It is a subtype of spondyloarthritis and could also be the outcome of spondyloarthritis. It mainly affects joints in the spine and in the sacroiliac joint. The clinical diagnosis of early sacroiliitis, the most frequent clinical symptom often accompanied by inflammatory back pain, is often difficult because of the deep location and lack of motion.

The most common cause of this is inflammation of the sacroiliac joint – sacroiliitis. Early diagnosis of sacroiliitis of the spine on MRI is important as it ensures

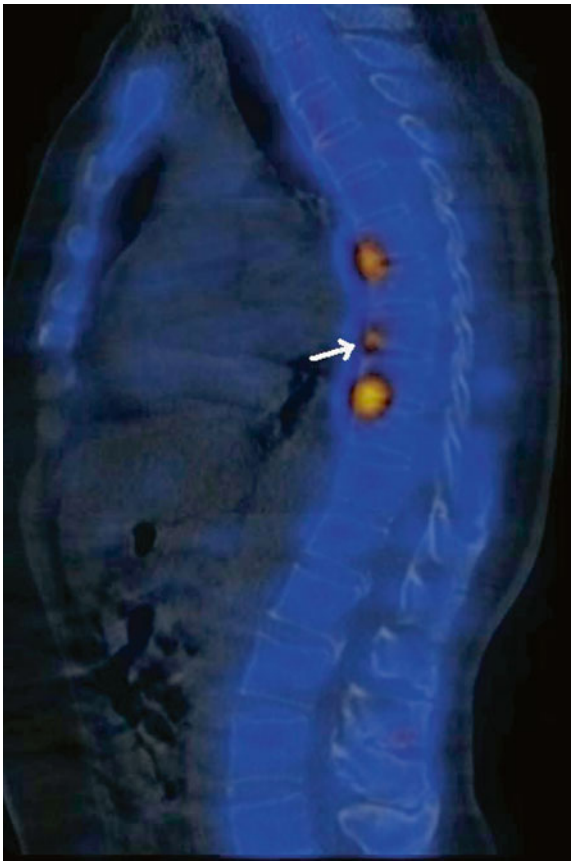

Fig. 12.14 A 37-year-old athletic female with compression fracture of T-11 vertebra. Sagittal MIP ^{99m}Tc-MDP SPECT/CT shows vertebral height compression with increased activity denoting an increased metabolic turnover in the fractured vertebra (*arrow*)

the sustainability of the performing athletes in their future endurance. Early diagnosis of sacroiliitis and other inflammatory lesions of the spine, i.e. spondylitis, can be detected by MRI. CT may not be accurate in assessing early sacroiliitis before the manifestation of erosions and other overt changes or in evaluating disease activity in cases with advanced sacroilitis. The role of bone scintigraphy in the evaluation of sacroilitis is controversial. At least three-phase bone scintigraphy is obligatory. However, the uptake can also be related to other skeletal problems. The disparity in opinion on the clinical utility of bone scintigraphy may partly be due to technical problems associated with increased accumulation of radiopharmaceutical at normal bone sites in close proximity to the sacroiliac joints. In one study, it is suggested that ^{99m}Tc MDP scanning is a useful primary investigation for the detection of spinal pseudarthrosis in patients with chronic ankylosing spondylitis who suffer late-onset back pain (Park et al. 1981).

SPECT/CT scanning overcomes these difficulties by improving the localisation in and around the sacroiliac joints. SPECT/CT scanning is superior to planar scintigraphy in distinguishing between inflammatory and mechanical causes of symptoms of sacroiliitis (Hanly et al. 1994) (Fig. 12.15). The sensitivity and specificity

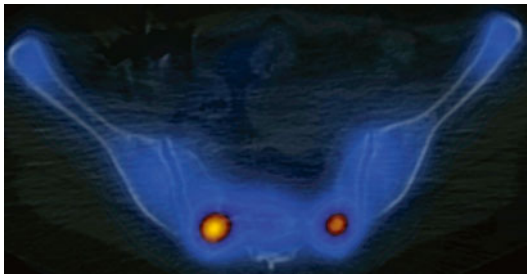

Fig. 12.15 A 68-year-old female with sacroilitis. MIP ^{99m}Tc-MDP SPECT/CT shows increased metabolic activity involving both posterior sacroiliac joints

of MRI for the detection of sacroilitis were reported to be 54 and 67 %, respectively. For bone scintigraphy with SPECT, this was 38 and 100 %, respectively (Hanly et al. 1994). However, these results were published before the era of the hybrid camera imaging.

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