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REVIEW ARTICLE

Skeletal scintigraphy with SPECT/CT in benign pediatric bone conditions

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Abstract Benign bone diseases present an ongoing challenge for pediatricians. Most of them are not life threatening, but may be associated with significant morbidity. Benign space occupying lesions are a source of pain and/or pathological fractures. Their symptoms may raise concern for malignancy and require a complex diagnostic workup. Late or inadequate treatment of bone infections may result in bone and joint destruction and lifelong functional impairment especially in young children. Bone damage due to altered blood supply or due to minor trauma can be difficult to identify. MRI is a cornerstone in modern assessment of pediatric bone disease, but bone scintigraphy remains a useful tool in this clinical field. Unlike MRI, bone scans are widely available, provide whole body rather than focused exploration, are less affected by metallic implants or devices and combined with CT in hybrid SPECT/CT systems, allow visualization of bone morphology and metabolism in a single imaging session. The clinical indication and imaging technique of skeletal SPECT/CT in children are still evolving although the benefit of this technique in evaluation of children with bone pain and/or serendipitously found bone lesions seems ascertained. Improvements in gamma camera technology allow the obtaining of high quality images with either shorter acquisition times and /or reduced radiopharmaceutical administered activities. Sedation is required much less for bone scans than for MRI.

Keywords Pediatric · Bone scan · SPECT/CT · Benign disease

Introduction

Benign bone diseases are relatively common in children. They can present as acute illnesses (e.g. acute osteomyelitis, bone infarction), localized pain with sometimes rapidly progressive symptoms (e.g. avascular necrosis, osteochondritis, osteoid osteoma), stable, or slowly growing, congenital asymptomatic bone disorders, benign space occupying lesions and as fractures due to trauma, pathological conditions with reduced bone density or due to stress injuries secondary to physical activities. Pain is the presenting symptom in the great majority of cases. Pain can be localized or ill defined. Its intensity can vary and may be associated with physical activities or the time of day or night. It may or may not respond to non-steroidal anti-inflammatory drugs as well. It is often difficult to localize the site and source of the pain in young non-verbal or non-cooperative children. Furthermore, propagation of the pain stimulus and the phenomenon of referred pain limit even more the ability to adequately localize the painful site. In these clinical settings the value of bone scintigraphy (BS) with its high sensitivity, high negative predictive value and fast whole body exploration remains valuable. Improvements in gamma camera technology in regard to sensitivity and resolution as well as optimization of the recommended pediatric administered doses according to the EANM/SNMMI reference tables [1] reduce the radiation dose to the patient to less than 3 mSv.

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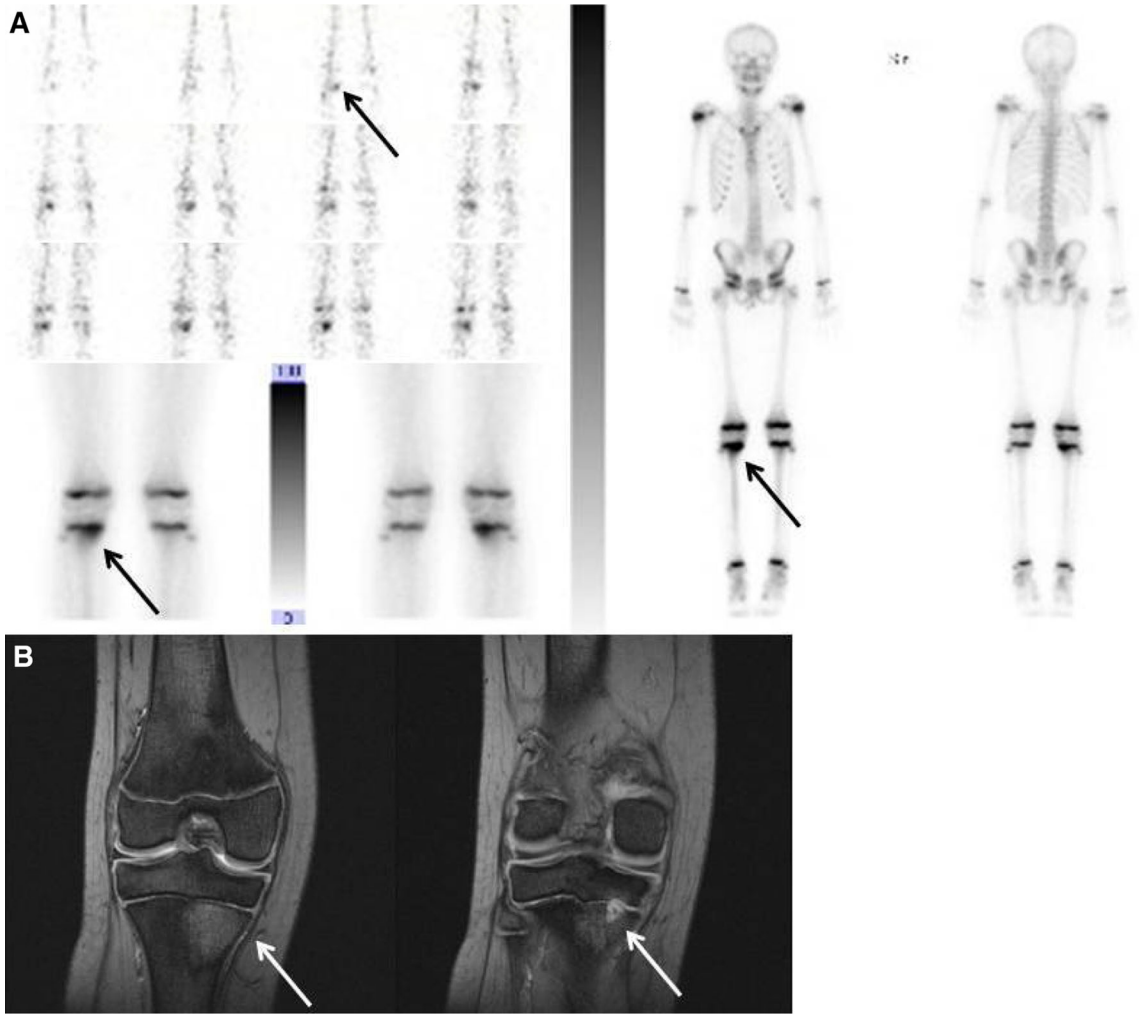

Fig. 1 Non-traumatic knee pain in a 12-year-old boy. **a** 3-phase (angiogram, *top left*, blood pool, *bottom left*) plus wholebody (*right*) bone scan shows a clear abnormality at the right tibia, close to the metaphyseal plate (*arrows*). Such a finding requires an MRI evaluation, so no SPET/CT was performed to avoid a potential increase of gonadal irradiation. MRI (**b** T2 weighted images) confirmed an osteomyelitis

Compared to MRI, a cornerstone of morphologic evaluation of musculoskeletal diseases in children, BS less frequently requires sedation or anesthesia, are not affected by the presence of metallic implants and can be performed safely in children with impaired renal function.

