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RESEARCH

[18F]FDG PET/CT imaging of spinal infections

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Abstract
The annual incidence of spinal infections has been rising significantly over the last years and is expected to increase even further. Spinal infections may include infection of the vertebral body and intervertebral disc (spondylodiscitis), paravertebral abscess, epidural abscess and septic arthritis of the facet joints. Positron emission tomography (PET) with [18F]FDG has high sensitivity for detecting spinal infections, may help in differentiating between spinal infection subtypes and is able to detect dissemination of infection outside the spine. [18F]FDG PET/CT is especially indicated if MRI is inconclusive, in patients with contra-indications for MRI, in postoperative patients with or without spinal hardware and in patients with bacteremia to find foci of infection. Here, we present a concise overview of the spectrum of [18F]FDG PET/CT imaging findings in spinal infections.

Keywords Spinal infection · Spondylodiscitis · Epidural abscess · Facet joint arthritis · [18F]FDG · PET/CT imaging

Introduction

The incidence of spinal infections has been rising significantly in recent years [1, 2] and is expected to increase further, along with progressive ageing of the population and increasing use of instrumentation after spinal surgery. Magnetic resonance imaging (MRI) is the preferred method of diagnostic imaging in suspected spinal infection, but current guidelines also confirm the usefulness of positron emission tomography (PET) with [18F]FDG, especially if MRI is inconclusive, in patients with contra-indications for MRI or in postoperative patients with or without spinal hardware [3]. Furthermore, [18F]FDG PET/CT can be used as primary imaging modality in the diagnostic work-up of patients with fever of unknown origin or bacteremia to search for the primary focus of infection or dissemination of infection, which regularly demonstrates spinal infection. Thus, the utilization of [18F]FDG PET/CT in spinal infection is expected to increase.

Infections of spinal structures may include infections of the vertebral body (termed vertebral osteomyelitis or spondylitis), infections of the intervertebral disc (discitis), paravertebral or epidural abscesses and septic arthritis of the facet joints [4]. At presentation, infections of the vertebral body and intervertebral disc usually co-exist and are collectively termed spondylodiscitis. Spinal infections can be pyogenic (bacterial), granulomatous (tuberculosis, or fungal) or parasitic, but most infections are caused by *Staphylococcus aureus* [5]. Spinal infections can occur anywhere in the spinal column, but most frequently in the lumbar spine, except tuberculosis, which affects the thoracic spine more frequently [6]. Here, we present a concise overview of the spectrum of [18F]FDG PET/CT findings in spinal infections.

PET/CT of spinal infection

[18F]FDG PET/CT has high sensitivity for demonstrating spinal infection with a sensitivity of 94.8% and specificity of 91.4% [7]. Direct comparisons with MRI has confirmed high sensitivity of both methods [8, 9] and some studies showed even higher accuracy for [18F]FDG PET/CT than

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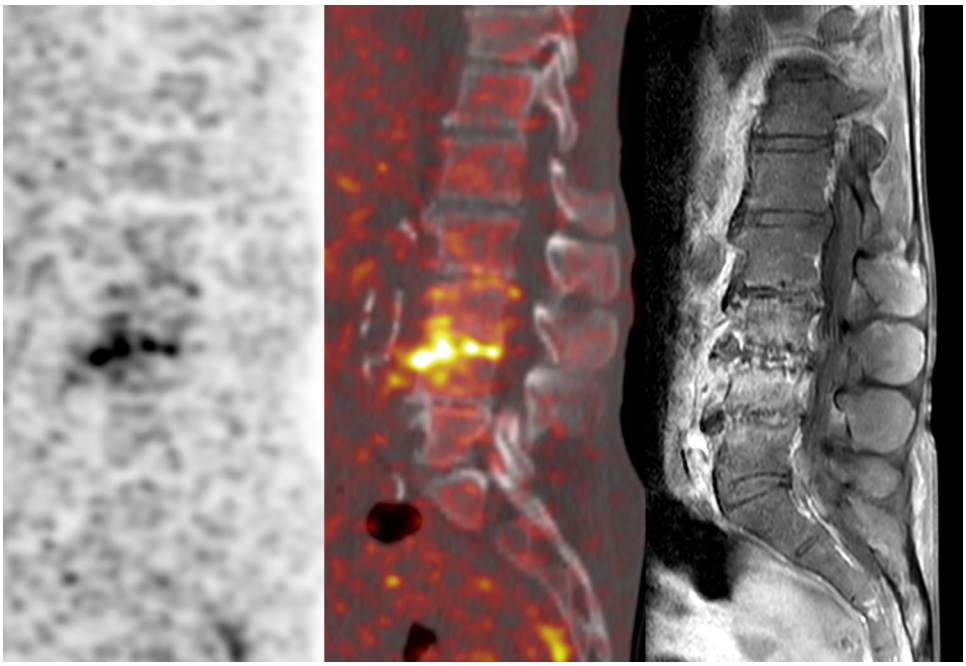

Fig. 1 Spondylodiscitis. A 59-year old woman with fever and back pain. Her medical history includes diabetes mellitus and hemodialysis-dependent IgA nefropathy. Blood culture was positive for *S. aureus*. Portals of entry were necrotic wounds at the first and second digit of her right foot, necessitating amputation. [^{18}F]FDG PET/CT shows disciform uptake in the intervertebral disc at level L3-L4, suggestive of spondylodiscitis (sagittal PET and fused PET/CT images at left and middle panels). MR imaging was performed two days later to exclude intraspinal extension (sagittal T1-weighted gadolinium-enhanced image at right panel), which confirms spondylodiscitis without intraspinal extension

MRI [10, 11], especially in early detection [12]. [^{18}F]FDG PET/CT has also shown high sensitivity for postoperative spine infection in patients with and without spinal instrumentation [13, 14] and may contribute in early treatment response monitoring [15–17].

[^{18}F]FDG PET/CT is considered positive for spinal infection if the uptake at the suspected site is higher than the adjacent vertebrae and surrounding soft tissues [3, 18]. Semiquantitative analysis of [^{18}F]FDG uptake using standard uptake values (SUV_{max}) has not resulted in a clear cut-off value for differentiation between positive and negative findings [18]. False-negative findings may be due to low-virulence bacteria and previous antimicrobial therapy. False-positive findings may be caused by inflammation in degenerative or rheumatic diseases, recent vertebral fractures, postoperative inflammation and bone tumors [7], but visual interpretation with pattern recognition can often differentiate these lesions.

Spondylodiscitis

Spondylodiscitis most often results from hematogenous spreading of microorganisms originating from a distant infection (e.g. skin or urinary tract infections, endocarditis, infected vascular access sites or septic arthritis) [19, 20]. Other routes include direct inoculation (e.g. during spine surgery, epidural injection or penetrating trauma) and contiguous extension of an infection in adjacent soft tissues. Hematogenous spreading of infection in spinal structures occurs primarily through segmental and metaphyseal arteries supplying the vertebral bodies, which branch into an anastomotic network in the endplates [6]. In children, this network extends into the intervertebral disc, but in adults it regresses and terminates in the endplates. As a result, spondylodiscitis in children usually begins in the intervertebral disc and spondylodiscitis in adults usually begins in the endplates with subsequent extension into the relatively avascular disc due to bacterial proteolytic enzymes [6]. At presentation, spondylitis and discitis usually co-exist and [^{18}F]FDG PET/CT typically shows increased uptake in the endplates and intervertebral disc (Fig. 1). However, in elderly patients, disc degeneration may be followed by ingrowth of vascularized granulation tissue causing secondary vascularization and, as a result, primary discitis is still possible (Fig. 2) [21]. Also, vertebral osteomyelitis without signs of discitis (Fig. 3) may be found. Spondylodiscitis may also extend into the facet joint (Fig. 4). The low dose CT may demonstrate erosion of the endplates or frank bone destruction with loss of vertebral height (Fig. 5). Progressive infection may lead to vascular occlusion resulting in avascular necrosis of the vertebral body, bone infarction, compression fracture with deformity, instability and risk of compression on spinal cord, cauda equina or nerve roots [22]. With further extension of infection, paravertebral soft tissues may become infected.

