Diagnostic Extravasations - Patient Harm: References and Synopsis

#	Reference	Synopsis
1	Bogsrud TV, Lowe VJ. Normal variants and pitfalls in whole-body PET imaging with 18F FDG. Appl Radiol. (2006) 35:16–30.	Article insinuates that re-imaging may occur in dose infiltrations due to the infiltrate producing false positives/negatives due to artifacts or hot clots.
2	Sonoda LI, Ghosh-Ray S, Sanghera B, Dickson J, Wong WL. FDG injection site extravasation: potential pitfall of misinterpretation and missing metastases.Clin Nucl Med. (2012) 37:1115–6. doi: 10.1097/RLU.0b013e318266cbdb	Case image report: extravasation in the left antecubital fossa could have led to a significant difference in patient management and treatment if the images were not interpreted carefully.
3	Ozdemir E, Poyraz NY, Keskin M, Kandemir Z, Turkolmez S. Hot-clot artifacts in the lung parenchyma on F-18 fluorodeoxyglucose positron emission tomography/CT due to faulty injection techniques: two case reports. Korean J Radiol. (2014) 15:530–3. doi: 10.3348/kjr.2014.15.4.530	Two case reports detail that paravenous injection may lead to hot-clot artifacts in the lung parenchyma that may result in false positives and/or additional imaging procedures for the patient.
4	Schaefferkoetter JD, Osman M, Townsend DW. The importance of quality control for clinical PET imaging. J Nucl Med Technol. (2017) 45:265–6. doi: 10.2967/jnmt.117.198465	Radiotracer administration problems can never be completely eliminated, but such problems can be minimized with continuous feedback quality control and quality assurance measures.
5	van der Pol J, Voo S, Bucerius J, Mottaghy FM. Consequences of radiopharmaceutical extravasation and therapeutic interventions: a systematic review. Eur J Nucl Med Mol Imaging. (2017) 44:1234–43. doi: 10.1007/s00259-017-3675-7	Diagnostic extravasations likely underreported due to lack of regulatory requirements. Vast majority of diagnostic extravasations do not include dosimetry or patient follow-up (3,013/3,016). In addition, image quality might be significantly affected by a large extravasation leading to a lower degree of tracer uptake in the target tissue (organ) and to the potential need for a new scan. Extravasation of therapeutic radiopharmaceuticals can lead to severe soft tissue lesions. Lesions may result in surgical intervention.

#	Reference	Synopsis
6	Bennett P. Dose Infiltration. (2018). Available online at: https://www.instagram.com/p/BespZWGjUxy/?hl=en&taken-by=nuclear_radiology (accessed March 22, 2021).	Case report: Depositing radiotracer paravenously can degrade image quality and can result in the 3D image being uninterpretable.
7	Bennett PA, Mintz A, Perry B, Trout A, Vergara-Wentland P. Specialty Imaging: PET Positron Emission Tomography With Correlative CT and MR. Philadelphia, PA: Elsevier (2018).	Severe dose infiltration can decrease uptake in areas of normal biodistribution, rendering the exam uninterpretable. Artifacts and pitfalls are common causes of unclear, inaccurate, and false-positive conclusions.
8	Kiser JW, Crowley JR, Wyatt DA, Lattanze RK. Impact of an 18F-FDG PET/CT radiotracer injection infiltration on patient management – a case report. Front Med. (2018) 5:143. doi: 10.3389/fmed.2018.00143	Case report: severe infiltration in right antecubital fossa on initial scan masked metastatic cancer. Repeat scan performed resulted in finding stage 4 disease. Demonstrates that severe extravasation of the radiopharmaceutical dose degrades image quality.
9	Penney HF, Styles CB. Fortuitous lymph node visualization after interstitial injection of Tc-99m-MDP. Clin Nucl Med. (1982) 7:84–85. doi: 10.1097/00003072-198202000-00012	Right axillary lymph node displayed abnormal uptake after partial interstitial injection of Tc99m. Repeat scan performed seven weeks later showed no abnormalities in the right axilla. Lymph node visualization was due to interstitial nature of injection.
10	Vieras F. Serendipitous lymph node visualization during bone imaging. Clin Nucl Med. (1986) 11:434. doi: 10.1097/00003072-198606000-00018	Case report: Tc99m uptake by the right axillary lymph nodes occurred due to extravasation during bone imaging. Patient had no clinical evidence of lymphatic abnormalities leading to this type of finding may be a source of erroneous interpretation (i.e. mimic rib lesions).
11	Wallis JW, Fisher S, Wahl RL. 99Tcm-MDP uptake by lymph nodes following tracer infiltration: clinical and laboratory evaluation. Nucl Med Commun.(1987) 8:357–63. doi: 10.1097/00006231-198705000-00006	Visualization of normal lymph nodes ipsilateral and proximal to an extravasated injection of Tc99m is not uncommon in patients. The uptake by the lymph nodes will dramatically increase with