The emergence of hybrid SPECT/CT systems within the last decade, meant a big leap forward for the clinical impact of BS. The fusion of images showing bone anatomy and bone metabolism simultaneously acquired offers new opportunities for "one-stop" lesion characterization and new challenges in performing high quality scans without significantly raising the radiation exposure [2]. This technique allows precise spatial localization of the scintigraphic findings [3, 4]. This fact, coupled with the high intrinsic spatial resolution of the tomographic slices, makes it possible to appreciate not only if a lesion is hypermetabolic but also which part of the lesion is hypermetabolic, resulting in an outstanding improvement in assessing the relationship between metabolic and anatomical abnormalities.

The availability of ^{18}F, as a PET bone-seeking agent requires a careful analysis about the advantages it can offer in respect to conventional gamma emitting radiopharmaceuticals. The superior resolution of the PET/CT system and the shorter study duration (final images are obtained in a maximum time of 90 min) are definite advantages [5–7], whilst the need for a whole-body CT and the more likely need for deep sedation appear as drawbacks in the benign disease clinical setting. In addition, in this era of enhanced requirements for maintenance of certification, physicians continuing education will be stressed as they should learn to read images with features different from those traditionally obtained with diphosphonates, due to the different pharmacokinetics of the radiopharmaceuticals [8].

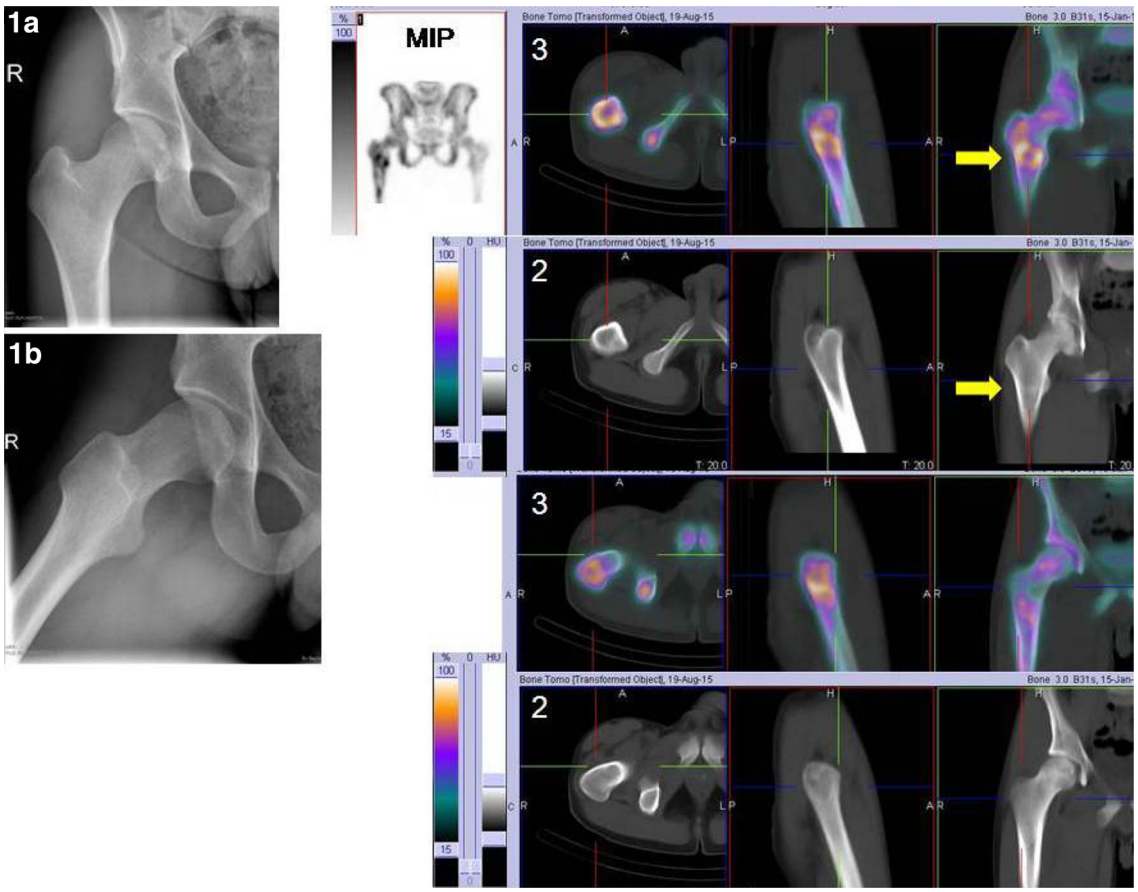

Fig. 2 Male, 17 years old, with progressively worsening hip pain. Plain X-ray film (**1a**, AP view, **1b** extrarotated view) was reported as normal. Also the CT (**2**) performed during hybrid nuclear scan showed no major abnormalities. SPET/CT scan (**3**) showed an increased uptake involving the whole femoral head and the proximal portion of the diaphysis (*arrows*). MRI subsequently showed a space-occupying lesion into the trabecular bone later diagnosed as a Ewing's sarcoma

Technique

A planar whole body scan should always be acquired, irrespective to the localization of symptoms. In smaller children, multiple static images with a large overlap are recommended, to avoid longer immobilization time. In children, the bone uptake and the consequent blood clearance are faster, allowing to obtain high quality images at earlier times post injection than in adults (120–150 min post-injection in adolescents and 90 min post injection in young infants). The three-phase bone scan technique is recommended, for increasing information on soft tissue pathologies with no added irradiation. Blood pool images encompassing the whole body as well are recommended [9]. For a child less than 6 years of age, a two-phase acquisition, 5 and 90 min post injection may be more practical than a three-phase acquisition, because in many general nuclear medicine departments, the pediatric injections are done in a dedicated room. Furthermore, the blood flow dynamic images only seldom provide information that is not present in the early tissue phase (blood pool) images. Parents must encourage the children to drink and to void frequently, for reducing radiation burden prior to injection and between the phases of the study.

SPECT/CT

The advent of hybrid systems fulfilled the dream of nuclear medicine to be able to precisely allocate radiopharmaceutical distribution to an anatomical detailed map. Of course, when dealing with bone diseases, the CT component of the image carries independent, very valuable information, not hampered at all by the lack of contrast media administration. Hybrid systems are equipped with CT systems with slices varying from 2 to 64. This can influence the quality of volumetric reconstruction. Some artifacts are unavoidable when reconstructing thin, 2 mm slices acquired with 1–16 slice CT systems, and the quality of a dedicated bone CT scan is not attainable. Nevertheless, we must obtain the