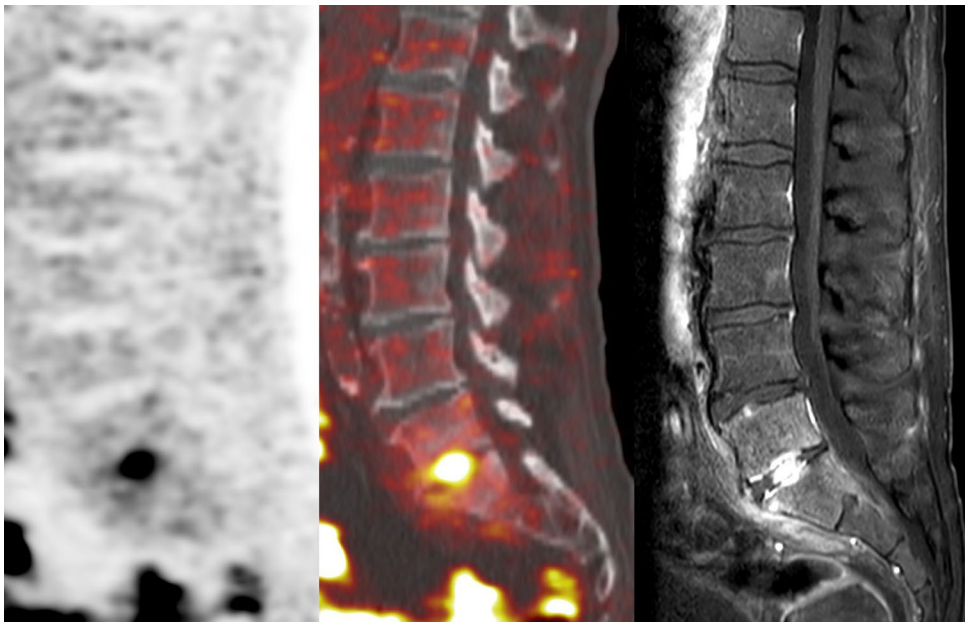

Fig. 2 Discitis. A 72-year old man with a history of esophageal carcinoma and recent prostatic abscess with *S. aureus* bacteremia, now presents with back pain. Repeated blood cultures are negative. [^{18}F]FDG PET/CT shows focal uptake in the intervertebral disc at level L5-S1, suggestive of discitis (sagittal PET and fused PET/CT images at left and middle panels), extending laterally into the paravertebral soft tissues. MR imaging was performed two days to exclude intraspinal extension (sagittal T1-weighted gadolinium-enhanced image at right panel), which confirms discitis

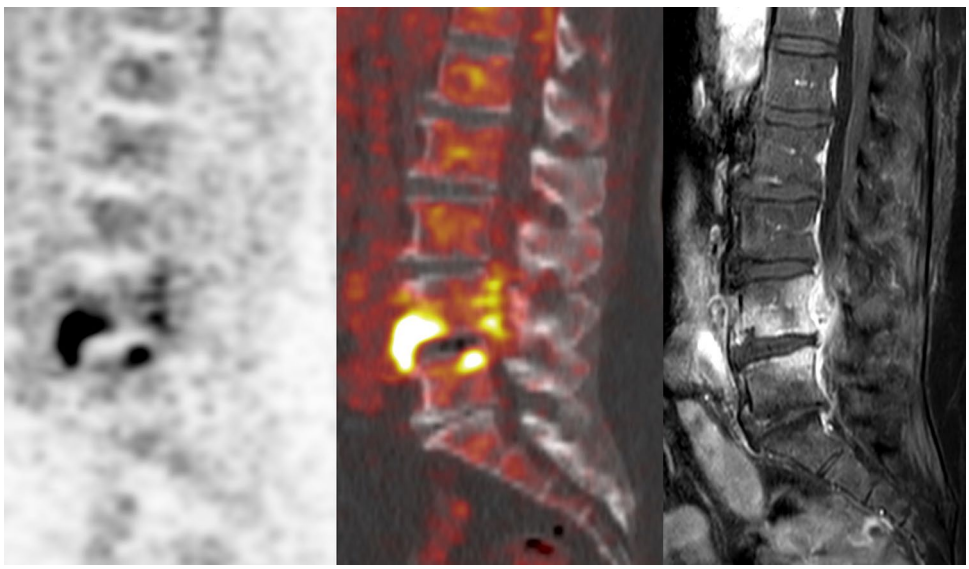

Fig. 3 Vertebral osteomyelitis. A 79-year old woman with fever and back pain. Blood cultures were positive for *Proteus mirabilis* and *E. coli*. Portal of entry has not been identified. [^{18}F]FDG PET/CT shows increased uptake in the L4 and L5 endplates, but no increased uptake in the intervertebral disc (sagittal low dose CT, PET and fused PET/CT images at left and middle panels). Following relapse of fever, MR imaging was performed two weeks later (sagittal T1-weighted gadolinium-enhanced image at right panel), which confirms abnormal signal intensity in the L4 and L5 vertebrae, but not in the intervertebral disc. Additional bone biopsy was negative

[^{18}F]FDG PET/CT findings range from unilateral paravertebral uptake (Fig. 6) to extensive paravertebral and epidural uptake (Fig. 7), which may involve neighboring structures such as the aorta (Fig. 8). Paravertebral infection may also lead to paravertebral abscesses or psoas muscle abscesses, while spread into the spinal canal may cause epidural abscesses. [^{18}F]FDG PET/CT is especially useful in postoperative patients (Fig. 9) as MRI may show artifacts from metallic implants. Spondylodiscitis usually involves a single