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		extravasation. Physician should be aware of the infiltration to avoid confusion with other pathologic forms of soft tissue uptake and to aid in scan interpretation.
12	Dogan AS, Rezai K. Incidental lymph node visualization on bone scan due to subcutaneous infiltration of Tc-99m MDP. A potential for false positive interpretation. Clin Nucl Med. (1993)18:208–9. doi: 10.1097/00003072-199303000-00004	Case report: TC99m MDP was present in axillary lymph nodes due to extravasation. Patient required repeat imaging to evaluate lymph node uptake. Follow-up scan showed no signs of tracer uptake in the same region. Take away lesson is soft tissue localization of radiotracer on bone scintigraphy may result in false-positive interpretations, if the activity overlies a bony structure.
13	Peller PJ, Ho VB, Kransdorf MJ. Extraosseous Tc-99m MDP uptake: a pathophysiologic approach. Radiographics. (1993) 13:715–34. doi: 10.1148/radiographics.13.4.8356264	Significant subcutaneous infiltration of Tc99m in the antecubital fossa can lead to axillary node visualization as the extravasated radiopharmaceutical is partially cleared through the lymph vessels.
14	Ongseng F, Goldfarb CR, Finestone H. Axillary lymph node uptake of technetium-99m-MDP. J Nucl Med. (1995) 36:1797–9.	Ipsilateral axillary lymph node visualization on PET can occur due to extravasation of Tc99m. In a study of subjects, 4 of the patients were required to have repeat scans due to extravasation.
15	Andrich MP, Chen CC. Bone scan injection artifacts. Clin Nucl Med. (1996) 21:260–2. doi: 10.1097/00003072-199603000-00021	Case reports: extravasation of Tc99m into soft tissues may lead to unusual artifacts in an adjacent bone proximal to the administration site.
16	Shih WJ, Wierzbinski B, Magoun S. Lymph node visualization in the elbow region. J Nucl Med. (1996) 37:1913.	Case report: extravasation of radiopharmaceutical around the dorsal wrist leads to superficial lymphatic drainage to the lymph node near the elbow. May lead to misinterpretation as a lesion.
17	Slavin JD Jr, Jung WK, Spencer RP. False-positive renal study with Tc-99m DTPA caused by infiltration of dose. Clin Nucl Med. (1996) 21:978–	Case report: extravasation of Tc99m DTPA produced a false-positive for renal

#	Reference	Synopsis
	80. doi: 10.1097/00003072-199612000-00019	dysfunction. Subsequent re-imaging after a short timeframe resulted in reduced activity.
18	Shih WJ, Han JK, Coupal J, Wierzbinski B, Magoun S, Gross K. Axillary lymph node uptake of Tc-99m MIBI resulting from extravasation should not be misinterpreted as metastasis. Ann Nucl Med. (1999) 13:269–71. doi: 10.1007/BF03164904	Case report: Axillary uptake in the extravasation of Tc99m should be carefully distinguished from lymphatic metastasis as this can lead to misinterpretation of the image.
19	Shih WJ, Collins J, Kiefer V. Visualization in the ipsilateral lymph nodes secondary to extravasation of a bone-imaging agent in the left hand: a case report. J Nucl Med Technol. (2001) 29:154–5.	Case report: extravasation of Tc99m can result in false-positive lesions of the lymph nodes in the wrist, elbow and axillary regions.
20	Pitman AG, Binns DS, Ciavarella F, Hicks RJ. Inadvertent 2-deoxy-2-[18F]fluoro-D-glucose lymphoscintigraphy: a potential pitfall characterized by hybrid PET-CT. Mol Imaging Biol. (2002) 4:276–8. doi: 10.1016/S1536-1632(02)00013-6	When extravasated, FDG outlines draining lymphatics and accumulates in regional lymph nodes. This may result in a false positive diagnosis if the reporting physician is not aware of the extravasation and pitfall of the scan. Additionally, if the lymph nodes draining the injection site are possible regional lymph nodes for the primary tumor, then the study is potentially compromised with regards to staging and would require repeating.
21	Chiang SB, Rebenstock A, Guan L, Burns J, Alavi A, Zhuang H. Potential false-positive FDG PET imaging caused by subcutaneous radiotracer infiltration.Clin Nucl Med. (2003) 28:786–8. doi: 10.1097/01.rlu.0000082677.96653.22	Case report: extravasation in the right antecubital fossa led to the suggestion of recurrent malignancy for non-Hodgkin lymphoma. Due to the possibility of subcutaneous infiltration, patient was subjected to a follow-up scan. Images did not demonstrate abnormal activity, which confirmed that the previous findings on the PET/CT were caused by subcutaneous extravasation.
22	Stauss J, Treves ST, Connolly LP. Lymphatic Tc-99m DMSA localization after partial-dose extravasation. Clin Nucl Med. (2003) 28:618–9. doi: 10.1097/00003072-200307000-00026	Case report: extravasation of Tc99m DMSA may result in lymphatic absorption and focal nodal localization with skeletal radiopharmaceuticals. Experienced