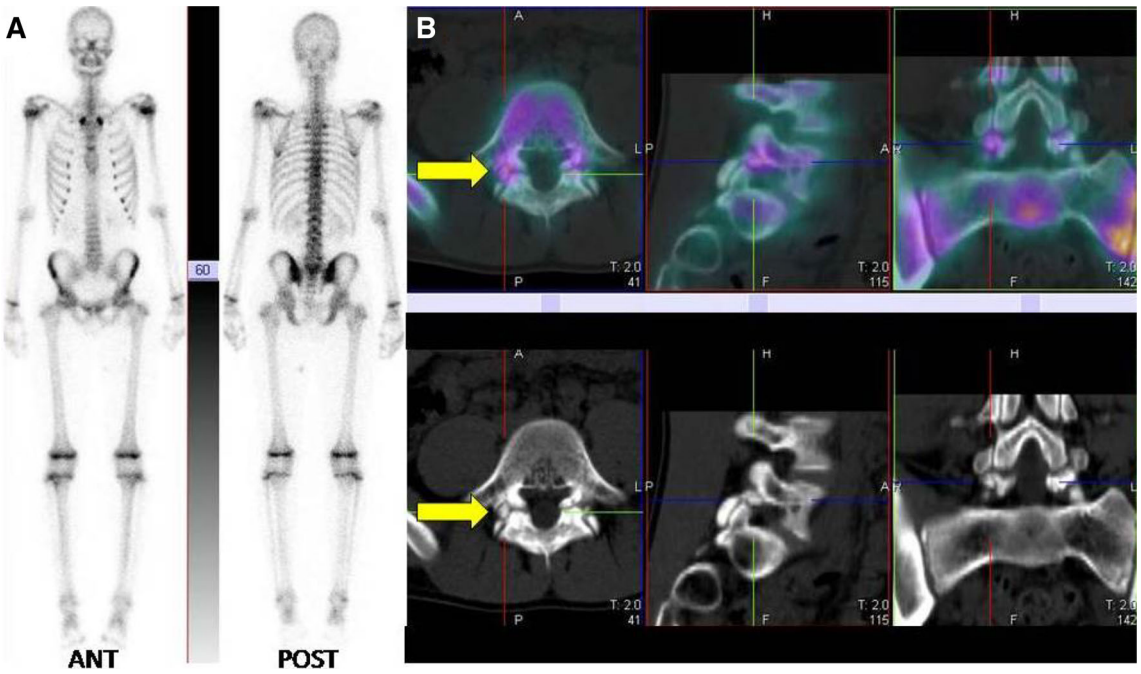

Fig. 3 Male, 14 years old, with backache lasting several months, clinically suspected to be due to vertebral damage. **a** Wholebody scan was unremarkable. **b** SPET/CT showed a mild uptake on the right L5-S1 level (*arrows*); CT images confirmed the diagnosis of right L5 spondylolysis

best quality possible images and maximize clinical throughput. More recently, iterative reconstruction principles and further resolution recovery software programs are available to further enhance these low dose images from the hybrid systems. In the presence of metallic implants, non-attenuation corrected images must be obtained, to avoid artifacts due to non-homogeneous correction. The increased radiation burden from the CT should be handled with caution especially in children. The tube setting parameters must carefully be optimized to minimize this increase, according to the ALARA principle, taking into account the natural high contrast of bone tissue and reducing the scan field according to the abnormalities of uptake observed in the reference scintigraphic image [10]. In certain circumstances, it is wiser not to perform SPECT/CT when the clinical context strongly suggest the need for an MRI (Fig. 1). When sedation is necessary, this must be performed according to the institutional guidelines and under the maximum safety regulations [11].

General indications

A literature search was made through Pubmed/Medline and Google Scholar databases using the keywords SPECT/CT, pediatric, bone scan, children, benign bone lesion, osteoid osteoma, osteomyelitis under various combination. 224 papers were found in the period 2006–2015. After exclusion of reviews, case reports and papers with an oncological topic about 30 original papers remained and the following is a summary of recent relevant literature.

Many benign tumor bone lesions more often show mild increased activity on scintigraphy. These lesions may include bone cysts, enchondromas and benign fibrous lesions. Recently Miller [12] described mild or faint increased activity on bone scintigraphy in a few cases of benign juxtacortical chondroma.

Osteoid osteoma is a common benign bone tumor. Park et al. found that all patients with osteoid osteoma in their series had positive bone scans in contrast to 29 % of their patients having negative radiographs. The use of SPECT-CT would then adequately diagnose these patients as CT was more helpful than MRI in their series of patients. However, if scintigraphy did not adequately identify a lesion, then additional imaging with MRI may be warranted depending on clinical symptoms [13].

In children who have been treated for malignancy, osteonecrosis has a range of incidence reported between 1 and 72 %. On a review of this topic by Kaste et al. [14] scintigraphy is described as sensitive for this diagnosis as it can provide a wholebody assessment. However, MRI has largely replaced scintigraphy for this diagnosis as it has better specificity because of better anatomic detail and its lack of ionizing radiation.

In a review article on bone pain in children, McCarville [15] states that Langerhans cell histiocytosis and osteomyelitis are the two commonest benign conditions causing bone pain. She also noted that Langerhans cell

