Blood pool phase SPECT: leading a new era in bone scintigraphy?

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Introduction

Bone scintigraphy is a fundamental technique in skeletal imaging within nuclear medicine, especially in rheumatology and orthopaedics. The late phase acquisition offers valuable functional insights into bone remodelling, while the early-phase acquisitions (vascular and blood pool phases) provide information on local blood flow (1). Over time, the acquisition protocol for bone scintigraphy has evolved significantly, marked by two major advancements: the gradual abandon of vascular phase acquisition for most indications and the introduction of Single Photon Emission Computed Tomography/Computed Tomography (SPECT/CT) (2). While it is widely recognised that SPECT/CT outperforms planar acquisition in the late phase (1), there is still a scarcity of research on blood pool SPECT, with only a limited number of studies available (3-7). Accurate assessment of inflammatory processes adds significant value to the diagnosis, especially as the pain often caused by inflammation can be a common indication for bone scans, especially in the lower limbs.

This article aims to illustrate the usefulness of blood pool SPECT in the daily practice.

Technical considerations

There are no yet published guidelines and studies that provide clear recommendations on the optimal acquisition time for blood pool SPECT images. Current research offers limited justification for the selected acquisition protocols and often overlooks acceptable noise levels in the reconstructed images. In contrast, scan duration recommendations for late phase bone imaging are more well-defined. The European Association of Nuclear Medicine (EANM) guidelines suggest a planar acquisition time of 4 to 10 minutes for late phase bone imaging. For late phase SPECT imaging, the EANM advises extending the imaging time to 10 to 30 minutes, representing a 2.5 to 3-fold increase compared to planar scan durations (8).

Increasing the recommended planar acquisition times proportionally for blood pool images would suggest an acquisition duration of 7 to 15 minutes. However, to minimise the effect of osteoblastic activity on tracer distribution, it is important that the blood pool acquisition is completed within 15 minutes of radiotracer injection. Therefore, an acquisition time of under 12 minutes is recommended to ensure prompt image capture (1).

To reduce patient radiation exposure, it is often recommended to use full diagnostic CT during late phase imaging and a low-dose protocol or no CT during the blood pool phase. In practice, I would recommend twice a CT in the mid and distal extremities and a more personalized approach according to age for the trunk and proximal joints. If the latter phase CT is minimised or skipped, images can be fused with late phase diagnostic CT, though this is challenging with limb imaging due to positioning differences. Ultra-low dose CT protocols (80-100 kV and 20-60 mAs) can reduce doses to below 1 mSv, with dose reduction varying by body region and CT reconstruction methods used (8).

Interpretation

A thorough understanding of soft tissue anatomy is essential, including proximal and distal entheses, common sites of tenosynovitis and bursitis, articular capsules and recesses. Knowledge of basic CT signs of soft tissue inflammation such as tendon and synovial thickening, synovial effusion and hypodensity due to oedema is also beneficial.

It is important to be aware of the normal appearance of blood pool SPECT in different anatomical locations, as shown in figure 1. In addition to urinary and vascular activity, certain normal findings should be noted, such as the typical increased activity at the fingertips and moderate activity in the deep plantar arch.

To be more efficient, we propose a multi-phase analysis approach that identifies three distinct patterns (2), as shown in figure 2.

- **Pattern "A"** is commonly observed in osseous inflammatory diseases. This pattern is characterised by focal moderate/intense activity on the blood pool phase and generally more diffuse (or occasionally focal) uptake on the late phase, highlighting the

most inflammatory areas. It can serve as a "needle in a haystack" indicator, helping to identify fracture within diffuse bone oedema or suggest an infectious aetiology.

- **Pattern "B"** is associated with para-osseous inflammatory diseases. It features increased blood pool uptake centred on the inflammatory site and late uptake on adjacent bone. A typical example is enthesitis, where late phase imaging provides only indirect insight into the underlying process (referred to as the "Plato's cave effect").
- **Pattern "C"** is seen in extra-osseous inflammatory conditions. It is characterised by increased activity localised to the site of inflammation only in the blood pool phase. No abnormalities are seen in the late phase. Examples include bursitis, tendinitis (if away from the enthesis), muscle and ligament injuries.

