



Considerations Regarding Radiation Exposure in Performing FDG-PET-CT

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The development of dual-modality positron emission tomography/computed tomography (PET-CT) systems with near-simultaneous acquisition capability has addressed the limited spatial resolution of PET and has improved accurate anatomical localization of sites of radiotracer uptake detected on PET. PET-CT also allows for CT-based attenuation correction of the emission scan without the need for an external positron-emitting source for a transmission scan. This not only addresses the limitations of the use of noisy transmission data, therefore improving the quality of the attenuation-corrected emission scan, but also significantly decreases scanning time.

However, this comes at the expense of increased radiation dose to the patient compared to either PET or CT alone. The radiation dose results both from the injected radiotracer 18F-2-fluoro-2-deoxy-D-glucose (FDG), which is ~7 mSv from an injected dose of 10 mCi (given the effective dose of 0.019 mSv/MBq [0.070 rem/mCi] for FDG¹), as well as from the external dose of the CT component, which can run as high as 25 mSv. This brings the total dose of FDG-PET-CT to a range of ~8 mSv up to 30 mSv, depending on the type of study performed as well as the anatomical region and number of body parts imaged, although several recent studies have reported a typical average dose of ~14 mSv for skull base -to-thigh FDG-PET-CT examinations.^{2,3,4,5,6,7,8} The critical organ after FDG administration is the urinary bladder, which is exposed to 0.16 mGy/MBq (0.59 rad/mCi) in adults, although this can be reduced with patient hydration and increased patient voiding frequency.¹

Reduction of FDG dose with the use of currently available PET-CT systems can be challenging due to the short half-life of FDG (109.8 min) and limitations imposed by patient size. Larger patients may have resultant images with lower signal-to-noise ratios and reduced image quality. For significantly heavy patients (>90 kg), increase of scanning time (time per bed position) rather than increase of FDG activity is preferable to improve image quality without increasing dose.⁹ Interestingly, a recent report suggests that FDG dose can be reduced by 50% without a loss of diagnostic performance in the setting of whole body PET-CT for the oncological patient.¹⁰ Further research will be required to determine how low the requisite FDG dose can be reduced for use with currently available PET-CT instrumentation without compromising diagnostic quality.



Table 1-Methods to decrease radiation exposure in FDG-PET-CT

Optimize utilization of FDG-PET-CT	Optimize protocols to reduce dose while maintaining sufficient image quality
Perform FDG-PET-CT only when clinically indicated <ul style="list-style-type: none"> Use evidence-based guidelines for guidance, including American College of Radiology (ACR) Appropriateness Criteria®, Society of Nuclear Medicine and Molecular Imaging (SNMMI) Procedure Guidelines, European Association of Nuclear Medicine (EANM) Procedure Guidelines, National Comprehensive Cancer Network (NCCN) Clinical Practice Guidelines in Oncology, among others) Implement use of decision support systems 	PET-related methods to reduce dose <ul style="list-style-type: none"> Optimize/minimize injected dose of FDG Encourage hydration and frequent voiding to reduce urinary bladder and adjacent pelvic organ radiation dose from FDG excretion Use 3D PET emission acquisition mode Use time-of-flight (TOF) information in image reconstruction Increase duration of acquisition time per bed position
Use alternative non-ionizing radiation imaging technologies (US, MRI) whenever possible	CT-related methods to reduce dose <ul style="list-style-type: none"> Minimize z-axis coverage whenever possible Decrease tube voltage (kVp) Decrease tube current and exposure time (mAs) Increase pitch Use automatic tube current modulation
Consider use of PET/MRI in place of PET-CT for certain clinical applications to reduce dose, although more research data is needed	
Perform routine quality assurance and quality control of imaging instrumentation and optimization of imaging protocols	
Monitor patient dose exposure from individual imaging examinations and on a cumulative basis	
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Newer imaging units with faster crystals produce higher light output, which may be used to shorten exam times or to allow use of lower doses of FDG. Time-of-flight (TOF) information in image reconstruction also appears promising in the ongoing efforts to reduce dose.^{7,11,12} TOF can pinpoint the origination of positron annihilation more accurately compared to non-TOF reconstruction. This improves the signal-to-noise ratio, reduces image degradation due to attenuation and scatter, and can improve image quality in heavy patients without having to increase injected dose.^{13,14} The 3D PET emission acquisition mode also allows for a reduction in injected dose by up to 50% relative to the recommended FDG dose for the 2D mode of acquisition.^{1,15}