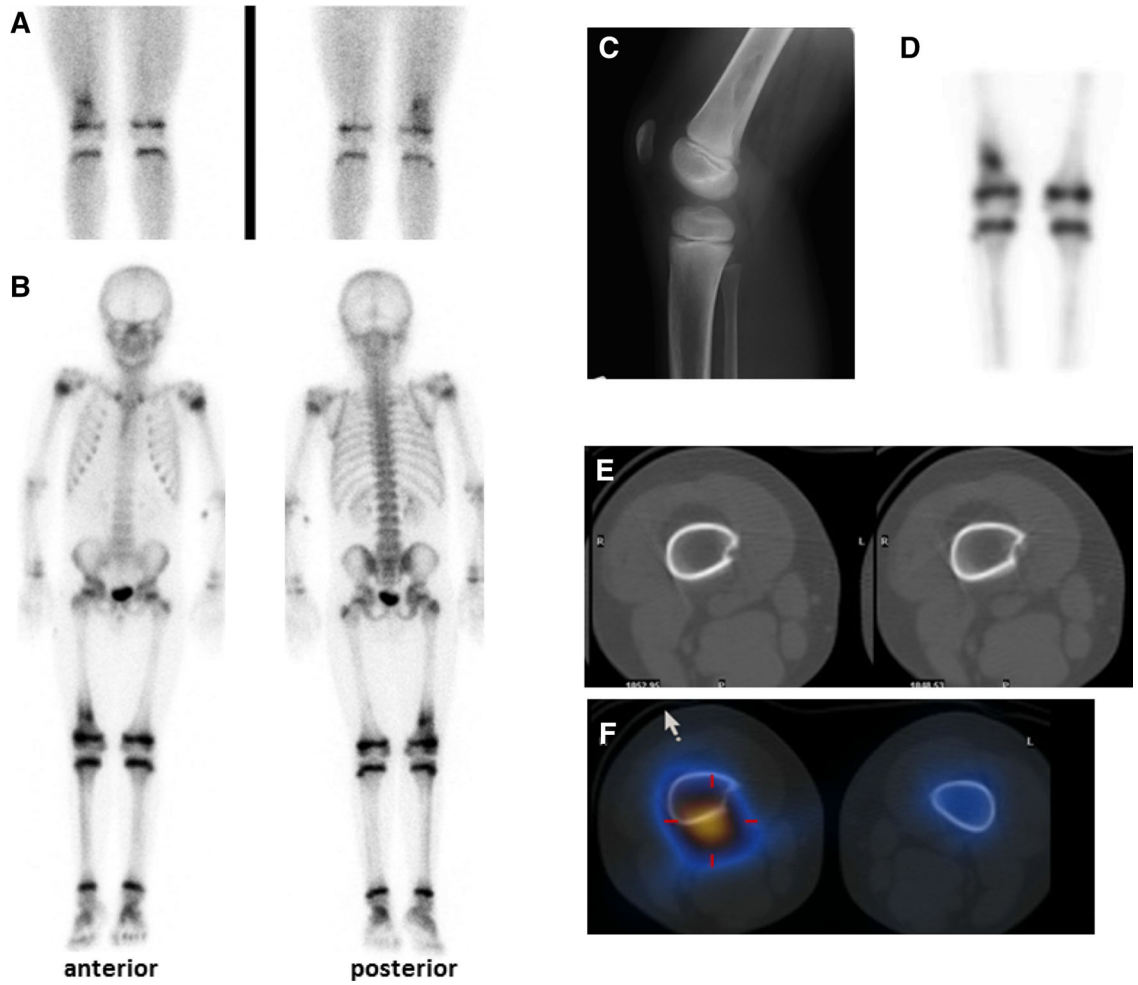

Fig. 4 A 7-year-old boy presented with right distal hip pain. Blood pool images (**a**) showed focal hyperemia at the right distal thigh. Whole body skeletal phase images (**b**) showed intense focal uptake at the distal diaphysis of the right femur surrounded by a zone of diffuse uptake. Plain lateral X-ray of the femur (**c**) showed a well defined lytic lesion that raised the possibility of a benign cortical defect, The intensity of uptake in this lesion on the bone scan was worrisome. A SPECT/CT was performed for further evaluation. The MIP image (**d**) shows intense focal uptake in the lesion. Selected slices from the non-diagnostic low dose CT (**e**) show a benign cortical lytic lesion with a break in the external border of the lesion suggesting fracture or erosion of the thin cortex, explaining the intense uptake demonstrated on the fused image (**e**)

histiocytosis can often have a negative bone scan in up to 20 % of cases. While radiographic skeletal survey is still the mainstay for lesion detection, the addition of 18-FDG PET CT may be more valuable in detecting and following metabolically active lesions.

In an article on management of low back pain in athletes by Siaryo and Nagamachi [16], three stages of spondylolysis are described: early, progressive, terminal where there is bone absorption in an incomplete fracture, then complete fracture and ultimately pseudoarthrosis described for the appearance of these three stages on CT scan. SPECT-CT can clearly identify these three stages and correlate the presence and degree of metabolic activity to correspond with these clinical stages. The value in determining stage relates to potential management. The first two stages present with pain from fracture and hard bracing may heal the fracture. The third or pseudoarthrosis stage may respond to treatment for synovitis symptoms and pain management; but there is little chance of fracture healing with conservative management, so determining with scintigraphy whether the lesion remains metabolically active may help the referring physician determine if more aggressive therapy is needed.

Specific clinical indications

Bone pain

The high sensitivity of bone scans in determining bone involvement in cases of alarming unexplained pain (sometime an early manifestation of bone malignancy) [15]

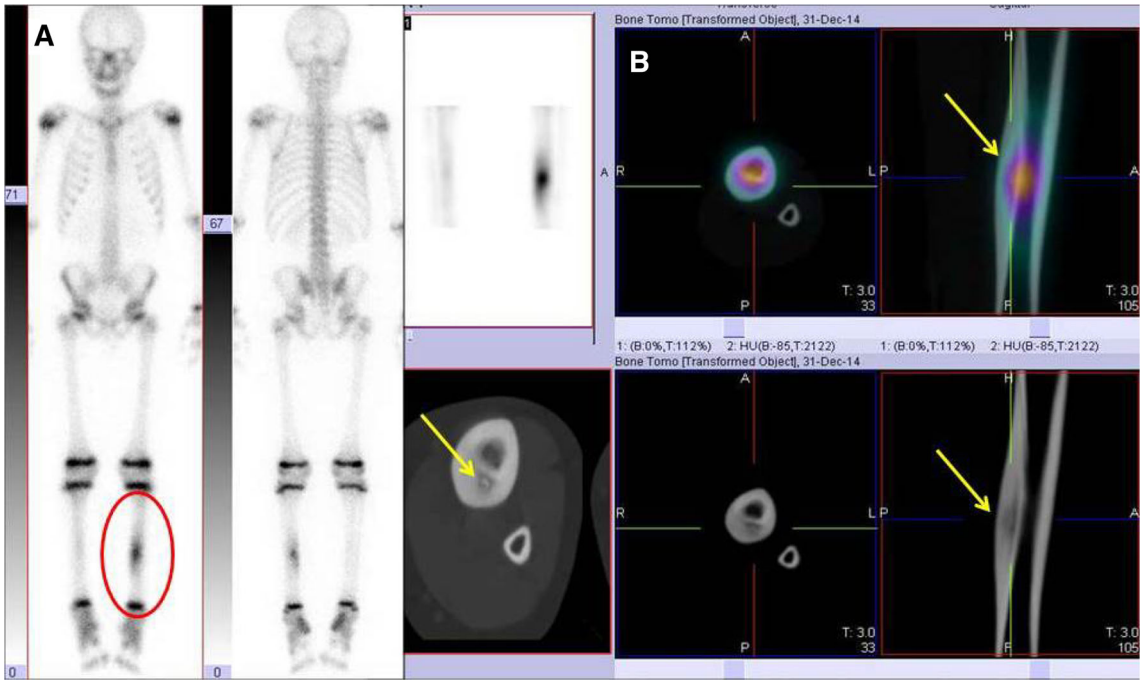

Fig. 5 An 8-year-old girl. Pain at the left leg lasting for about 3 months. X-ray suspected an osteoid osteoma. Wholebody scan (**a**) clearly depicts the "hot spot" at the middle third of the tibial shaft with a fainter uptake by the surrounding sclerotic reaction. **b** SPET/CT shows the nidus, confirming the presence of an osteoid osteoma

(Fig. 2) and the precise localization of the pain source in a specific region in the skeleton are valuable especially in cases of referred bone pain. The increasing number of children participating in sports, including both competitive and recreational settings, has seen an increase in the presence of sport-related lesions. Bone scans are highly valuable in assessing the skeletal involvement in children's sport injuries [17]. Chronic repetitive bone stress from strenuous physical activities may result in microtrauma and produce subtle lesions (typically stress fractures) that are difficult to detect especially when the spine [16], hands or feet are involved. Sometimes the only complaint is a mild, chronic distress and sometimes the symptoms are underestimated by the patient themselves. BS is then extremely sensitive in localizing the lesion site, due to the high tracer localization at the damaged site. The abnormalities detected on the bone scan, in these cases, help determine the extent of the area that requires CT scanning The coregistration of the metabolic abnormalities depicted on the bone scan in SPECT/CT studies improves the identification of abnormalities on the CT slices. SPECT/CT in the context of stress related injuries is especially beneficial in evaluation of spinal [18] pelvic and extremity lesions [19] (Fig. 3).