#	Reference	Synopsis
		practitioners estimate that partial-dose extravasation occurs in approximately 8% of children undergoing nuclear medicine studies.
23	Farsad M, Ambrosini V, Nanni C, Castellucci P, Boschi S, Rubello D, et al. Focal lung uptake of 18F-fluorodeoxyglucose (18F-FDG) without computed tomography findings. Nucl Med Commun. (2005) 26:827–30. doi: 10.1097/01.mnm.0000175786.27423.42	Case reports: paravenous administration of radiopharmaceuticals (FDG-18) may result in hot clots (lung micro embolism).
24	Vallabhajosula S, Killeen RP, Osborne JR. Altered biodistribution of radiopharmaceuticals: role of radiochemical/pharmaceutical purity, physiological, and pharmacologic factors. Semin Nucl Med. (2010) 40:220–41. doi: 10.1053/j.semnuclmed.2010.02.004	Common problems associated with radiopharmaceuticals is an unanticipated or altered biodistribution. This can result from dose infiltration, which may cause significant artifacts and compromise the utility and/or accuracy of nuclear medicine studies.
25	Long NM, Smith CS. Causes and imaging features of false positives and false negatives on (18)F-PET/CT in oncologic imaging. Insights Imaging. (2011) 2:679–98. doi: 10.1007/s13244-010-0062-3	Injection of radioactive clot following blood withdrawal into the syringe during FDG administration can result in pulmonary hotspots. Additionally, extravasation can result in subcutaneous tracking of FDG along lymphatic channels in the arm resulting in uptake in axillary nodes.
26	Manohar K, Agrawal K, Bhattacharya A, Mittal BR. New axillary lymph nodal F-18 fluoro-deoxy glucose uptake in an interim positron emission tomography scan - not always a sign of disease progression. Indian J NuclMed. (2011) 26:192–3. doi: 10.4103/0972-3919.106703	FDG may accumulate in non-malignant conditions causing potential pitfalls leading to false-positive interpretations, resulting in unnecessary invasive procedures.
27	Wagner T, Brucher N, Julian A, Hitzel A. A false-positive finding in therapeutic evaluation: hypermetabolic axillary lymph node in a lymphoma patient following FDG extravasation. Nucl Med Rev Cent East Eur. (2011) 14:109–11. doi: 10.5603/NMR.2011.00025	Case report: false-positive finding in the right axillary lymph node due to radiopharmaceutical extravasation.
28	Liu Y. Fluorodeoxyglucose uptake in absence of CT abnormality on PET-CT: What is it? World J Radiol. (2013) 5:460–7. doi: 10.4329/wjr.v5.i12.460	Focal FDG accumulation in lung parenchyma without abnormal CT findings share a common characteristic with partial paravenous injection of radiotracer. The damage to the vein due to extravasation causes the formation of blood clots at the site of injury, which in turn detach from the

#	Reference	Synopsis
		vein, enter the small pulmonary vasculature and are seen as hot spots in the distal lung.
29	Giron J, Lacout A, Marcy, P.-Y. Accuracy of positron emission tomography may be improved when combined with postcontrast high- resolution computed tomography scanIn Regard to Pepek et al. Pract Radiat Oncol. (2014) 5:e549–50. doi: 10.1016/j.prro.2014.12.008	PET helps in accurate staging of hilar lymph nodes of the lungs, but extravasation of FDG may lead to false-positive hot spots.
30	Simpson DL, Bui-Mansfield LT, Bank KP. FDG PET/CT: artifacts and pitfalls. Contemporary Diagnostic Radiol. (2017) 40:108. doi: 10.1097/01.CDR.0000513008.49307.b7	False-positive or false-negative PET/CT examination results can occur due to the presence of artifacts. Artifacts can be created by an error in the radiopharmaceutical administration process.
31	Agency IAE. The Role of PET/CT in Radiation Treatment Planning for Cancer Patient Treatment. (2008). Available online at: https://wwwpub. iaea.org/books/iaeabooks/8016/The-Role-of-PET-CT-in-Radiation-Treatment-Planning-for-Cancer-Patient-Treatment (accessed March 22, 2021).	Guide for accurate imaging as part of the treatment process for most malignancies managed with radiation therapy. Guide accentuates defining the gross tumor volume (GTV) as the single most important step in planning treatment; subsequent steps depend on it. Extravasation will lead to incorrect treatment plans making the entire process futile.
32	Weber WA. Use of PET for monitoring cancer therapy and for predicting outcome. J Nucl Med. (2005) 46:983–95.	SUV is most commonly used parameter for assessing tumor glucose use. Because SUV measurements can be integrated relatively easily into routine PET acquisition protocols, at present SUV represents the parameter that is most clinically useful for monitoring tumor response. However, common issues related to erroneous SUV measurement includes extravasation of the radiopharmaceutical.
33	Bunyaviroch T, Coleman RE. PET evaluation of lung cancer. J Nucl Med. (2006) 47:451–69.	Paravenous FDG injection is a common source of error in measurement of SUV. This results in incorrect low SUV