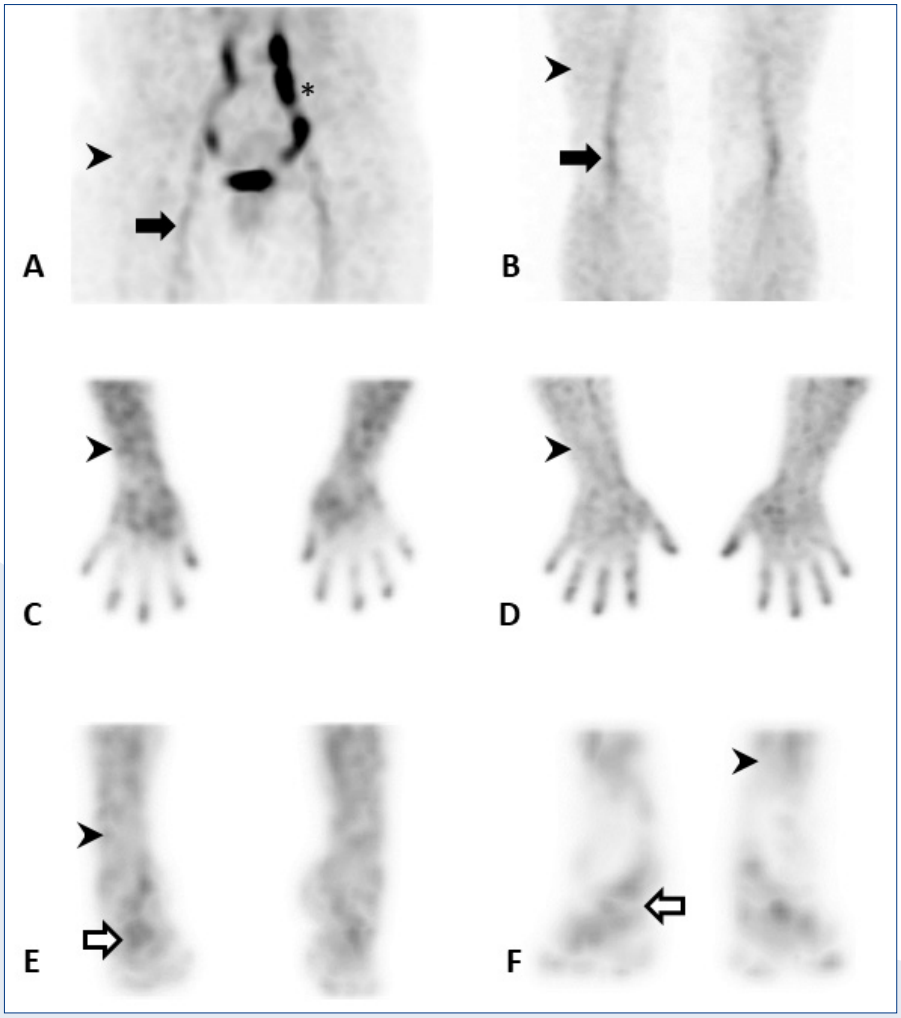

Figure 1. Normal blood pool SPECT. Normal aspect of pelvic region (A), knees (B), hands (C and D) and feet (E and F) on Maximum Intensity Projection images. To be noted: intense urinary activity in pelvic regions (*), moderate vascular activity (plain arrows on images A and B), little muscular activity (arrow heads). Focal moderate activity on the fingertips is common (images C and D) and linear moderate activity of deep plantar arch can be observed approximatively in 50% of case (hollow arrow, images E and F).

Clinical cases

The following six clinical cases were acquired using a General Electrics (GE) Discovery 870 cadmium zinc telluride (CZT) SPECT/CT (General Electrics, Milwaukee, USA) with the following acquisition parameters: blood pool and late phase SPECT were acquired using 30 projections of 20 seconds each, step-and-shoot mode (acquisition time 10-15 min). Low-dose CT parameters were 100 kV, maximum 130 mAs with modulation, slice thickness and spacing 1.25 mm, iterative reconstruction. CT parameters for diagnostic quality were 120 kV, maximum 140 mAs with modulation, slice thickness 0.625 mm and spacing 0.5 mm, iterative reconstruction.

1. A 23-year-old male patient was referred for evaluation of the left forefoot pain, after a long march 10 days earlier. Blood pool SPECT showed an intense focal uptake in the distal diaphysis of the left second metatarsal. Late phase SPECT showed a very intense, more diffuse uptake at the same site. The CT showed a very mild periosteal reaction. The diagnosis was a recent stress fracture of the distal diaphysis of the left second metatarsal. It is a pattern "A" case (figure 3).
2. An 84-year-old female patient was referred for suspected loosening of her left total knee arthroplasty (TKA). The prosthesis had been in place for over twenty years. Blood pool SPECT showed intense and diffuse activity around the left TKA. Late phase SPECT showed intense increased activity at the bone-prosthesis interface of the left TKA. The diagnosis was a septic loosening of the left TKA, which was confirmed by the white blood cell scan and articular punction. This is a pattern "A" case (figure 4).