BS is helpful and frequently employed in cases of suspected child abuse [20] as a complementary evaluation to a wholebody skeletal survey, but BS alone is not recommended as the only study in suspected child abuse and very little experience exists about additional information given by hybrid imaging.

Benign bone tumors and tumor-like lesions

Benign space-occupying lesions of the bones are often serendipitously detected by X-rays performed for other reasons or because of local pain [21] The findings may be due to either primary benign bone tumors or tumor-like bone lesions. Although MRI remains the main pillar of the diagnostic architecture, it is known that useful diagnostic hints like endosteal scalloping, subtle cortical erosion, early periosteal reaction or subtle matrix mineralization able to address a malignant/bening suspicion are better depicted by CT [22]. These changes normally are coupled with an increased bone remodeling and radiopharmaceutical uptake, so it may be foreseen that SPECT/CT would increase their identification. The intensity of the radiopharmaceutical uptake at BS helps to distinguish between stable lesions and growing ones, too. Enchondromas, periosteal chondromas, osteomas (bone islands), simple bone cysts, non-ossifying fibromas (NOF), cortical fibrous defects, benign fibrous histocytomas and the very rare osteopoikylosis [23, 24]. normally show faint or unremarkable peripheral uptake. SPECT/CT precisely shows the areas of weight-bearing bone stress or dangerous erosion of the cortex as areas of localized higher uptake, especially when dealing with NOF, and may help to predict

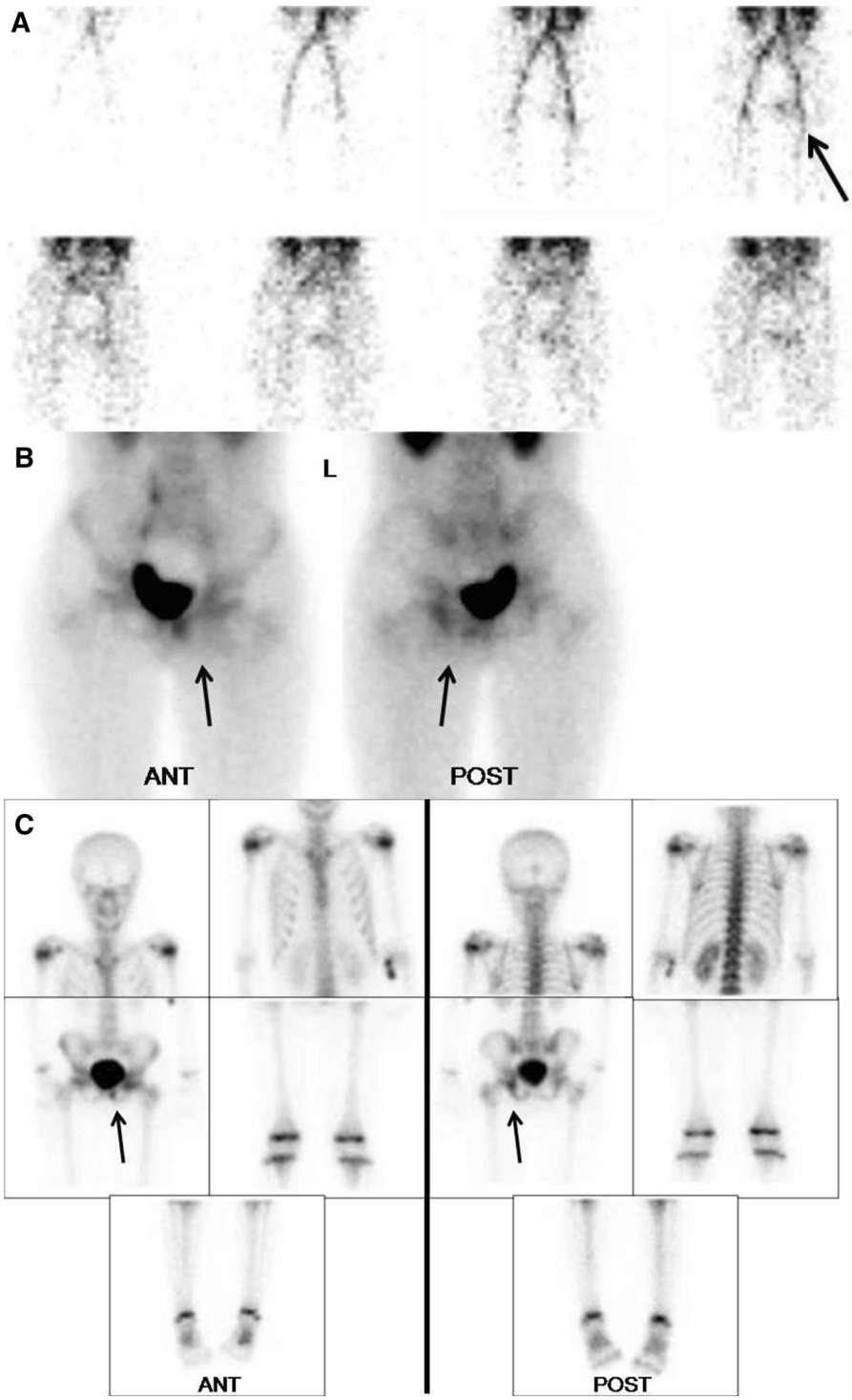

Fig. 6 Girl, 9 years old, with sudden onset of pain at the left hip, accompanied by mild signs of inflammation, partially improved with non-steroidal anti-inflammatory drugs therapy. 3 phase bone scan (**a** angiogram, **b** blood pool images) shows increased blood flow and pool in the left hemipelvis (*arrows*), with increased bone uptake involving both ileo-pubic and ischio-pubic branches (**c**)

the risk of spontaneous fractures (Fig. 4) and then the necessity of chirurgical management (curettage) in an otherwise "don't touch lesion" [25]. SPECT/CT is also very helpful, in patients with known bone malignancy, for the differential diagnosis between metastasis and synchronous benign alterations [26]. Other lesions (aneurismal bone cysts, fibrous dysplasia (FD) areas, osteoid osteomas and osteoblastomas) are characterized by increased