#	Reference	Synopsis
		calculations because the area under the time-activity curve is smaller.
34	Hall N, Zhang J, Reid R, Hurley D, Knopp M. Impact of FDG extravasation on SUV measurements in clinical PET/CT. Should we routinely scan the injection site? J Nucl Med. (2006) 47:115P.	Total of 190 PET/CT studies reviewed with 39 (21%) having visible focus of FDG activity at the injection site. Of the 39 patients, 36 had extravasated activity totaling less than 1% or less of the total injected dose and 3 patients had activity greater than 1% of the injected dose. Conclusion reached is if significant extravasation occurs it can have large impact on SUV values and may warrant routine acquisition of injection site data. *This study did not take into consideration the biological clearance of the extravasation during uptake period, and as a result may underestimate the percent of severe extravasations.*
35	Teymouri C, Botkin C, Osman M. FDG dose extravasation in PET/CT: frequency and impact on SUV measurements. J Nuclear Med. (2007) 48:475P.	Retrospective study of 398 whole body FDG-PET/CT scans (including extremities). Of the 398 scans reviewed, 46 (11.5%) had extravasations. Conclusions reached is that dose extravasation is commonly encountered with PET/CT but underreported due to omitting injection site from FOV. Extravasation can lead to underestimation of SUV max by average of 36.5% in the liver and 35.3% in the mediastinum. Extravasation should be reported to avoid false interpretations of PET/CT exams.
36	Fernolendt H, Bundschuh R, Winter A, Scheidhauer K, Schwaiger M. Paravenous activity in PET/CT – Influence on SUV and correction. J Nuclear Med. (2008) 49:416P.	Paravenous administration activity can induce errors in SUV calculation. If activity deposits at the administration site are present, the amount should be measured. If more than 1% of activity remains at the administration site, corrections should be made for appropriate SUV values.

#	Reference	Synopsis
37	Boellaard R. Standards for PET image acquisition and quantitative data analysis. J Nuclear Med. (2009) 50 (Suppl.1):11S−20S. doi: 10.2967/jnumed.108.057182	Multiple factors affect 18F-FDG quantification with paravenous administration of the dose included since the rate and quantity of FDG delivery are reduced, resulting in incorrect SUV calculations. The SUV range may be affected from 0-50% (unpublished data). Because the net amount of administered dose is directly used in the SUV calculation, the exact FDG dose given to the patient must be known.
38	Kelly M. SUV: Advancing Comparability and Accuracy. (2009). Available online at: https://www.mpcphysics.com/documents/SUV_Whitepaper_ Final_11.17.09_59807428_2.pdf (accessed March 22, 2021).	Paravenous administration of the dose injection will result in underestimation of SUV.
39	Agency IAE. IAEA Human Health Series No. 27. PET/CT Atlas on Quality Control and Image Artefacts. Vienna, Austria: IAEA (2014). Available: https://www.iaea.org/publications/10424/pet/ct-atlas-on-qualitycontrol-and-image-artefacts (accessed March 22, 2021).	Case report: PET images depicted infiltration resulting in neck lesion SUV underestimation. Recommended guidance is to image patients from top of the head to visualize possible infiltration, but this technique should be balanced against additional CT radiation exposure.
40	Lee JJ, Chung JH, Kim, S.-Y. Effect of (18)F-fluorodeoxyglucose extravasation on time taken for tumoral uptake to reach a plateau: animal and clinical PET analyses. Ann Nucl Med. (2016) 30:525–33. doi: 10.1007/s12149-016-1090-y	The time taken for tumoral uptake to reach a plateau is not affected by extravasation. In routine practice, the imaging time of approximately 60 min post-injection need not be modified even if extravasation is identified. However, tumor SUV may be underestimated in cases of extravasation.
41	Lee JJ, Chung JH, Kim, S.-Y. Effect of extravasation on optimal timing of oncologic FDG PET. J Nuclear Med. (2016) 57:1413.	Extensive extravasation does not affect the tumor uptake plateau time. In routine practice, even if extravasation is identified, imaging time that is 60 minutes after FDG injection needs no modification. However, tumor SUV itself can be underestimated in case of extravasation.
42	Burrell S, MacDonald A. Artifacts and pitfalls in myocardial perfusion imaging. J Nucl Med Technol. (2006) 34:193–211.	A potential cause of myocardial perfusion imaging artifacts is the technologist. Errors