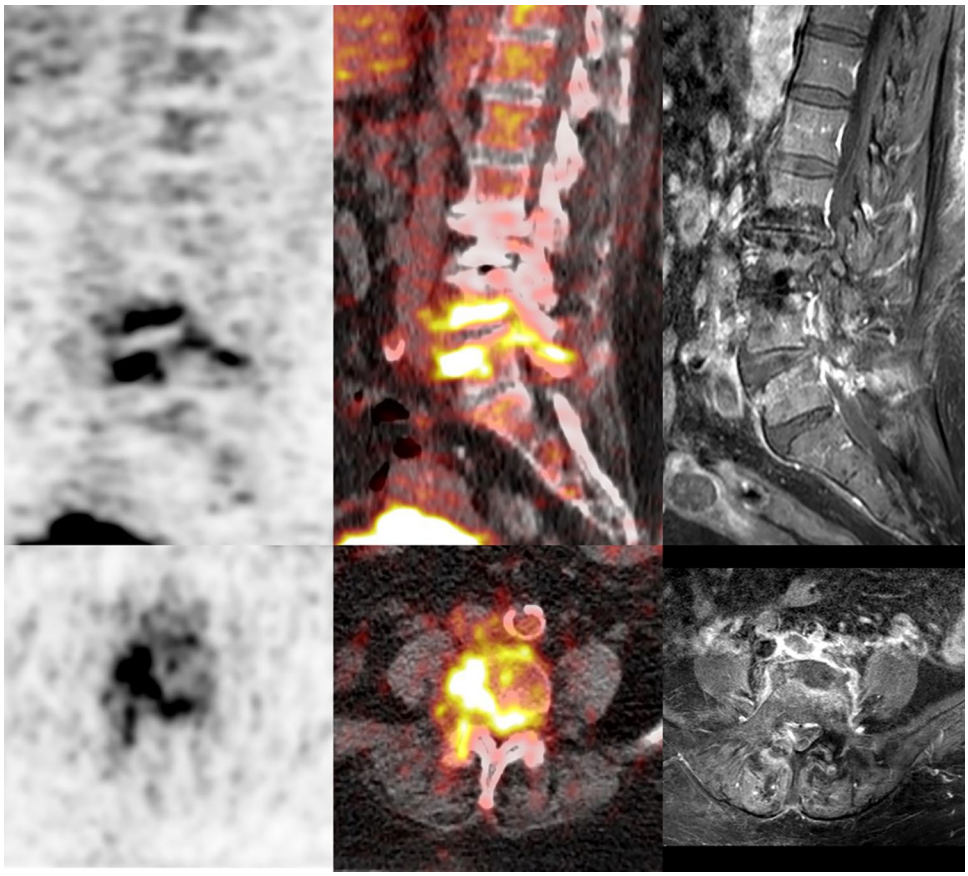

Fig. 4 Spondylodiscitis extending into facet joint. An 82-year old woman with ulcerative colitis, treated with prednisolone and adalimumab, and recent spondylodiscitis L4-L5 and endocarditis, treated with flucloxacilline 6 weeks, now presents with recurrence of back pain and leukocytosis, elevated C-reactive protein and erythrocyte sedimentation rate. Blood culture is (again) positive for *S. epidermidis*. MR imaging shows enhancement at level L4-L5 extending into the facet joint (sagittal and axial T1-weighted gadolinium-enhanced images at right panel). [^{18}F]FDG PET/CT was performed the next day to evaluate dissemination of infection, which confirms increased uptake at level L4-L5 and facet joint (sagittal and axial PET and fused PET/CT images at left and middle panels)

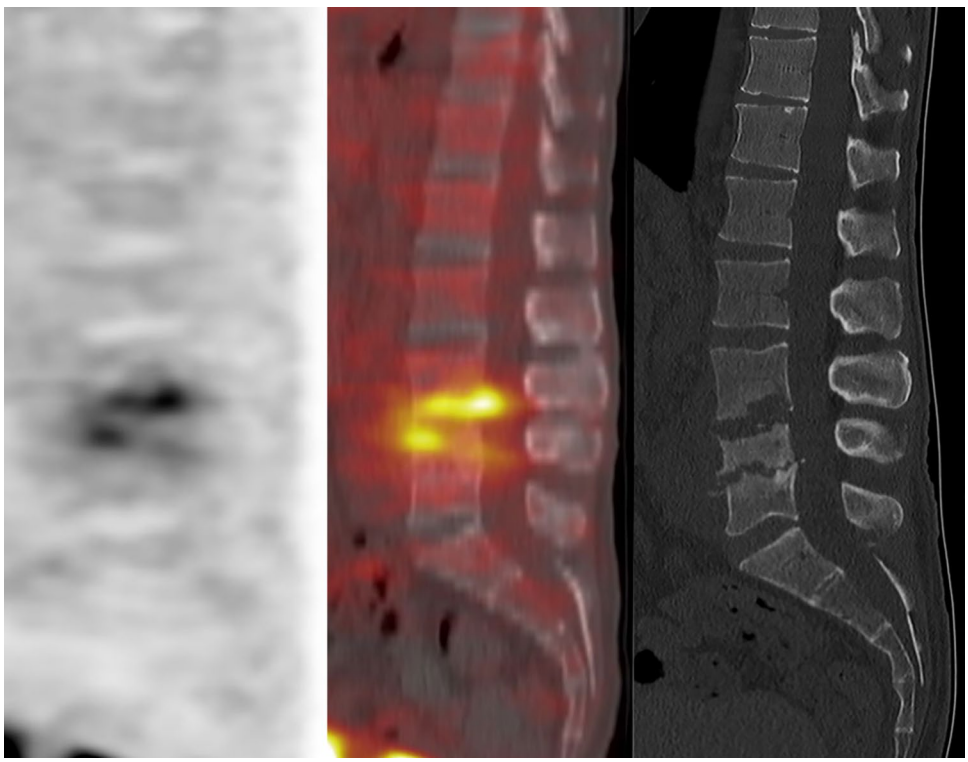

Fig. 5 Spondylodiscitis with bone destruction. A 46-year old man with recent spondylodiscitis at level L4-L5 with psoas abscess, resulting from *S. aureus* bacteremia. Portal of entry was not identified. Treatment included abscess drainage and intravenous flucloxacilline. After approximately 3 months, there was recurrence of back pain, subfebrile temperature and blood cultures were again positive for *S. Aureus*. [^{18}F]FDG PET/CT shows normal uptake at level L4-L5, but increased uptake at level L3-L4 (sagittal PET and fused PET/CT images at left and middle panels). Diagnostic CT shows bone destruction of the L4 vertebra with erosion of the endplates and loss of height (right panel)

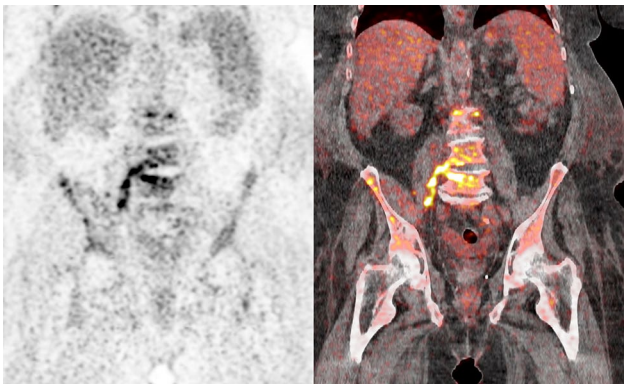

Fig. 6 Spondylodiscitis with unilateral paravertebral extension. A 61-year old man with back pain, fever and sepsis. His medical history includes alcohol abuse and Child–Pugh B liver cirrhosis. Blood culture was positive for *Streptococcus anginosus*. Portal of entry was either a recent dental extraction or a skin wound at the lateral malleolus. [^{18}F]FDG PET/CT shows increased uptake in the L4 and L5 endplates at the right lateral side, extending into the paravertebral soft tissues along the psoas muscle (coronal PET and fused PET/CT images at left and right panels), suggestive of spondylodiscitis. No MRI was performed because the abdominal circumference did not fit into the MRI gantry

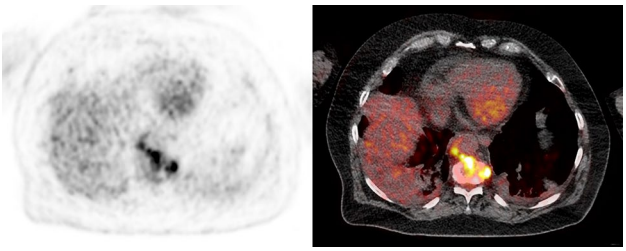

Fig. 8 Spondylodiscitis with paravertebral extension. A 77-year old man with fever and COVID-19 infection. Blood cultures were positive for *E. faecalis*. Portal of entry has not been identified. [^{18}F]FDG PET/CT shows increased uptake in the intervertebral disc and adjacent endplates and vertebral bodies at level Th10-Th11, extending ventrally into the paravertebral soft tissues along the descending thoracic aorta (axial PET and fused PET/CT images at left and right panels), suggestive of spondylodiscitis