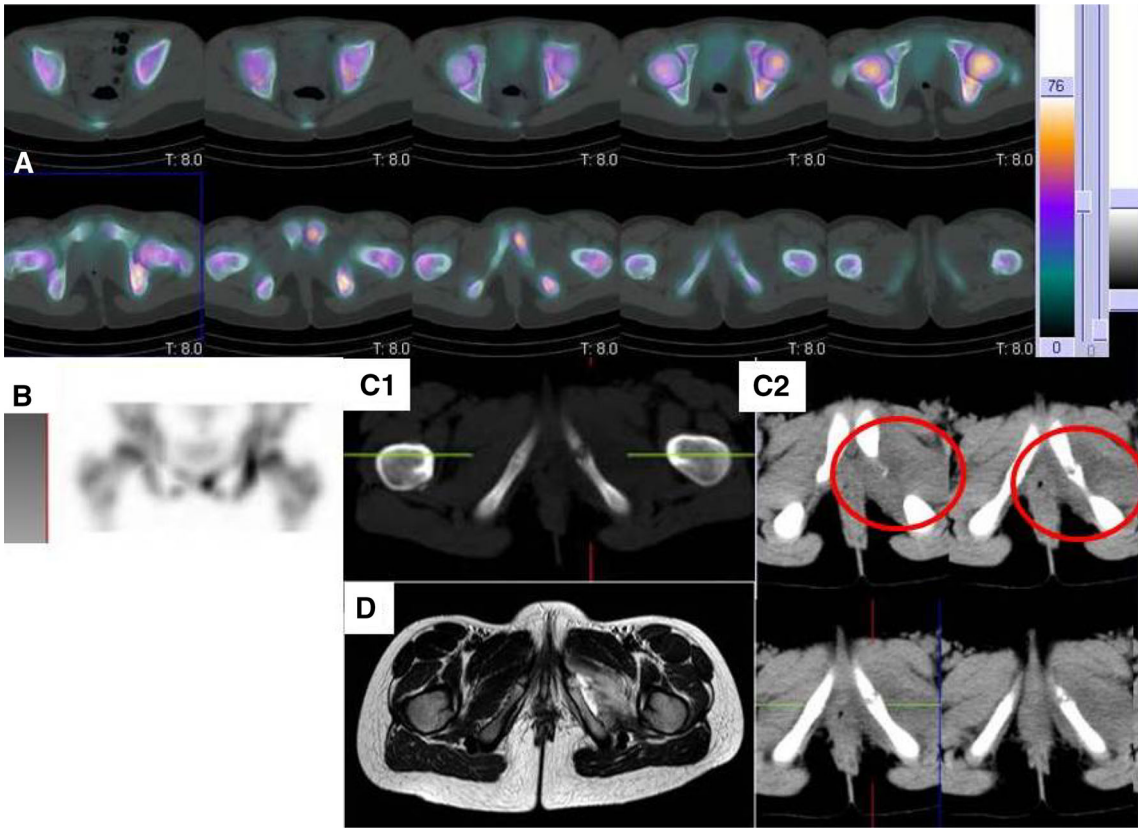

Fig. 7 Same patient of Fig. 6: SPET/CT: **a** better assessment of the entity of the bone involvement. **b** MIP image showing the limited CT scan length. The CT, with the low-dose tube setting, is able to show **C1**) the damaged ischiopubic growth plate and **C2**) the oedematous enlargement of the ischio- ad ileopubic muscles (*red circles*), due to diffusion of infection from to bone to the soft tissues. All findings were confirmed by MRI (**d**)

activity; the latter two very intense. SPECT/CT is very useful for studying these lesion, and can become a "one stop shop" (Fig. 5), especially for osteoid osteoma [27]. This particularly painful lesion may arise in nearly every bone, may mimic arthritis [28] or stress fracture. Plain X-ray film sometime shows false negative findings, whilst with MRI an excessive amount of oedema may hide the nidus [22]. Wholebody BS unerringly identifies the site of the abnormality as an area of intense uptake, also if the lesion is only few millimeters wide. A subsequent SPECT/CT carefully focused at the "hot spot" can make the diagnosis, due to the ability of the CT component in identifying the lucent nidus soaked within the sclerotic reaction responsible for the very high uptake [13, 29]. This specific uptake may produce the so-called "double density" sign that can be seen. BS may moreover assist the surgical resection [30] and retain its high sensitivity in identifying the relapses. Other key features visible with CT helpful for differential diagnosis are the calcifications of osteoblastoma, the different density levels of aneurismal bone cysts or the complex pattern of FD. In addition, for diseases often affecting multiple bone sites such as FD and chronic recurrent multifocal osteomyelitis (CRMO) [31], bone scans provide a more efficient wholebody survey than other diagnostic imaging modalities.

Infection

Haematogenous osteomyelitis (HOM) of non-violated bone is a known problem in the pediatric age group. Its incidence can vary from 0.4 cases/100,000 from a recent British survey [32] to the over 10/10,000 incidence in less developed countries [33].The bone scan is a very sensitive first line diagnostic tool for HOM, especially in younger children or when the localization of the site is difficult (limping child or backache). In this clinical setting, the easier and faster wholebody exploration often is advantageous over MRI, especially when sedation is necessary for the latter. More often, BS can help in differentiating osteomyelitis from arthritis, due to the possibility of evaluating the blood flow and blood pool using the 3-phase technique, or in determining bone involvement in the case of infection in surrounding soft tissues. SPECT/CT helps to better evaluate the extent and localization of the bone/soft

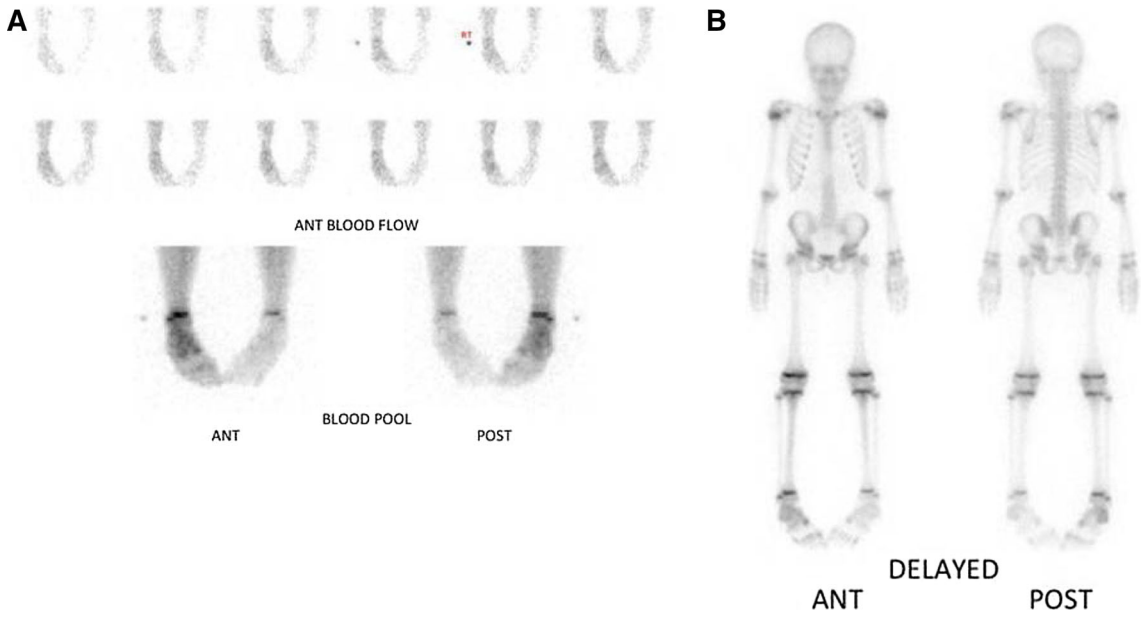

Fig. 8 Twelve year old girl has had pain in the region of her left fifth metatarsal. No significant trauma history. Bone scan was performed to rule out a stress fracture in the left fifth metatarsal. The bone scan identifies a three phase (blood flow, blood pool, (**a**) and delayed imaging (**b**) cold abnormality in the left foot and leg. Correlative radiographs are normal. The findings are in keeping with "cold variant" of reflex sympathetic dystrophy (chronic regional pain syndrome). No fracture or focal abnormality is seen in the left foot fifth metatarsal region. She was treated with physiotherapy and analgesia

tissue involvement (Figs. 6, 7). In some specific conditions, for example infection of the jaw, SPECT/CT may be useful in distinguishing HOM from non-infectious involvement of the bone [34]. However, the morphological definition of MRI for soft tissue involvement, particularly in the now prevalent antibiotic resistant staphylococcal infection, is unreachable [35–37] and so, apart from some very specific clinical setting, the added value of SPECT/CT in acute bone infection is limited.