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		in processing, injection administration, gating, attenuation, and quality control can all be contributing factors.
43	Erthal L, Erthal F, Beanlands RSB, Ruddy TD, deKemp RA, Dwivedi G. False positive stress PET-CT imaging in a patient with interstitial injection. J Nucl Cardiol. (2017) 24:1447–50. doi: 10.1007/s12350-016-0634-9	Case report: physicians should be cognizant of the presence of artifacts as it can lead to misinterpretation of a PET study. Artifacts may be caused by substantial radiopharmaceutical activity outside of the FOV.
44	Murthy LV, Bateman TM, Beanlands RS, Berman DS, Borges-Neto S, Chareonthaitawee P, et al. Clinical quantification of myocardial blood flow using PET: joint position paper of the SNMMI cardiovascular council and the ASNC. J Nuc Med. (2018) 59:269–97. doi: 10.2967/jnumed.117.201368	Extravasation or incomplete delivery of the radiopharmaceutical may result in inaccurate myocardial blood flow estimates and accuracy. Use of automatic injectors facilitates uniform radiopharmaceutical delivery and increases the reliability of quantification of myocardial blood flow.
45	Qutbi M. Masking effect of radiopharmaceutical dose extravasation during injection on myocardial perfusion defects during SPECT myocardial perfusion imaging: a potential source of false negative result. Mol Imaging Radionucl Ther. (2018) 27:141–3. doi: 10.4274/mirt.88942	Dose extravasation during SPECT MPI can be considered a major source of false negative results. Recommendation is to check the administration site prior to imaging to avoid incorrect interpretation.
46	Waxman AD, Herholz K, Lewis DH, Herscovitch P, Minoshima S, Ichise M, et al. Society of Nuclear Medicine Procedure Guideline for FDG PET Brain Imaging. (2009). Available online at: http://snmmi.files.cms-plus.com/docs/Society%20of%20Nuclear%20Medicine%20Procedure%20Guideline%20for%20FDG%20PET%20Brain%20Imaging.pdf (accessed March 22, 2021).	The purpose of this guideline is to assist nuclear medicine practitioners in recommending, performing, interpreting, and reporting the results of F-18FDG brain metabolic imaging.
47	Minoshima S, Drzezga AE, Barthel H, Bohnen N, Djekidel M, Lewis DH, et al. SNMMI procedure standard/EANM practice guideline for amyloid PET imaging of the brain 1.0. J Nucl Med. (2016) 57:1316–22. doi: 10.2967/jnumed.116.174615	Administration site should be routinely inspected for dose infiltration.
48	Fleming JS, Zivanovic MA, Blake GM, Burniston M, Cosgriff PS. Guidelines for the measurement of glomerular filtration rate using plasma sampling. Nucl Med Commun. (2004) 25:759–69. doi: 10.1097/01.mnm.0000136715.71820.4a	GFR studies utilize very low levels of radioactivity. Extravasation of the radiopharmaceutical will invalidate test results. Quality control for extravasation

#	Reference	Synopsis
		should be conducted via a radiation monitor.
49	Murray AW, Barnfield MC, Waller ML, Telford T, Peters AM. Assessment of glomerular filtration rate measurement with plasma sampling: a technical review. J Nucl Med Technol. (2013) 41:67–75. doi: 10.2967/jnmt.113.121004	Extravasation should be avoided in glomerular filtration rate assessments since they will invalidate a study or cause inaccurate glomerular filtration rate measurements.
50	Ponto JA. Preparation and Dispensing Problems Associated With Technetium Tc-99m Radiopharmaceuticals. (2004). Available online at: https://pharmacyce.unm.edu/nuclear_program/freelessonfiles/Vol11Lesson1.pdf (accessed March 22, 2021).	In multi-gated acquisition (MUGA) studies used to assess the impact of a patient's chemotherapy treatment on myocardial function, an extravasation can result in suboptimal radiolabeling of blood cells with corresponding increased amounts of residual, unreacted free pertechnetate and lead to inappropriate cessation of chemotherapy treatment.
51	European Medicines Agency. DaTSCAN, INN- Ioflupane (123I) Injection Issues. Amsterdam: European Medicines Agency (2004).	Scientific discussion regarding the utilization of DaTSCAN for differentiating essential tremors from Parkinson's Syndromes. Specifically, in dopamine transporter imaging studies assessing Parkinson's disease an extravasation of the radiopharmaceutical (in this case, Ioflupane I-123) can confound the dopamine transfer study results.
52	Alliance QIB. QIBA Profile: Quantifying Dopamine Transporters With 123Iodine Labeled Ioflupane in Neurodegenerative Diseases. Oak Brook, IL: QIBA (2017).	Several radiopharmaceuticals can quantify and help distinguish between neurodegenerative causes in Parkinson's disease and Diffuse Lewy Body Dementia. However, a caveat with regards to such nuclear medicine studies includes administration of the radiopharmaceutical, which cannot be compromised by extravasation.
53	Hur S, Bauer A, McMillan N, Krupinski EA, Kuo PH. Optimizing the ventilation–perfusion lung scan for image quality and radiation exposure. J	Dosing for the perfusion phase must be accurate; significant infiltration would