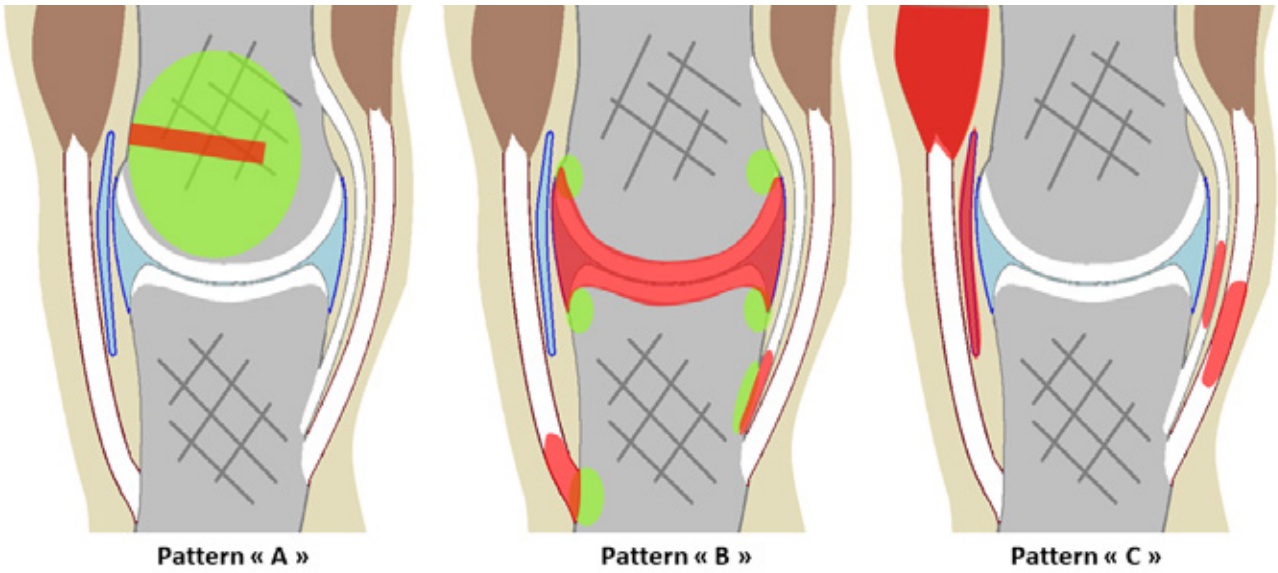

Figure 2. Three patterns encountered using blood pool and late phase SPECT. The areas involved on blood pool SPECT are displayed in red and those involved on late phase SPECT are in green.