Vascular diseases

The final group of bone diseases in the pediatric age group we will discuss are related to an altered blood supply to the bones, and include bone infarction, avascular necrosis and reflex sympathetic dystrophy/chronic regional pain syndrome. Bone infarction may be a complication of malignant disease or secondary to treatment with high dose steroids [14, 38]. Haemoglobinopathies such as sickle cell disease and metabolic diseases such as Gaucher's disease are especially prone to bone infarction [39]. Occasionally, BS may help to differentiate a sickle crisis from osteomyelitis, especially when there is involvement of ribs or other bones that would be rarely affected by infection. Hybrid imaging can be a step forward in these patients, allowing distinction between acute and chronic abnormalities. The CT component can show calcium deposition in the marrow in lesions that may still have increased uptake on bone scans. This would suggest a healing lesion rather than an acute infarct. The skeletal site most prone to avascular necrosis is the femoral head [40]. in which the landmark of a "cold spot" at the ossification nucleus in a well-timed bone scan can sometimes be easier to interpret than the MR findings [41]. In these patients SPECT/CT can show the typical findings with improved spatial resolution compared to planar imaging, obviating the need for pinhole views (pinhole collimators are rarely available in nuclear medicine departments with modern equipment). The CT component of SPECT/CT can also provide important information on the possibility of fractures or collapse of the proximal femoral epiphysis, information that may be required for planning therapy and for assessing its effectiveness [42]. Careful tailoring of the CT scanning field to the site of skeletal abnormalities on the bone scan can achieve a great reduction in the radiation burden. Reflex sympathetic dystrophy or chronic regional pain syndrome can also be found in the pediatric age group, and is frequently overlooked [43]. BS makes the diagnosis far easier in typical cases, when the triad increased blood flow/increased blood pool/diffuse increased bone uptake is present; in children more often we can find the uncommon features of reduced blood flow and decreased delayed activity, but hybrid imaging is only seldom [44] normally necessary for the diagnosis (Fig. 8).

Conclusions

Hybrid imaging integrates in a single imaging session functional/metabolic information on tracer distribution and CT morphologic information, enhancing their respective diagnostic yield. Currently, there is still not enough availability and experience with F-18 fluoride PET/CT in children, so the majority of hybrid studies are SPECT/CT with 99mTc-labeled diphosphonates. BS still retains its value as a sensitive and safe tool for diseased site localization thanks to its fast wholebody survey, with the potential of SPECT/CT to improve the specificity and diagnostic throughput, especially in cases in which CT is still necessary. The superior resolution and soft tissue contrast of MRI makes this modality essential when malignant lesions are suspected, as is in case of infection with suspicion of soft-tissue involvement, whose evolution in pyomiositis can lead to tissue necrosis requiring surgical intervention, sometime heralded by a delayed response to antibiotic treatment. The relative cost/benefit ratio of radiation burden and sedation should be weighted on a case by case basis. When hybrid imaging is required it is of paramount importance set up the CT parameters (tube setting, scan field) according to optimized pediatric protocols [10, 45, 46].

Compliance with ethical standards

Conflict of interest All the authors (Diego De Palma, Zvi Bar-Sever, Helen R. Nadel) declare no conflict of interest.
This article does not contain any studies with human or animal subjects performed by the any of the authors.