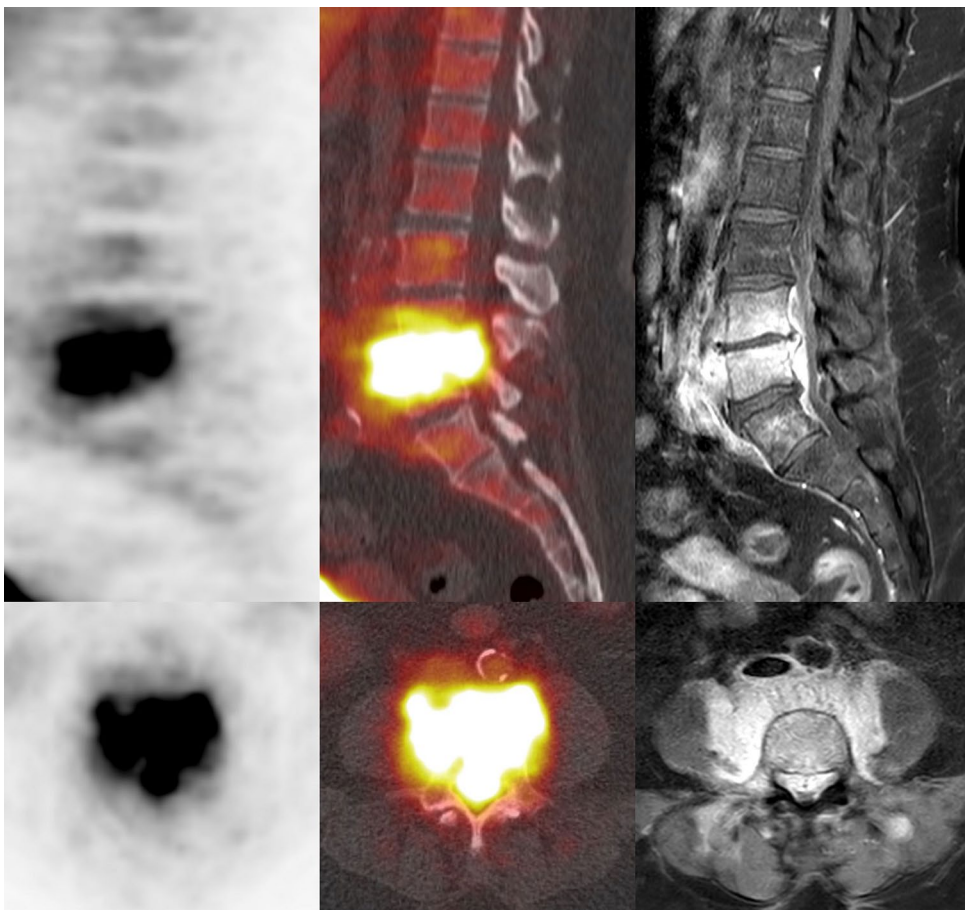

Fig. 7 Spondylodiscitis with paravertebral and epidural extension. A 55-year old woman with back pain and elevated C-reactive protein, but no fever. Blood cultures were positive for *E. coli*. Portal of entry has not been identified. MR imaging indicates spondylodiscitis, with increased signal intensity in the intervertebral disc and adjacent endplates and vertebral bodies at level L3-L4, extending into the paravertebral soft tissues, psoas muscles and epidural space (sagittal and axial T1-weighted gadolinium-enhanced images at right panel). [^{18}F]FDG PET/CT was performed on the same day for evaluation of disseminated infection (sagittal and axial PET and fused PET/CT images at left and middle panels) shows increased uptake in the intervertebral disc and adjacent endplates and vertebral bodies, extending into the paravertebral soft tissues, psoas muscles and epidural space

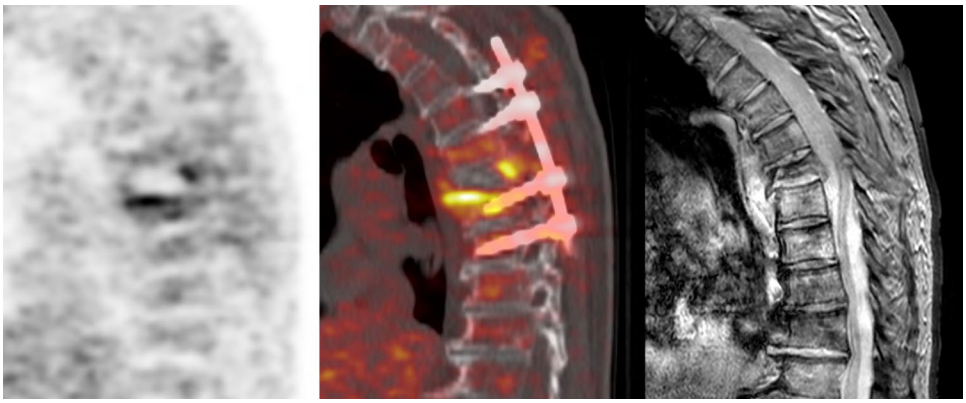

Fig. 9 Spondylodiscitis in postoperative patient. An 82-year old woman with diabetes mellitus presents with progressive paresis of both legs, starting the day before. MR imaging shows collapse of vertebra Th7 with an epidural mass and compression on the spinal cord (sagittal T1-weighted gadolinium-enhanced image at right panel). Laminectomy Th7 with posterior fixation of levels Th5 through Th9 was performed. Histopathological examination of surgical biopsies demonstrated active inflammation. Cultures were negative. [^{18}F]FDG PET/CT was performed to evaluate dissemination of infection, which confirms increased uptake at level Th7 (sagittal and axial PET and fused PET/CT images at left and middle panels)

level, but occasionally multiple contiguous or noncontiguous levels are infected (Fig. 10) [20, 23].

A classification system has been proposed [24], distinguishing normal [^{18}F]FDG distribution (score 0), slightly increased uptake in the inter- or paravertebral region (no infection, score 1), clearly increased uptake in the intervertebral space (discitis, score 2), clearly increased uptake in the intervertebral space and endplates of the adjacent vertebrae (spondylodiscitis, score 3) and clearly increased uptake in the intervertebral space and endplates with soft-tissue abscess (spondylodiscitis, score 4). Score 2 may be further subdivided, distinguishing increased uptake in the intervertebral disc (discitis, score 2A) and increased uptake only in the vertebrae without pathological changes in the intervertebral disc (osteomyelitis without discitis, score 2B) [8].

Paravertebral and epidural abscess

Infection of paravertebral tissues with abscess formation may occur as a complication of spondylodiscitis and is typically visible as increased [^{18}F]FDG uptake with central photopenia. As spondylodiscitis frequently affects the lumbar spine, paravertebral abscesses often include psoas muscle abscesses (Fig. 11). MRI has higher sensitivity than [^{18}F]FDG PET/CT for demonstrating epidural and spinal abscesses, but [^{18}F]FDG PET/CT has higher sensitivity for paravertebral and psoas muscle abscesses as these may be situated outside the field-of-view of the MRI [8, 12].

Abscess formation in the epidural space between the vertebral periosteum and spinal dura mater can occur as an isolated lesion without involvement of other spinal structures (termed primary epidural abscess) or as a complication of spondylodiscitis or facet joint arthritis (termed secondary epidural abscess) or iatrogenic inoculation during invasive procedures [25]. Epidural abscesses may be seen on [^{18}F]FDG PET/CT as increased uptake within the spinal canal, but a photopenic center may not be visible (Fig. 12). Epidural abscesses generally extend over multiple vertebrae [25, 26] as micro-organisms can spread in the epidural space without anatomical resistance (Fig. 13).

Septic arthritis of the facet joint

Primary septic arthritis of the facet joint occurs by hematogenous spread of infection, but facet joints can also become infected by direct inoculation or extension from adjacent spondylodiscitis or soft tissue infections. Septic arthritis of facet joints can also lead to secondary epidural or paraspinal abscesses [27]. [^{18}F]FDG PET/CT demonstrates increased uptake inside and around the involved facet joint, usually unilateral, either as an isolated infection (Fig. 14) or an extension from adjacent spondylodiscitis or neighboring soft tissue infection (Fig. 15). Characteristic signs of arthritis such as erosive changes and widening of the joint space may be visible on low-dose CT.