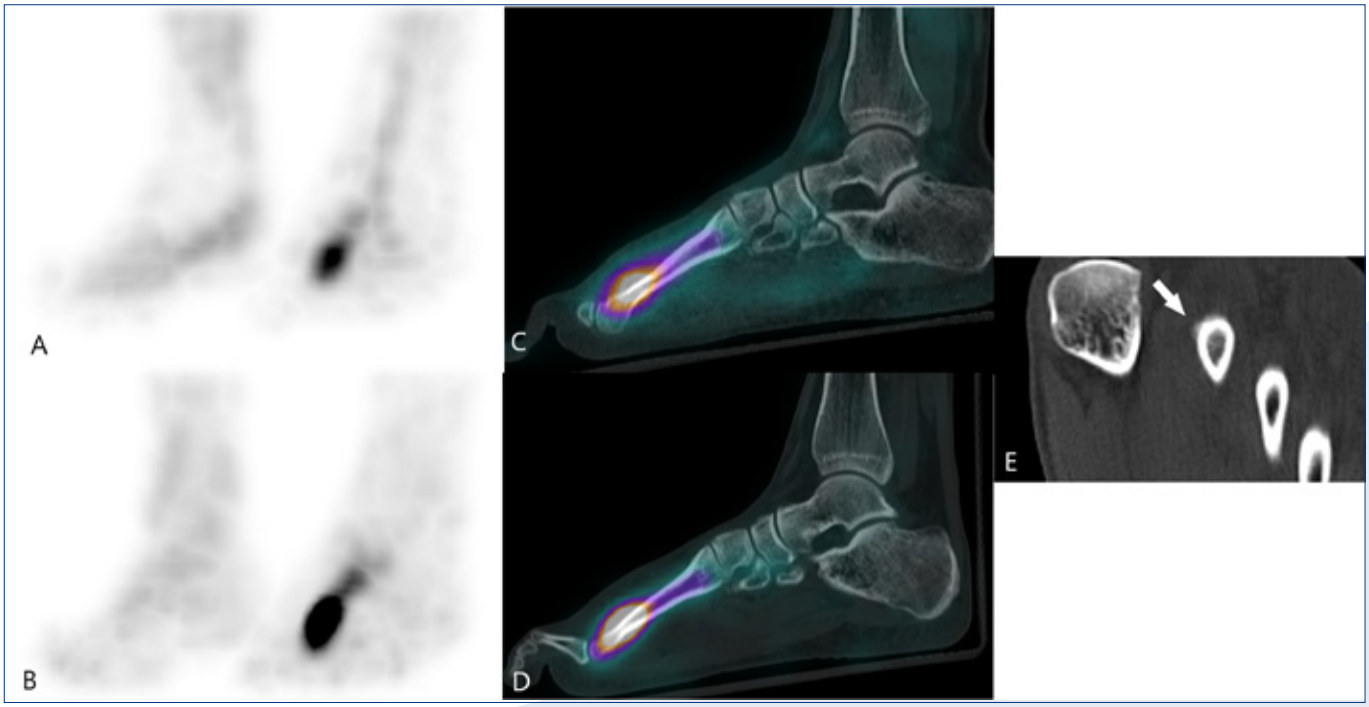

Figure 3. Blood Pool phase (image A for MIP, C for sagittal fused image), late phase (image B for MIP, D for sagittal fused image). E for transaxial CT (plain arrow showing the very mild periosteal reaction).

3. A 56-year-old male patient was referred for evaluation of right heel pain without evidence of trauma. A stress fracture of the right calcaneus is suspected. Blood pool SPECT showed an intense and linear uptake in the third posterior part of the right plantar fascia. Late phase SPECT showed an intense and focal uptake on the plantar side of the right calcaneus. CT showed a calcaneal spur. The diagnosis was right plantar fasciitis and a stress fracture was ruled out. This is a pattern "B" case (figure 5).
4. A 71-year-old female patient was referred for evaluation of pain

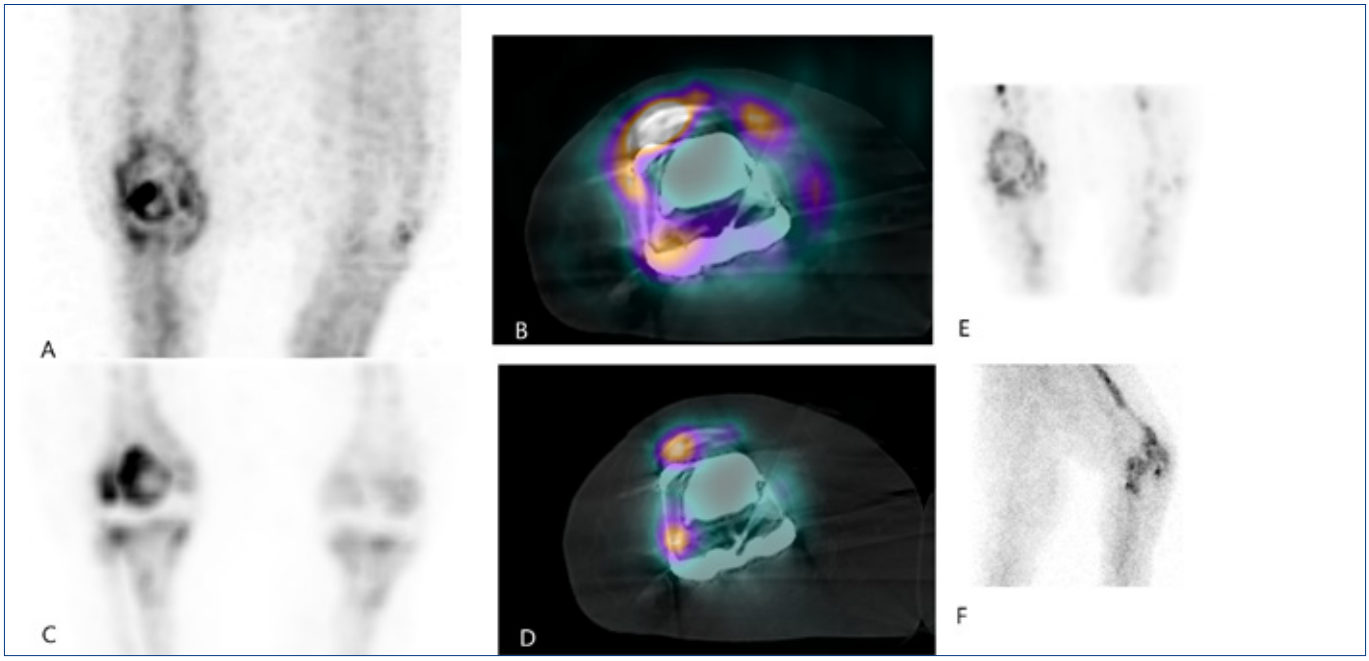

Figure 4. Blood Pool phase (image A for MIP, C for transaxial fused image), late phase (image B for MIP, D for transaxial fused image), 3h white blood cell scan (image E for MIP, F for planar profile image).