References

1. Lassmann M, Treves ST, EANM/SNMMI Paediatric Dosage Harmonization Working Group (2014) Paediatric radiopharmaceutical administration: harmonization of the 2007 EANM paediatric dosage card (version 1.5.2008) and the 2010 North American consensus guidelines. Eur J Nucl Med Mol Imaging 41((5):1036
2. Nadel HR (2010) Pediatric bone scintigraphy update. Semin Nucl Med 40((1):31–40
3. Even-Sapir E, Flusser G, Lerman H, Lievshitz G, Metser U (2007) SPECT/multislice low-dose CT: a clinically relevant constituent in the imaging algorithm of nononcologic patients refereed for bon scintigraphy. J Nucl Med. 48(2):319–324
4. Andersen JB, Mortensen J, Bech BH, Hoigaard L, Borgwardt L (2011) First experiences from Copenhagen with single photon emission computed tomography/computed tomography. Nucl Med Commun 32(5):356–362
5. Segall G, Delbeke D, Stabin MG, Even-Sapir E, Fair J, Sajdak R, Smith GT (2010) SNM practice guideline for sodium 18F-fluoride PET/CT bone scans 1.0. J Nucl Med 51(11):1813–1820
6. Drubach LA, Connolly SA, Palmer EL 3rd (2011) Skeletal scintigraphy with 18F-NaF PET for the evaluation of bone pain in children. AJR Am J Roentgenol 197(3):713–719
7. Grant FD (2014) ^{18}F-fluoride PET and PET/CT in children and young adults. PET Clin 9(3):287–297
8. Cuccurullo V, Cascini G, Rossi A, Tamburrini O, Rotondo A, Mansi L (2011) Pathophysiological premises to radiotracers for bone metastases. Q J Nucl Med Mol Imaging 55(4):353–373
9. Stauss J, Hahn K, Mann M, De Palma D (2010) Guidelines for paediatric bone scanning with 99mTc-labelled radiopharmaceuticals and 18F-fluoride. Eur J Nucl Med Mol Imaging 37(8):1621–1628
10. Nadel HR (2014) SPECT/CT in pediatric patient management. Eur J Nucl Med Mol Imaging 41(Suppl 1):S104–S114
11. Boswinkel JP, Litman RS (2005) Sedating patients for radiologic studies. Pediatr Ann 34(8):650–654
12. Miller SF (2014) Imaging features of iuxtacortical chondroma in children. Pediatr Radiol 44:56–63
13. Park JH, Pahk K, Kim S, Lee SH, Song SH, Coe JG (2015) Radionuclide imaging in the diagnosis of osteoid osteoma. Oncol Letters 10:1131–1134
14. Kaste SC, Karimova EJ, Neel MD (2011) Osteonecrosis in children after therapy for malignancy. Am J Roentgenol 196(5):1011–1018
15. McCarville MB (2009) The child with bone pain: malignancy and mimickers. Cancer Imaging 9:S115–S121
16. Sairyo K, Nagamachi A (2016) State-of-the-art management of low back pain in athletes: Instructional lecture. J Orthop Sci (in press)
17. Gurd DP (2011) Back pain in the young athlete. Sports Med Arthrosc 19(1):7–16
18. Alkhawaldeh K, Al Ghuweri A, Kawar J, Jaafreh A (2014) Back pain in children and diagnostic value of ^{99m}Tc MDP bone scintigraphy. Acta Inform Med 22(5):297–301
19. Linke R, Kuwert T, Uder M, Forst R, Wuest W (2010) Skeletal SPECT/CT of the peripheral extremities. Am J Roentgenol 194(4):W329–W335
20. Section on Radiology (Di Pietro MA, Brody AS, Cassady CI, Kleinman PK, Wyly JB, Applegate KE, Wood BP, Zerin JM, Mercado-Deane MG, Seibert JJ, Stolic A) American Academy of Pediatrics (2009) Diagnostic imaging of child abuse. Pediatrics 123(5):1430–5
21. Wang K, Allen L, Fung E, Chan CC, Chan JC, Griffith JF (2005) Bone scintigraphy in common tumors with osteolytic components. Clin Nucl Med 30(10):655–671
22. Wyers MR (2010) Evaluation of pediatric lesions. Pediatr Radiol 40:468–473
23. Korkmaz MF, Elli M, Ozkan MB, Bilgici MC, Dagdemir A, Korkmaz M, Tosun FC (2015) Osteopokilosis: report of a familial case and review of the literature. Rheumatol Int 35(5):921–924
24. Ceroni D, Dayer R, De Coulon G, Kaelin A (2011) Benign fibrous histiocytoma of bone in a paediatric population: a report of 6 cases. Musculoskelet Surg 95(2):107–114
25. Blaz M, Palczewski P, Swjatkowski J, Golebiowski M (2011) Cortical fibrous defect and non ossifying fibromas: the analysis of radiological features in 28 cases and review of the literature. Pol J Radiol 76(4):32–39
26. Sharma P, Singh H, Bal C, Kumar R (2014) Non ossifying fibroma mimicking distant metatstasis of osteosarcoma on 99mTc MDP bone scintigraphy: diagnosis with SPECT/CT. Indian J Nucl Med Jul-Sep 29(3):163–164
27. Sharma P, Mukherjee A, Karunanithi S, Nadarajah J, Gamanagatti S, Khan SA, Bal C, Kumar R (2014) 99mTc-Methylene diphosphonate SPECT/CT as the one-stop imaging modality for the diagnosis of osteoid osteoma. Nucl Med Commun 35(8):876–883
28. Von Chamier G, Holl-Wieden A, Stenzel M, Raab P, Darge K, Girschick HJ, Beer M (2010) Pitfalls in diagnostics of hip pain:

osteoid osteoma and osteoblastoma. Rheumatol Int 30(3):395–400
29. Iyer RS, Chapman T, Chew FS (2012) Pediatric bone imaging diagnostic imaging of osteoid osteoma. AJR Am J Roentgenol 198(5):1039–1052
30. Blaskiewicz DJ, Sure DR, Hedequist DJ, Emans JB, Grant F, Proctor MR (2009) Osteoid osteomas: intraoperative bone scan-assisted resection. Clinical article. J Neurosurg Pediatr 4(3):237–244
31. Acikgoz G, Averill LW (2014) Chronic recurrent multifocal osteomyelitis: typical patterns of bone involvement in whole-body bone scintigraphy. Nucl Med Commun 35(8):797–807
32. Guillerman RP (2013) Osteomyelitis and beyond. Pediatr Radiol 43(Suppl 1):S193–S203
33. Shivarathre D, George H, Kaimal N, James L (2009) Epidemiology of acute haematogenous osteomyelitis in children–a single unit's experience over three different time-periods. Acta Orthop Belg 75(1):81–86
34. Stoesser N, Pocock J, Moore CE, Soeng S, Hor P, Sar P, Limmathurotsakul D, Day N, Kumar V, Khan S, Sar V, Parry CM (2013) The epidemiology of pediatric bone and joint infections in Cambodia, 2007–11. J Trop Pediatr 59(1):36–42
35. Bulouri C, Merwald M, Huellner MW, Veit-Haibach P, Kuttenberger J, Perez-Jago M, Seifert B, Strobel K (2013) Performance of orthopantomography, planar scintigraphy, CT alone and SPECT/CT in patients with suspected osteomyelitis of the jaw. Eur J Nucl Med Mol Imaging 40(3):411–417
36. Browne LP, Mason EO, Kaplan SL, Cassady CL, Krishnamurthy R, Guillerman RP (2008) Optimal imaging strategy for community acquired *Staphylococcus Aureus* musculoskeletal infections in children. Pediatr Radiol 38(8):841–847
37. Pugmire BS, Shailam R, Gee MS (2014) Role of MRI in the diagnosis and treatment of osteomyelitis in pediatric patients. World J Radiol 6(8):530–537
38. Gurion R, Tangpricha V, Yow E, Schanberg LE, McComsey GA (2015) Avascular necrosis in pediatric systemic lupus erythematosus: a brief report and review of the literature. Pediatric Rheumatology. doi:10.1186/s12969-015-0008-x
39. Almeida A, Roberts I (2005) Bone involvement in sickle cell disease. Br J Haematol 129(4):482–490
40. Dimeglio A, Canavese F (2011) Imaging in Legg-Calvé-Perthes disease. Orthop Clin North Am 42(3):297–302
41. De Palma D (2015) Radionuclide studies with bone-seeking radiopharmaceuticals in Pediatric bening bone diseases. In: Mansi L, Lopci E, Cuccurullo V, Chiti A (eds), Clinical nuclear medicine in pediatrics. Springer International Publishing Switzerland, chapter 8
42. Fontecha CG, Roca I, Barber I, Menendez ME, Collado D, Mascarenhas VV, Barrera-Ochoa S, Soldado F. (2015) Femoral head bone viability after free vascularized fibular grafting for osteonecrosis: SPECT/CT study. Microsurgery. doi:10.1002/micr.22452
43. Murray CS, Cohen A, Perkins T, Davidson JE, Sills JA (2000) Morbidity in reflex sympathetic dystrophy. Arch Dis Child 82:231–233
44. Usmani S, Panchadar S, Banna AA (2015) Three-phase 99mTc-MDP Bone scintigraphy and SPECT/CT in pediatric pseudodistrophy. Clin Nucl Med 40(11):902–904
45. Fahey FH, Palmer MR, Strauss KJ, Zimmerman RE, Badawi RD, Treves ST (2007) Dosimetry and adequacy of CT-based attenuation correction for pediatric PET: phantom study. Radiology 243(1):96–104
46. Gelfand MJ, Lemen LC (2007) PET/CT and SPECT/CT dosimetry in children: the challenge to the pediatric imager. Semin Nucl Med 37(5):391–398