#	Reference	Synopsis
	Nuclear Med Technol. (2014) 42:51–4. doi: 10.2967/jnmt.113.128900	compromise the image quality creating the opportunity for false negative interpretations.
54	Mallick S, Petkova D. Investigating suspected pulmonary embolism during pregnancy. Respir Med. (2006) 100:1682–7. doi: 10.1016/j.rmed.2006.02.005	The false negative rates for the diagnosis of PE are high; undiagnosed PE has a mortality rate as high as 30%. Extravasation of the radiopharmaceutical during PE imaging studies has serious implications to the mother and the fetus.
55	Goel S, Bhargava P, Depuey EG. Recognition of dose infiltration on pulmonary ventilation-perfusion scintigraphy. Radiol Case Rep. (2011) 6:562. doi: 10.2484/rcr.v6i4.562	Case report: dose extravasation of Tc99m MAA can cause uneven distribution of the radioactivity in the vascular bed and can significantly lower the amount of radioactivity reaching the lungs. This can cause inaccuracy and misinterpretation of the images of a ventilation-perfusion scan.
56	Naddaf SY, Collier BD, Elgazzar AH, Khalil MM. Technical errors in planar bone scanning. J Nuclear Med Technol. (2004) 32:148–53.	Compton scatter from activity caused by an extravasated radiopharmaceutical may cause confusion and inaccurate diagnoses.
57	Vano-Galvan S, Rodriguez-Rey C, Vano-Galvan E, Jaen P. Technetium and blood extravasation before gammagraphy: a case report. Cases J. (2009) 2:141. doi: 10.1186/1757-1626-2-141	Case report: extravasation of Tc99m-pertechnetate resulted in a black/purple colored lesion. Extravasation may result in imaging artifacts and the imaging procedure should be repeated. Symptoms may appear after several days or weeks. *Authors incorrectly concluded that radiation injury symptoms could arise immediately. Additionally, authors incorrectly concluded that "patients and physicians must be reassured because of the non-vesicant property of technetium." This indicates that the authors are unaware that technetium can produced tissue injury as a result of ionizing radiation.*

Additional References Supporting the Monitoring of Radiopharmaceutical Administrations

#	Reference	Synopsis
1	Osborne, D., J. W. Kiser, J. Knowland, D. Townsend and D. R. Fisher (2021). "Patient-specific Extravasation Dosimetry Using Uptake Probe Measurements." Health Phys. DOI: 10.1097/HP.0000000000001375	Extravasated radiopharmaceutical administrations can result in unintentional doses that exceed well-established radiation protection and regulatory limits; they should be identified and characterized to determine whether the patient should be followed for adverse tissue reactions that may present later in time.
2	Tsorxe, I. Y. and R. B. Hayes (2021). Dose Estimation for Extravasation of 177-Lu, 99m-Tc, and 18-F, North Carolina Policy Collaboratory	Extravasation of common diagnostic as well as therapeutic radiopharmaceuticals can surpass regulatory reporting thresholds. Since dosimetry is not routinely performed for such extravasations, the potential patient harm from radiopharmaceutical extravasations is underestimated.
3	Lattanze RK, Osman M, Ryan KA, Frye SA, Townsend DW. Usefulness of Topically Applied Sensors to Assess the Quality of 18F-FDG Injections and Validation against Dynamic Positron Emission Tomography (PET) Images. Frontiers in Medicine. 2018	The quality and quantification of PET/CT studies are of clinical importance and require the radiopharmaceutical dose to be administered correctly. Monitoring of radiopharmaceutical administration during the uptake period serves as a quality control measure to not only identify extravasations, but also reduce extravasation rates and improve patient care.
4	Muzaffar, R. et al. Novel method to detect and characterize 18F-FDG infiltration at the injection site: a single-institution experience. J Nucl Med Technol. 45:267-271	Extravasation of the administered radiopharmaceutical affects image quality and SUV quantification. Monitoring of radiopharmaceutical administrations informs physicians of extravasation severity allowing physicians to make informed decisions regarding patient care. Additionally, monitoring may provide factors contributing to high extravasation rates and can suggest improvements to reduce such rates.