Reduction of dose from the CT component of PET-CT may be undertaken in various ways. The attenuation-correction CT scan typically extends from the skull base to the proximal thighs. However, the anatomical extent may be reduced further in certain situations. For example, elimination of imaging of the pelvis for lesions such as head and neck cancer or other primary tumors that do not frequently spread to the pelvis may reduce dose, although more data is needed before adopting this type of strategy. Newer reconstruction techniques such as



adaptive statistical iterative reconstruction (ASIR) and model-based iterative reconstruction (MBIR), which are being adapted increasingly, may prove more valuable in reducing dose in the future. Through use of ASIR, the dose of diagnostic CT can potentially be reduced by up to 65% in adults without compromising image quality.^{16,17} Similarly, MBIR can allow for up to 80% reduction of radiation dose, although the prolonged processing time may limit its routine use in clinical practice.^{18,19}

Image noise, which degrades CT image quality, is inversely related to the X-ray beam energy and increases as tube current or tube voltage decreases. The challenge to the practicing radiologist and nuclear medicine physician is to determine the acceptable range of image quality and to establish the minimum radiation doses needed to achieve this range. Many PET-CT devices default to 140 kVp for attenuation correction scans; however, reduction to 80-120 kVp can significantly reduce the dose and should be considered in adult patients.^{20,21,22,23} Lower tube currents and exposure times (as low as 16-50 mAs) may also be used to decrease radiation dose while maintaining adequate image quality.²⁴ Automatic tube current modulation (or automatic exposure control [AEC]), which automatically adapts tube current in both angular and longitudinal directions according to patient size, can be useful to reduce patient dose exposure by 20-60% while maintaining predefined image noise or image quality characteristics.^{25,26,27} Organ-based tube current modulation (TCM), in which tube current is decreased as the X-ray tube passes over the anterior surface of the body and increased over the posterior surface of the body, can also be implemented to decrease dose to anterior superficial radiosensitive organs such as the breast, thyroid gland and eye lens by up to 50% without compromising image quality.^{28,29,30} Increasing pitch has also been reported as a means to decrease CT dose exposure.^{31,32}

Careful selection of patients to be imaged should be a priority of the radiologist/nuclear medicine physician and the referring physician in order to avoid unnecessary repeated exposure. Risk-benefit ratios of whole body PET-CT must be carefully evaluated before each study is ordered. This is especially important in cases where the clinical utility is less well established, in addition to the younger patient population who may survive for many years after the treatment and cure of their malignancy.^{4,33,34} Communication between the referring physician, various clinical departments and the radiologist/nuclear medicine physician is essential to avoid unnecessary and repetitive imaging or excessive re-staging in patients who may have already been imaged previously at the same or other locations. Collaborative effort between radiologists/nuclear medicine physicians, imaging technologists and medical physicists is also critical to ensure optimization of scanning protocols to reduce dose while maintaining image quality. Participation in dose registries, such as the American College of Radiology (ACR) Dose Index Registry[®] (DIR), can allow facilities to compare their CT dose indices to regional and national values for optimization of patient radiation doses for medical imaging. Use of alternative non-ionizing radiation imaging technologies (US, MRI) is also recommended whenever possible to reduce dose exposure over time.³⁵



Furthermore, use of PET/MRI as an alternative to PET-CT may also be feasible for certain clinical applications to reduce dose, although more research on this topic is needed.

The search for strategies in effective reduction of whole body dose without compromising critical diagnostic information should continue to be an essential part of optimizing FDG-PET-CT imaging protocols.

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