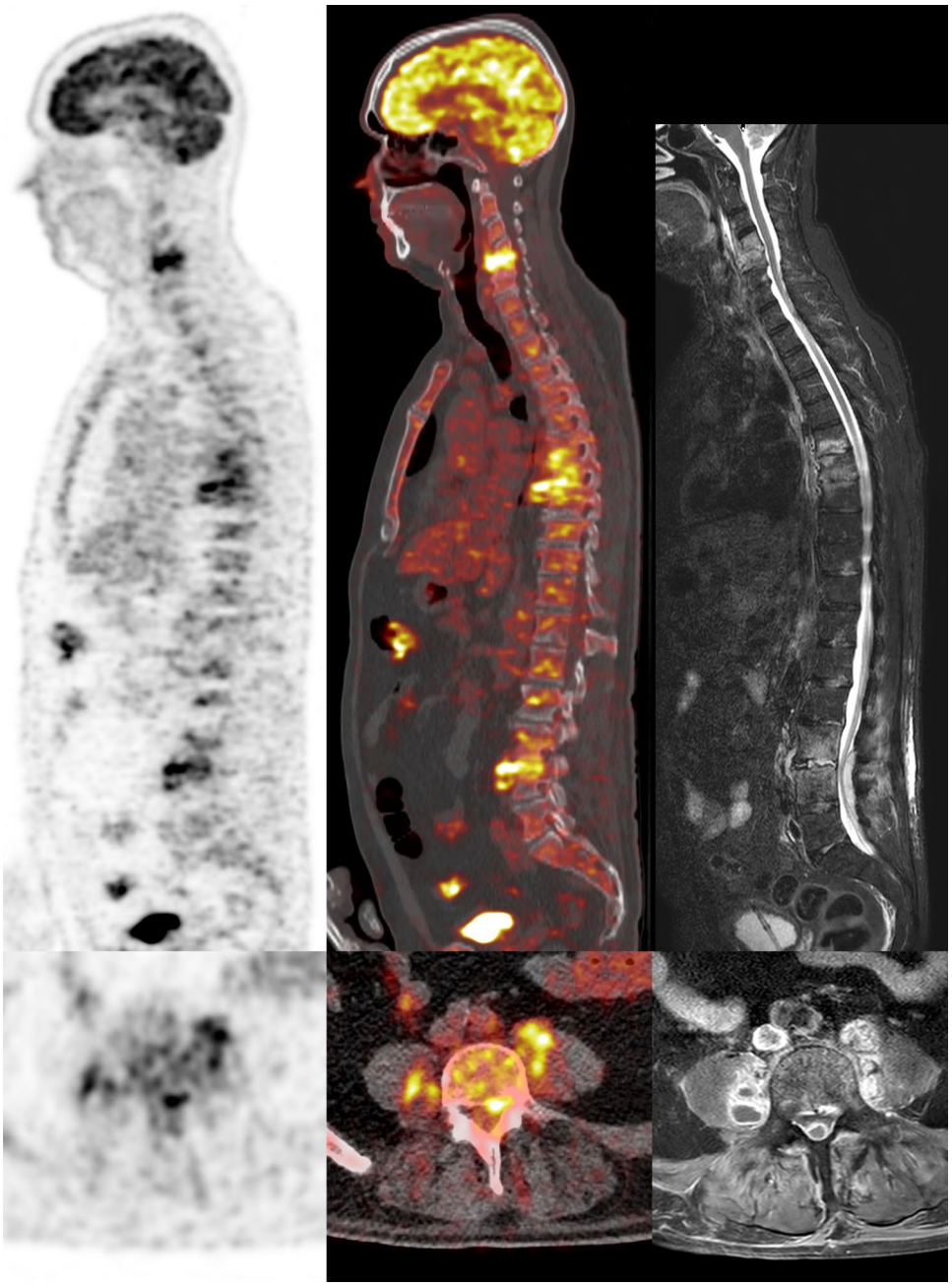

Fig. 10 Multilevel spondylodiscitis. A 66-year old man with back pain, fever and diabetes mellitus de novo. Blood and urine cultures were positive for *S. aureus*. [^{18}F]FDG PET/CT shows increased uptake at levels C4-C5, Th6-Th7, Th7-Th8 and L3-L4 (sagittal PET and fused PET/CT images at left and middle panels and axial images at lower panel), suggestive of spondylodiscitis. MR imaging was performed three days later for evaluation of epidural extension (sagittal T2-weighted STIR image at right panel), which confirms spondylodiscitis with epidural abscess and psoas muscle abscess (lower panel, axial T1-weighted gadolinium-enhanced image at L4 level)

Current guidelines and future perspectives

Current guidelines [3] indicate that in suspected spinal infection, the first diagnostic imaging modality should be MRI, but in postoperative patients or patients with contra-indications for MRI, the first imaging modality should be [^{18}F]FDG PET/CT. Furthermore, [^{18}F]FDG PET/CT should be performed in case of inconclusive MRI results. [^{18}F]FDG PET/CT may be performed for treatment response monitoring, but currently there is insufficient data to support definitive recommendation.

Efforts to improve diagnostic accuracy include the use of hybrid PET/MRI to combine highly sensitive metabolic and high-resolution anatomic imaging which may increase

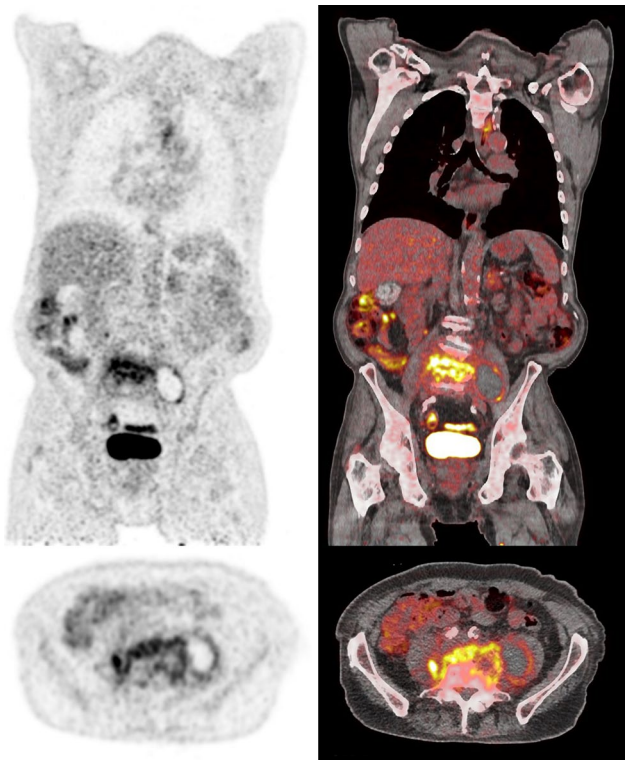

Fig. 11 Spondylodiscitis with psoas abscess. A 69-year old man with a history of diabetes mellitus, alcohol abuse and recent cholangitis requiring endoscopic retrograde cholangiopancreatography (ERCP), complicated by sepsis. [^{18}F]FDG PET/CT demonstrates spondylodiscitis at level L4-L5 extending into the left psoas muscle with a large photopenic area, suggestive of abscess. Culture of CT-guided aspiration of the psoas abscess was positive for *E. coli*

diagnostic certainty than either modality alone [28]. Recent development of total-body PET scanners with long axial field-of-view (LAFOV) allows increased detection efficiency of coincidence photon pairs, resulting in improved signal-to-noise ratio, which may improve detection of smaller or lower-contrast structures [29], such as small abscesses or low-grade infections. Total body PET also allows significant reduction in injected activity or scanning time, which reduces movement artifacts and improves comfort levels for these patients (who often have significant back pain). In addition, novel radiotracers with potentially higher specificity for bacterial infections are currently in development [30], including 2-[^{18}F]F-PABA (which is a substrate for folic acid synthesis, which bacteria use for nucleic acid synthesis) and [^{18}F]FDS (which is a sorbitol analogue that is only metabolized by *Enterobacteriaceae*).