#	Reference	Synopsis
5	Kiser, JW., et al. Impact of an 18F-FDG PET/CT Radiotracer Injection Infiltration on Patient Management – A Case Report. Front Med. DOI: 10.3389/fmed.2018.00143	The quality of a PET/CT image can be degraded by extravasation through delivery of an inadequate radiopharmaceutical dose. In this case report, a staging PET/CT scan confirmed the presence of a single, large lung mass. However, extravasation of the radiopharmaceutical led to a repeat PET/CT study, resulting in the visualization of distant metastases that changed the original treatment plan.
6	Sanchez S, Currie GM. Topical device detection of 18F FDG dose leakage. J Nucl Med Technol. 48(3):283-84	Case report: routine radiopharmaceutical administration monitoring identified a mimicked extravasation in which autoinjector dose leaked during infusion onto the pillow on which the patient's arm had rested. Monitoring of the administration provided for timely evaluation and problem solving both of which benefited the patient.
7	Kiser, JW., et al. Assessing and reducing PET/CT radiotracer infiltrations: lessons in quality improvement and sustainability. JCO Oncology Practice. 16(7):e6360e640	Extravasation of the radiopharmaceutical dose can affect PET/CT results and lead to unnecessary and/or inappropriate treatments and procedures. Routine quality control and continuous monitoring of radiopharmaceutical administrations can reduce and sustain the reduction of extravasation rates.
8	Wong, TZ, et al. Quality Improvement Initiatives to Assess and Improve PET/CT Injection Infiltration Rates in Multiple Centers. J Nucl Med Technol. 47(4):326-331.	A quality improvement plan related to monitoring radiopharmaceutical administrations can reduce extravasation rates, determine extravasation associative factors, and improve/sustain radiopharmaceutical administration quality.
9	Osborne, D. et al. Assessing and reducing PET radiotracer infiltration rates: a single center experience in injection quality monitoring methods and quality improvement. BMC Med Imag. 20(3). DOI: 10.1186/s12880-020-0408-3	Development of a quality improvement plan to monitor radiopharmaceutical administrations can reduce extravasation rates.
10	Osman MM, Muzaffar R, Altinyay ME, Teymouri C. FDG Dose Extravasations in PET/CT: Frequency and Impact on SUV Measurements. Front Oncol. 2011;1:41	Radiopharmaceutical dose extravasations are commonly encountered (10.5%) in PET/CT. However, it is underreported by at least 31% due

#	Reference	Synopsis
		to omitting injection site from the FOV. When present, extravasations may lead to underestimation of SUVmax.
11	Bains A, Botkin C, Oliver D, Nguyen N, Osman M. Contamination in 18F-FDG PET/CT: An initial experience. J Nucl Med. 2009;50:2222	Efforts should be made to minimize the occurrence of radiopharmaceutical administrations to avoid false positive interpretation of the exam.
12	Boellaard R, Delgado-Bolton R, Oyen WJG, et al. FDG PET/CT: EANM procedure guidelines for tumour imaging: version 2.0. Eur J Nucl Med Mol Imaging. 2015;42:328-354	Extravasation of the radiopharmaceutical administration warrants imaging of the administration area. Extravasation should be reported to the imaging physician since the content of the images affect patient management and clinical outcomes.
13	McIntosh C, Abele J. Frequency of Interstitial Radiotracer Injection for Patients Undergoing Bone Scan. https://car.ca/wp-content/uploads/AP003_Frequency_of_Interstitial_Radiotracer_Injection_for_Patients_Undergoing_Bone_Scan_McIntosh.pdf Accessed 16 September 2021.	All nine nuclear medicine sites (three hospitals and six centers) in Edmonton, Alberta contributed to a quality improvement project involving 450 Tc-99m MDP SPECT bone scans. They reported 79 infiltrations (17.5%). The centers' infiltration rates ranged from 0-44%.
14	Barber, SA, Fulp AH. Evaluating radiopharmaceutical administration quality: a journey of process improvement in PET/CT. Uptake 24(3)	Dose extravasation compromises the final PET images in several ways: standardized uptake values will be abnormally low, reconstruction artifacts create photopenia around the injection site (which may or may not be in the field of view), 3D image reconstructions are often unreadable, and extravasated tracer can travel through the lymphatic system, causing uptake in lymph nodes, which can be confused with cancer.
15	Williams, et al. Towards real-time topical detection and characterization of FDG dose infiltration prior to PET imaging. Eur J Nucl Med Mol Imaging 2016;43(13):2374-80.	Monitoring radiopharmaceutical administrations through the uptake period is critical for detecting extravasations. The dynamic information provided through monitoring may complement static PET/CT images and assist physicians in patient management.
16	Tumpa TR, Acuff SN, Osborne DR. Classification of infiltrated injections during PET/CT imaging applying deep learning technique.	Injected dose infiltration can negatively impact quantitative evaluation of Positron Emission