in the right midfoot over the past month, without evidence of trauma. Blood pool SPECT showed an intense and linear activity in the right anterior tibial tendon, specifically in the immediate area of the medial cuneiform. There was no significant uptake abnormality in the late phase. The CT showed a slight swelling of this part of the tendon. The diagnosis was a right anterior tibial tendinitis. It is a pattern "C" case (figure 6).

5. A 59-year-old female patient was referred for evaluation of unexplained pain of the left hip, without evidence of trauma. Blood pool SPECT showed a moderate activity opposite the left greater trochanter. There was no significant uptake abnormality in the late phase. The CT showed a centimetric, oblong and hypodense structure. The diagnosis was a bursitis of the left trochanter. It is a pattern "C" case (figure 7).
6. A 24-year-old male patient was referred for evaluation of the pain in the left fourth finger following a sports injury one month ago. It was a crush injury of the distal interphalangeal joint of the left fourth finger after a fall while climbing. Blood pool SPECT showed linear and relatively intense activity of the flexor tendon of the fourth left finger opposite the middle third of the proximal phalanx. There was no significant uptake abnormality in the late phase. CT showed a slightly thickened tendon. The diagnosis was a traumatic injury to the flexor tendon of the left fourth finger, opposite the middle third of the proximal phalanx. It is a pattern "C" case (figure 8).

Discussion

In this article, I have presented a series of clinical cases that highlight the potential advantages of blood pool SPECT imaging. The multi-phase bone scan's ability to detect abnormalities beyond typical osseous uptake is well established (1), but protocols traditionally using only planar imaging limit the identification of abnormalities to large structures such as tumours, organs, and synovitis in major joints like the knee or hip (1, 9-11). A prospective study by Cuviliers et al. demonstrated that blood pool SPECT provides superior resolution and sensitivity compared to planar imaging, alongside improved interobserver concordance and diagnostic confidence (4). Another recent multi-centre retrospective study by Icard et al, involving fifty patients, compared SPECT with pseudo-planar maximum intensity planar (MIP) and concluded that SPECT was superior to MIP. In addition, blood pool SPECT changed the diagnosis established by late phase imaging in 21/50 patients (3).

Unlike the classical interpretation of bone scintigraphy, which requires mental registration of an early planar image with a late phase SPECT image, leading to positional uncertainties, blood pool SPECT could serve as the final piece in this puzzle, improving