Conclusion

The incidence of spinal infections has been rising significantly in recent years and is expected to increase further. [^{18}F]FDG PET/CT has high sensitivity for demonstrating spinal infections, is able to differentiate between spinal infection types and can detect spread of infection. Its use will therefore likely increase, especially if MRI is inconclusive, in patients with contra-indications for MRI or in postoperative patients.

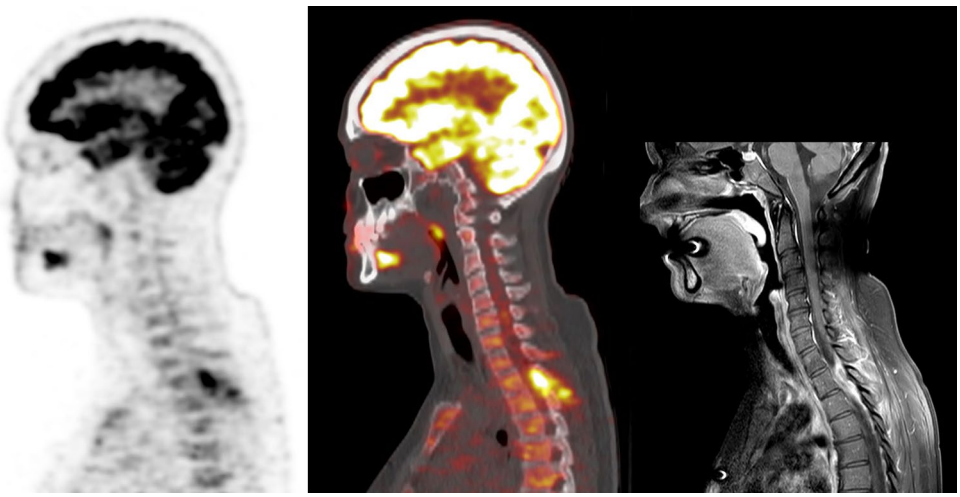

Fig. 12 Epidural abscess. A 32-year old woman with no relevant medical history, presents with back pain and fever. Blood culture was positive for *S. aureus*. Portal of entry has not been identified. [^{18}F]FDG PET/CT shows increased uptake in the spinal canal at level Th2-Th3 (sagittal PET and fused PET/CT images at left and middle panels). MR imaging was performed the next day to evaluate the spinal canal (sagittal T1-weighted gadolinium-enhanced image at right panel), which confirms an epidural abscess

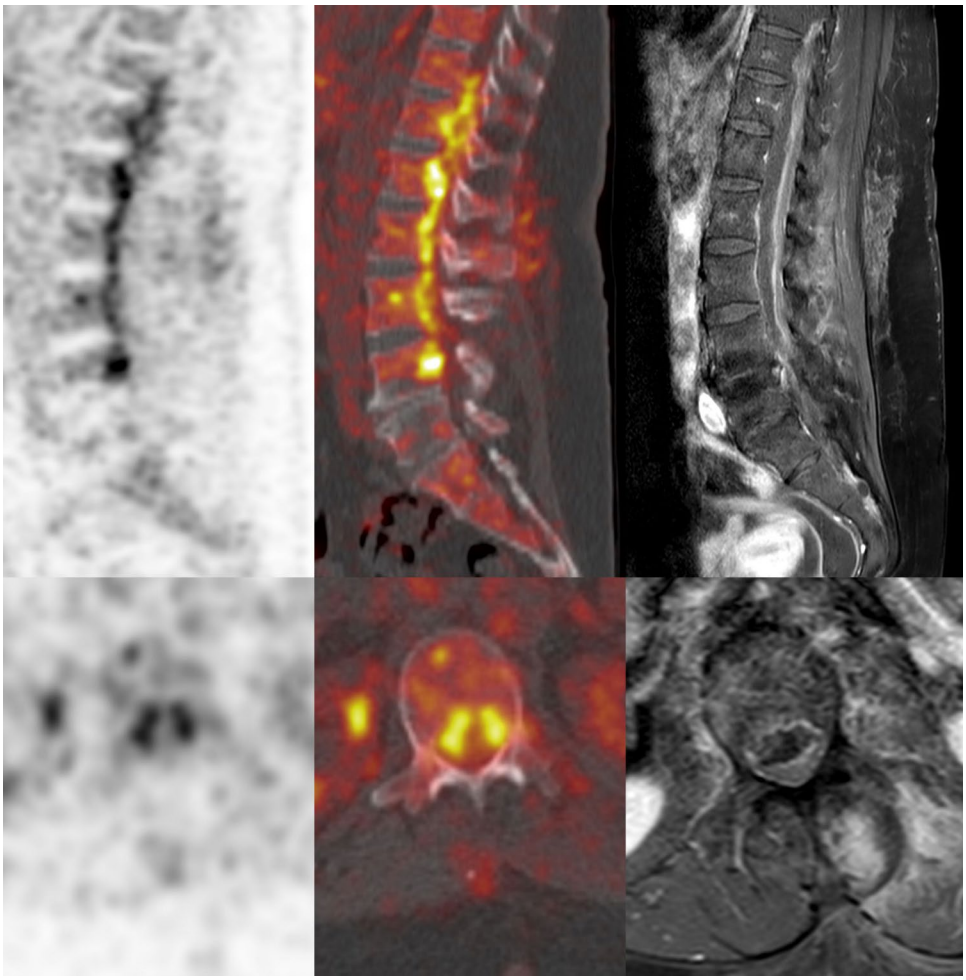

Fig. 13 Epidural abscess. A 54-year old woman with acute back pain with bilateral radiculopathy at level L5. There was no fever, but markedly elevated C-reactive protein at 544 mg/L (normal range 0–10 mg/L). Blood culture was positive for *Streptococcus anginosus*. Portal of entry has not been identified. MR imaging demonstrates an epidural abscess extending from level Th12 to level L5 (sagittal and axial T1-weighted gadolinium-enhanced images at right panel). Hemilaminectomy L2 with drainage of the abscess was performed. Additional [^{18}F] FDG PET/CT shows increased uptake in the spinal canal (sagittal and axial PET and fused PET/CT images at left and middle panels)