#	Reference	Synopsis
	2019 IEEE 31st International Conference on Tools with Artificial Intelligence (ICTAI), Portland, OR, USA, 2019, pp. 1781-85	Tomography (PET) data by leading to inaccurate calculation of Standardized Uptake Value (SUV) measurements and limiting bioavailability of the radiopharmaceutical in the patient.
17	Sanchez S, Currie GM. Topical sensor for the assessment of injection quality for 18F-FDG, 68Ga-PSMA and 68GaDOTATATE positron emission tomography. J Med Imaging Radiat Sci. 51(2):247-55	Extravasation and partial extravasation of PET doses are not only readily detectable through monitoring, but they are also preventable. Monitoring can provide the insights into variables that could eliminate extravasation as a cause of image quality or SUV accuracy issues.
18	Sanchez S, Currie GM. Topical sensor for the assessment of positron emission tomography dose administration; metric performance with an autoinjector. J Nucl Med Technol. Doi: 10.2967/jnmt.120.245043	Extravasation and partial extravasation of PET doses are readily detected and differentiated using TAC metrics. The metrics can provide the insights that could inform image quality or SUV accuracy issues.
19	Sanchez S, Currie GM. Topical Sensor Metrics for 18F-FDG Positron Emission Tomography Dose Extravasation. Radiography (2020) 27: 178-186	Partial extravasation undermines image quality and accuracy of quantitation, impacting efficacy of outcomes for patients. Characterization of extravasation informs decision making to optimize protocol and procedure, enhancing patient outcomes. Awareness provides the opportunity for education and training to minimize impact. The information can be used to drive policy and regulations to support improved techniques in practice.
20	Arveschoug, AK, et al. Extravasation of [177Lu]Lu-DOTATOC: case report and discussion. EJNMMI Res 2020.10(68)	In the case of extravasation of radioactive drugs used in peptide-receptor radionuclide therapy of neuroendocrine tumors, or in radionuclide therapy in general, rapid action is important to reduce or avoid complications. Dosimetry of the extravasation can help determine if a change in treatment course is necessary.
21	Zhu, Z., et al. Inadvertent intraarterial injection of (1)(8)F-FDG: a case report and literature review of hot forearm and hot hand signs. J Nucl Med Technol (2021) 39(4): 249-51	Unintentional intraarterial injection of radiopharmaceuticals may cause artifacts leading to difficulties in accurately interpreting PET/CT images.

#	Reference	Synopsis
22	Siebeneck, BM. Extravasation of yttrium-90 ibritumomab tiuxetan: a case study. Clin J Oncol Nurs (2008) 12(2):275-8	Yttrium-90 (Y-90) may act as a vesicant, potentially causing severe tissue damage if extravasation occurs. Patients administered Y-90 may not show signs or symptoms of extravasation until weeks or months after the IV injection.
23	Williams, G. et al. Extravasation of therapeutic yttrium-90-ibritumomab tiuxetan (zevalin): a case report. Cancer Biother Radiopharm (2006) 21(2):101-5	Extravasation of Y-90 can cause serious damage and potential tissue necrosis. Steps should be taken to address the occurrence of extravasation and to prevent the re-occurrence of extravasation.
24	Terwinghe, C. et al. Extravasation of Y-DOTATOC : case report and discussion of potential effects, remedies and precautions in PRRT. EJNMMI (2012) 39(S205):155.	Extravasation with 90Y can cause a lot of tissue damage depending on the local retention of the radiopharmaceutical. If monitoring for extravasation occurs, it can be properly managed and resolved without any local signs or symptoms.
25	Shih, W., et al. Visualization in the ipsilateral lymph nodes secondary to extravasation of a bone-imaging agent in the left hand: a case report. J Nucl Med Technol (2021) 29(3):154-5	Axillary or elbow lymph node visualization after subcutaneous extravasation of bone-imaging agent on a routine bone scintigraphy. Extravasation was captured by whole-body imaging, which is not a routine practice by nuclear medicine institutions.
26	Ishiwata, Y., et al. Fever of unknown origin (FUO): evaluation of 50 cases with 18F-FDG PET/CT. JNM (2015) 56(Sup 3):1953.	18F-FDG PET/CT may be utilized to determine the origin of FUO due to high sensitivity and specificity of the radiopharmaceutical. Extravasation of the radiopharmaceutical would impair the radiopharmaceutical's contribution to diagnosability.
27	Crowley, JR., et al. Detection of excess presence of 99mTc-MDP near injection site – a case report. Front Med (2021) DOI: 10.3389/fmed.2021.728542	Detection of excess radiopharmaceutical at the administration site allows for mitigation tactics to be applied early in the uptake period. Monitoring of radiopharmaceutical administrations allows for early detection of extravasation, which is important for image quality/quantification and patient care.