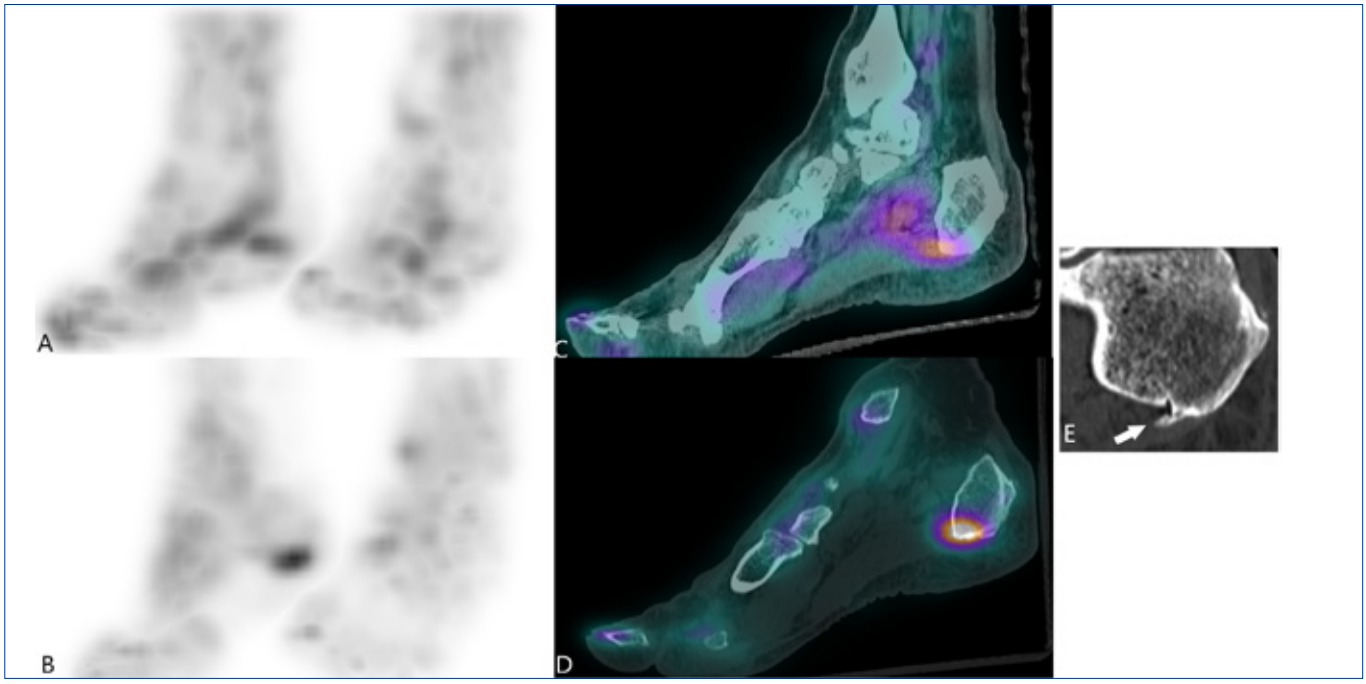

Figure 5. Blood Pool phase (image A for MIP, C for sagittal fused image), late phase (image B for MIP, D for sagittal fused image). E for sagittal CT (plain arrow showing the heel spur).