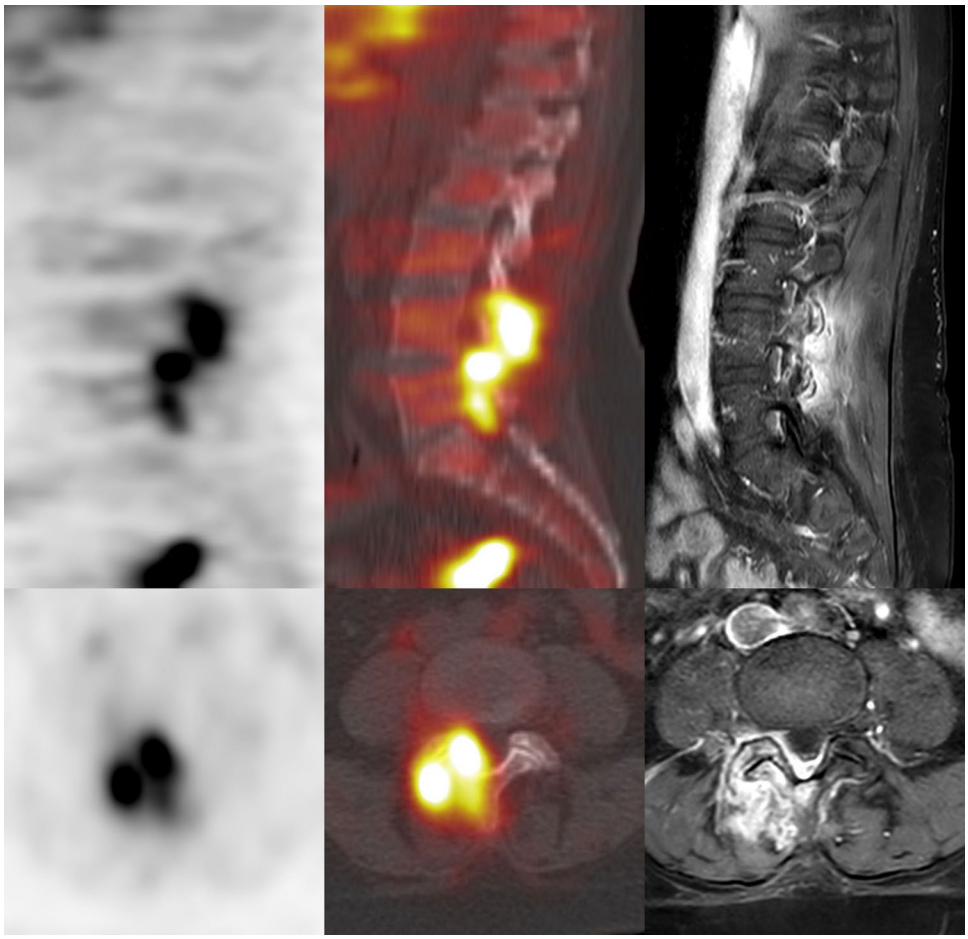

Fig. 14 Septic facet joint arthritis. A 55-year old woman with a history of sigmoid carcinoma with liver and lung metastases and a recent *Enterobacter cloacae* bacteremia from an infected peripherally inserted central catheter (PICC), now presents with fever without localizing symptoms. Repeated blood culture is negative. [^{18}F]FDG PET/CT shows increased uptake around the facet joints at level L3-L4 and L4-L5 on the right side (sagittal and axial PET and fused PET/CT images at left and middle panels), suggestive of septic arthritis. MR imaging performed the same day for evaluation of epidural extension (sagittal and axial T1-weighted gadolinium-enhanced images at right panel) confirms enhancement in the facet joints and surrounding soft tissues and an epidural abscess extending from level L3 to level S1

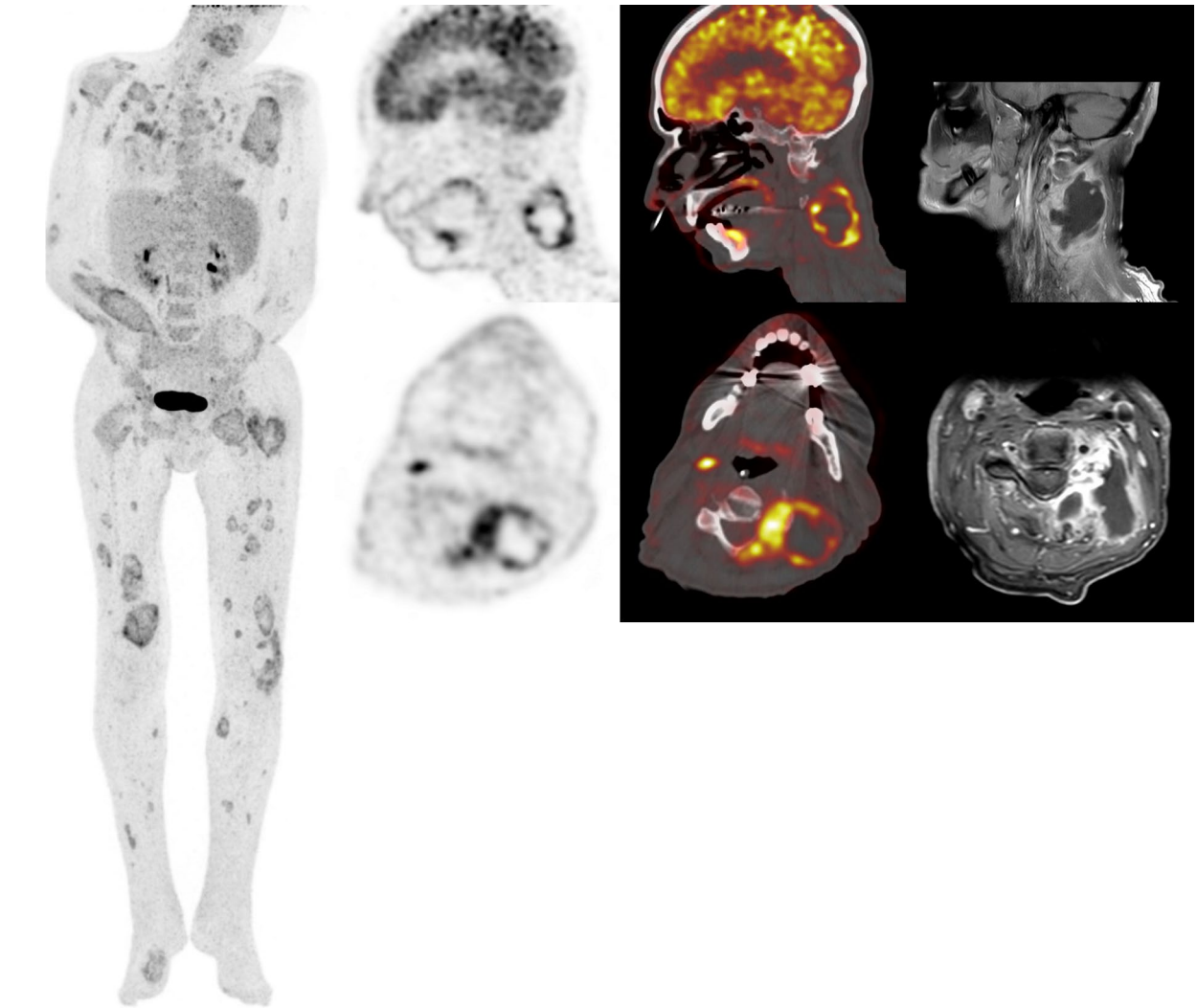

Fig. 15 Paravertebral abscess extending into facet joint. A 54-year old man presents with fever, sepsis and deep pancytopenia caused by de novo hairy cell leukemia, with multiple abscesses in peripheral skeletal muscles. Blood cultures were repeatedly negative, but cultures from several skeletal muscle abscesses demonstrated *S. aureus*. [^{18}F]FDG PET/CT showed an abscess in the paravertebral soft tissues extending into the facet joint and neural foramen at level C3-C4 on the left side (MIP image at left panel, sagittal and axial PET and fused PET/CT images at middle panels). MR imaging was performed the next day for evaluation of the spinal cord (sagittal and axial T1-weighted gadolinium-enhanced images at right panel), which confirmed extension in the neural foramen but no epidural extension

Author contributions EtB, MtB and SAF: data collection. All authors: manuscript writing.

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Data Availability Not applicable.

Declarations

Conflict of interest The authors declare no competing interests for this work.

References

1. Conan Y, Laurent E, Belin Y, Lacasse M, Amelot A, Mulleman D, Rosset P, Bernard L, Grammatico-Guillon L (2021) Large increase of vertebral osteomyelitis in France: a 2010–2019 cross-sectional study. Epidemiol Infect 149:e227
2. Kramer A, Thavarajasingam SG, Neuhoff J, Ponniah HS, Ramsay DSC, Demetriades AK, Davies BM, Shiban E, Ringel F (2023) Epidemiological trends of pyogenic spondylodiscitis in Germany: an EANS spine section study. Sci Rep 13:20225
3. Lazzeri E, Bozzao A, Cataldo MA, Petrosillo N, Manfrè L, Trampuz A, Signore A, Muto M (2019) Joint EANM/ESNR and ESCMID-endorsed consensus document for the diagnosis of spine infection (spondylodiscitis) in adults. Eur J Nucl Med Mol Imaging 46:2464–2487
4. Babic M, Simpfendorfer CS (2017) Infections of the spine. Infect Dis Clin N Am 31:279–297
5. Hadjipavlou A, Mader JT, Necessary JT, Muffolletto AJ (2000) Hematogenous pyogenic spinal infections and their surgical management. Spine 25:1668–1679
6. Raghavan M, Palestro CJ (2022) Imaging of spondylodiscitis: an update. Semin Nucl Med 53:152–166
7. Treglia G, Pascale M, Lazzeri E, Van der Bruggen W, Delgado Bolton RC, Glaudemans AWJM (2020) Diagnostic performance of ^{18}F-FDG PET/CT in patients with spinal infection: a systematic review and a bivariate meta-analysis. Eur J Nucl Med Mol Imaging 47:1287–1301
8. Kouijzer IJE, Scheper H, De Rooy JWJ, Bloem JL, Janssen MJR, Van den Hoven L, Hosman AJF, Visser LG, Oyen WJG, Bleeker-Rovers CP, De Geus-Oei LF (2018) The diagnostic value of ^{18}F-FDG-PET/CT and MRI in suspected vertebral osteomyelitis—a prospective study. Eur J Nucl Med Mol Imaging 45:798–805
9. Maamari J, Grach SL, Passerini M, Kinzelman-Vesely EA, Nassr A, Carr C, Diehn FE, Tande AJ, Murad MH, Berbari EF (2023) The use of MRI, PET/CT, and nuclear scintigraphy in the imaging of pyogenic native vertebral osteomyelitis: a systematic review and meta-analysis. Spine J 23:868–876
10. Kim SJ, Pak K, Kim K, Lee JS (2019) Comparing the diagnostic accuracies of F-18 fluorodeoxyglucose positron emission tomography and magnetic resonance imaging for the detection of spondylodiscitis: a meta-analysis. Spine 44:E414–E422
11. Yin Y, Liu X, Yang X, Guo J, Wang Q, Chen L (2018) Diagnostic value of FDG-PET versus magnetic resonance imaging for detecting spondylitis: a systematic review and meta-analysis. Spine J 18:2323–2332
12. Smids C, Kouijzer IJE, Vos FJ, Sprong T, Hosman AJF, De Rooy JWJ, Aarntzen EHJG, De Geus-Oei LF, Oyen WJG, Bleeker-Rovers CP (2017) A comparison of the diagnostic value of MRI and ^{18}F-FDG-PET/CT in suspected spondylodiscitis. Infection 45:41–49
13. Segawa T, Koga H, Oshina M, Fukushima M, Inanami H (2021) The diagnostic value of Fluorine-18 fluorodeoxyglucose positron emission tomography/computed tomography for the detection of surgical site infection after spine surgery. Spine 46:E602–E610
14. Paez D, Sathekge MM, Douis H, Giammarile F, Fatima S, Dhal A, Puri SK, Erba PA, Lazzeri E, Ferrando R, Filho PA, Magboo VP, Morozova O, Núñez R, Pellet O, Mariani G (2021) Comparison of MRI, [^{18}F]FDG PET/CT, and ^{99m}Tc-UBI 29–41 scintigraphy for postoperative spondylodiscitis—a prospective multicenter study. Eur J Nucl Med Mol Imaging 48:1864–1875
15. Russo A, Graziano E, Carnelutti A, Sponza M, Cadeo B, Sartor A, Righi E, Bassetti M (2019) Management of vertebral osteomyelitis over an eight-year period: the UDIPROVE (UDIne PROtocol on VErtebral osteomyelitis). Int J Infect Dis 89:116–121
16. Righi E, Carnelutti A, Muser D, Di Gregorio F, Cadeo B, Melchioretto G, Merelli M, Alavi A, Bassetti M (2020) Incremental value of FDG-PET/CT to monitor treatment response in infectious spondylodiscitis. Skeletal Radiol 49:903–912
17. Riccio SA, Chu AKM, Rabin HR, Kloiber R (2015) Fluorodeoxyglucose positron emission tomography/computed tomography interpretation criteria for assessment of antibiotic treatment response in pyogenic spine infection. Can Assoc Radiol J 66:145–152
18. Casali M, Lauri C, Altini C, Bertagna F, Cassarino G, Cistaro A, Erba AP, Ferrari C, Mainolfi CG, Palucci A, Prandini N, Baldari S, Bartoli F, Bartolomei M, D'Antonio A, Dondi F, Gandolfo P, Giordano A, Laudicella R, Massollo M, Nieri A, Piccardo A, Vendramin L, Muratore F, Lavelli V, Albano D, Burroni L, Cuocolo A, Evangelista L, Lazzeri E, Quartuccio N, Rossi B, Rubini G, Sollìni M, Versari A, Signore A (2021) State of the art of ^{18}F-FDG PET/CT application in inflammation and infection: a guide for image acquisition and interpretation. Clin Transl Imaging 9:299–339
19. McHenry MC, Easley KA, Locker GA (2002) Vertebral osteomyelitis: long-term outcome for 253 patients from 7 Cleveland-area hospitals. Clin Infect Dis 34:1342–1350
20. Mylona E, Samarkos M, Kakalou E, Fanourgiakis P, Skoutelis A (2009) Pyogenic vertebral osteomyelitis: a systematic review of clinical characteristics. Semin Arthritis Rheum 39:10–17
21. Leone A, Dell'Atti C, Magarelli N, Colelli P, Balanika A, Casale R, Bonomo L (2012) Imaging of spondylodiscitis. Eur Rev Med Pharmacol Sci 16(suppl 2):8–19
22. Duarte RM, Vaccaro AR (2013) Spinal infection: state of the art and management algorithm. Eur Spine J 22:2787–2799
23. D'Agostino C, Scorzolini L, Massetti AP, Carnevalini M, d'Ettorre G, Venditti M, Vullo V, Orsi GB (2010) A seven-year prospective study on spondylodiscitis: epidemiological and microbiological features. Infection 38:102–107
24. Hungenbach S, Delank KS, Dietlein M, Eysel P, Drzezga A, Schmidt MC (2013) ^{18}F-fluorodeoxyglucose uptake pattern in patients with suspected spondylodiscitis. Nucl Med Commun 34:1068–1074
25. Zimmerer SME, Conen A, Müller AA, Sailer M, Taub E, Flückiger U, Schwenzer-Zimmerer KC (2011) Spinal epidural abscess: aetiology, predisponent factors and clinical outcomes in a 4-year prospective study. Eur Spine J 20:2228–2234
26. Patel AR, Alton TB, Bransford RJ, Lee MJ, Bellabarba CB, Chapman JR (2014) Spinal epidural abscesses: risk factors, medical versus surgical management, a retrospective review of 128 cases. Spine J 14:326–330
27. Babic M, Ilaslan H, Shrestha N, Simpfendorfer CS (2020) Isolated septic facet joints: an underdiagnosed distinct clinical entity. Skeletal Radiol 49:1295–1303

28. Fahnert J, Purz S, Jarvers JS, Heyde CE, Barthel H, Stumpp P, Kahn T, Sabri O, Friedrich B (2016) Use of simultaneous ^{18}F-FDG PET/MRI for the detection of spondylodiskitis. J Nucl Med 57:1396–1401
29. Cherry SR, Jones T, Karp JS, Qi J, Moses WW, Badawi RD (2018) Total-body PET: maximizing sensitivity to create new opportunities for clinical research and patient care. J Nucl Med 59:3–12
30. Welling MM, Hensbergen AW, Bunschoten A, Velders AH, Roestenberg M, Van Leeuwen FWB (2019) An update on radiotracer development for molecular imaging of bacterial infections. Clin Transl Imaging 7:105–124