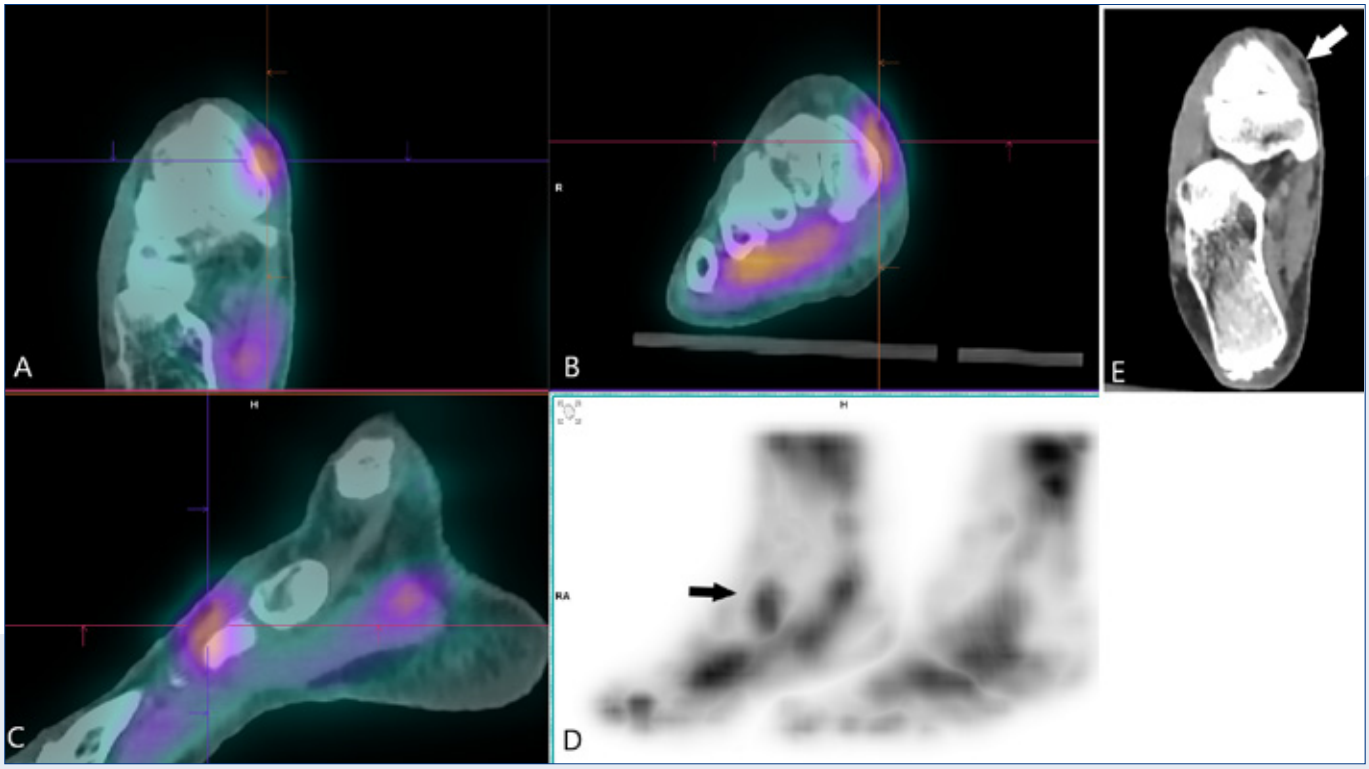

Figure 6. Blood Pool phase (image A for transaxial fused image MIP, B for coronal fused image, C for sagittal fused image, D for MIP), plain arrow showing on the image D the linear activity in the right anterior tibial tendon. E for transaxial CT (plain arrow showing the slight swelling of a part of the right anterior tibial tendon).

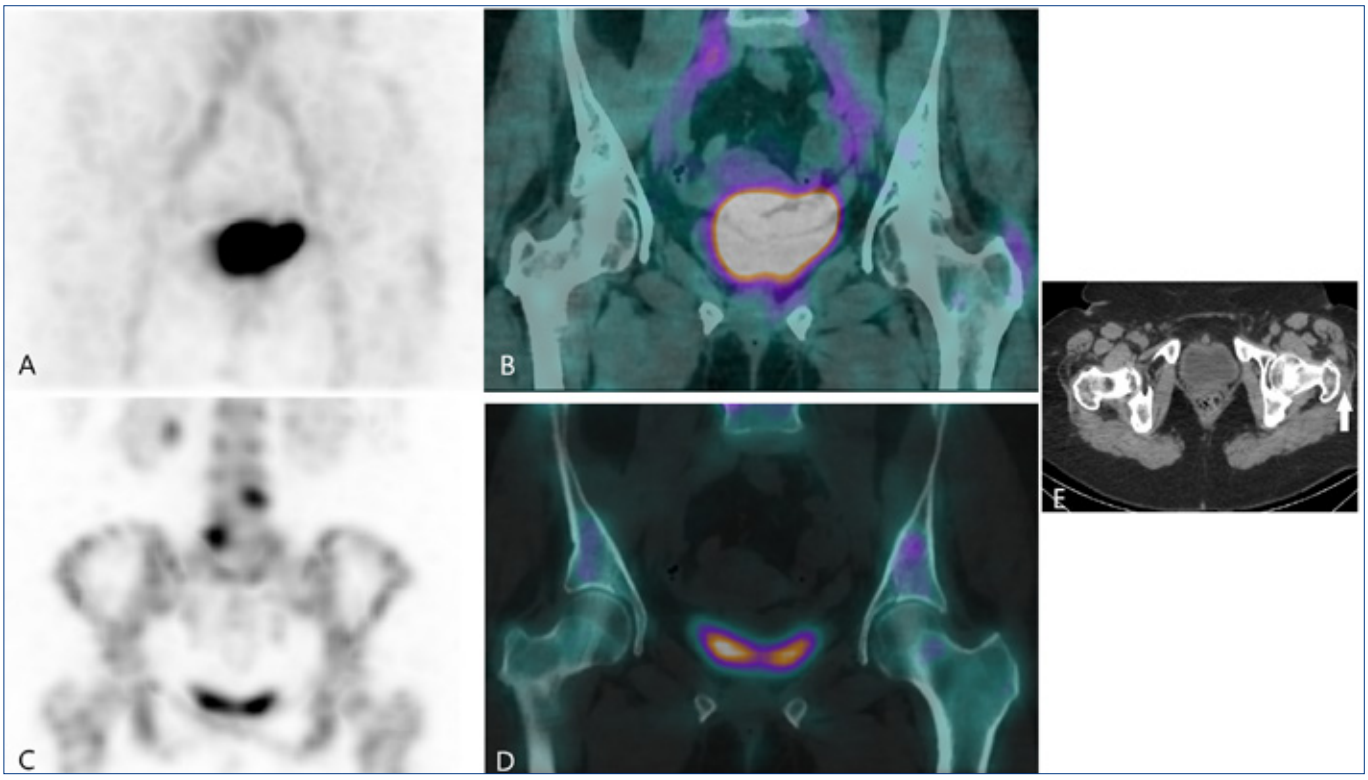

Figure 7. Blood Pool phase (image A for MIP, C for coronal fused image), late phase (image B for MIP, D for coronal fused image). E for transaxial CT (plain arrow showing the bursitis as a hypodense structure).

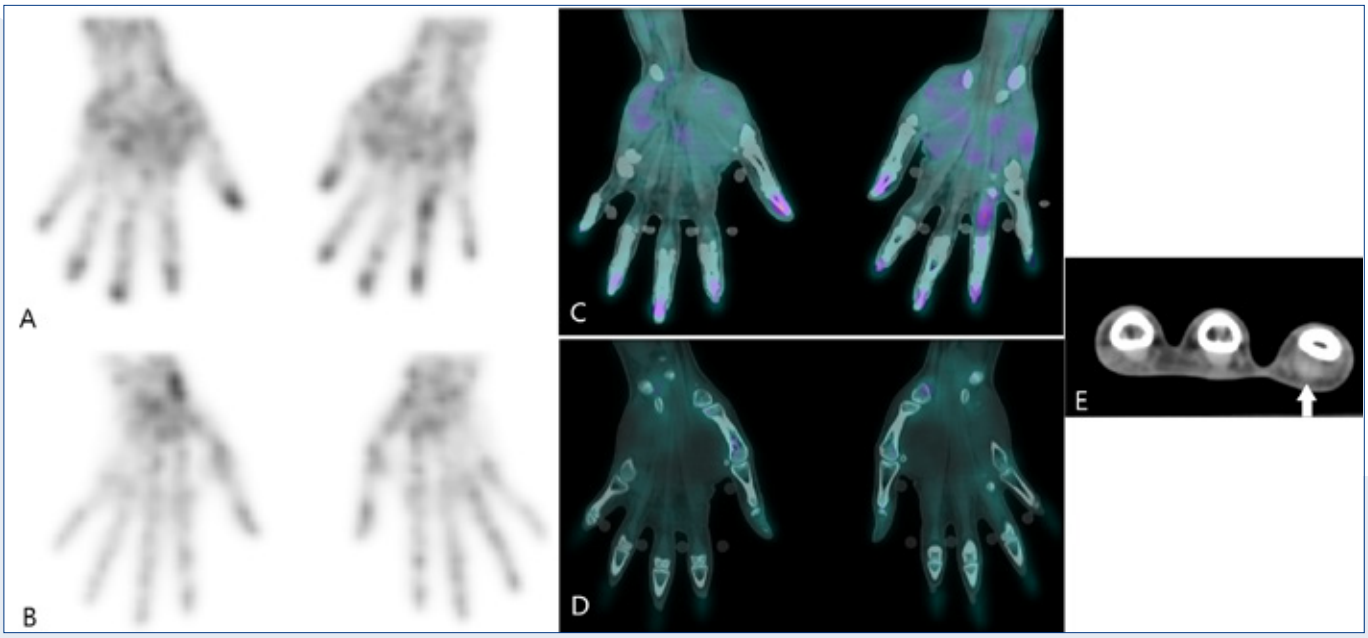

Figure 8. Blood Pool phase (image A for MIP, C for coronal fused image), late phase (image B for MIP, D for coronal fused image). E for transaxial CT (plain arrow showing the slightly thickened tendon).

interobserver concordance and diagnostic confidence.
The three patterns approach represents a preliminary attempt to structure the interpretation of multiphase SPECT bone scans and will require validation through further clinical studies.
The primary challenge for nuclear medicine physicians is to learn new semiology despite limited literature. They must distinguish normal findings and identify extraosseous pathologies (tendons, synovial bursae, sheaths) that were often missed with late SPECT alone. Emerging patterns include: extraosseous pathologies seen only in the blood pool phase (e.g., bursitis), pathologies visible in both phases (e.g., tendinitis in the blood pool phase with enthesis in the late phase), and bone pathologies appearing in both phases (e.g., fissures in the blood pool phase and diffuse bone reactions in the late phase) (2).
Radiation exposure concerns from CT scans during the early phase may arise. However, the dose associated with CT scans of extremities remains relatively low and is generally not problematic in terms of dosimetry. Given the complexity of anatomical correlations required in areas with multiple bones and joints, the risk-benefit analysis often favours the inclusion of CT.
For trunk imaging, this balance must be reassessed individually. Dose optimisation, especially using ultra-low dose CT protocols, should be a standard consideration (2).
In this age of shortages and increasing budgetary pressures, particularly in The Netherlands in recent years, the additional expense and time required for these imaging protocols must be justified by their significant diagnostic yield, improved clinical decision-making, and potential to reduce the need for further, more costly investigations or ineffective treatments.

Conclusion

Blood pool SPECT unveils a novel semiology within nuclear medicine, expanding the diagnostic capabilities of bone scans. It has the potential to significantly improve the diagnosis in selected orthopedic and rheumatological patients as demonstrated. Although the literature remains limited, it is promising and continuously growing. ♦

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