European Journal of Nuclear Medicine and Molecular Imaging (2021) 48:3755–3759
https://doi.org/10.1007/s00259-021-05505-x

EDITORIAL

First clinical experience of 106 cm, long axial field-of-view (LAFOV) PET/CT: an elegant balance between standard axial (23 cm) and total-body (194 cm) systems

Xiaoli Lan[1,2] · Muhsin H. Younis[3] · Ke Li[3] · Weibo Cai[3]

Published online: 23 August 2021

Conventional PET/CT scanners with standard axial field-of-view (SAFOV) usually cover around 23–26 cm [1, 2]. Over the last decade, however, there has been tremendous effort in the development of long axial field-of-view (LAFOV) PET/CT scanners, and several of them have entered the clinical arena [3–5]. It is well recognized that, with LAFOV PET/CT scanners, one could image better (e.g. reconstruct at higher resolution and detect smaller lesions), image faster, image longer after tracer injection, and image gently (e.g., at a much lower radiopharmaceutical dose than usual, which will enable more PET scans in the children population, as well as more repeated scans in the adult population) [1].

In the July issue of *European Journal of Nuclear Medicine and Molecular Imaging*, a superbly designed and executed study on the first clinical implementation of a LAFOV PET/CT scanner was reported by Dr. Rominger and colleagues from Bern University Hospital, University of Bern, Switzerland [5]. This is a prospective, non-randomized, dual-arm crossover, comparative imaging study with a clearly stated hypothesis and inclusion/exclusion criteria. The number of patients needed for the study (> 40) was calculated to provide robust statistical analysis. In addition, three PET tracers (^{18}F-FDG, ^{18}F-PSMA-1007, and ^{68}Ga-DOTA-TOC) and 2 PET isotopes (^{18}F and ^{68}Ga) were investigated, in order for the study to be more broadly applicable. The entire work was carried out in a very short time frame: the scanner was installed in October 2020, and the manuscript was received on January 25, 2021. This high efficiency is very impressive, especially considering that the COVID-19 pandemic in Switzerland was at its height during that time, not to mention that this was during the holiday season. While reading this manuscript in detail, one cannot help but think about the art of making Swiss watches. The study could not have been designed nor executed in a better way. Finally, the manuscript itself is highly satisfactory, from the presentation to the figures. All in all, this is an exemplary work on a topic that is truly state-of-the-art, which perfectly suits *EJNMMI*.

Two PET/CT systems from Siemens Healthineers were compared in this study [5]. One is the first Biograph Vision Quadra LAFOV PET/CT system (axial FOV 106 cm), with a sensitivity of ≥ 70 cps/kBq and a time resolution of 219 ps in ultra-high sensitivity mode. The other is the clinically well-established Biograph Vision 600 system (axial FOV 26.3 cm), with a sensitivity of ~ 16 cps/kBq and a time resolution of 214 ps [6]. Standardized doses of 3.5 MBq/kg of ^{18}F-FDG, 250 MBq of ^{18}F-PSMA-1007, or 150 MBq of ^{68}Ga-DOTA-TOC were administered intravenously into patients. Rather than total-body PET/CT scans from head to toe, regular whole-body scans (from skull-base to thighs on the SAFOV Biograph Vision scanner, or vertex to thighs on the LAFOV Biograph Vision Quadra scanner) were performed.

The technical and specific parameters for data acquisition, image reconstruction, data analysis, image interpretation, visual display (e.g., images were cropped to include only "eyes-to-thighs" to minimize differences between captured FOV in both systems to avoid potential bias from the two nuclear medicine physicians), statistical analysis, etc. were presented in exquisite detail in the manuscript, which will not be repeated here. In brief, PET/CT images were acquired

This article is part of the Topical Collection on Technology.

✉ Xiaoli Lan
xiaoli_lan@hust.edu.cn

✉ Weibo Cai
wcai@uwhealth.org

[1] Department of Nuclear Medicine, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China

[2] Hubei Key Laboratory of Molecular Imaging, Wuhan, China

[3] Departments of Radiology and Medical Physics, University of Wisconsin–Madison, Madison, WI, USA

on the SAFOV PET/CT scanner in continuous bed motion (CBM) with a table velocity of 1.1 mm/s, with an effective examination time of 16.06 min to capture a 106 cm FOV. In comparison, PET/CT images were acquired on the LAFOV PET/CT scanner in one-bed position for 10 min, and PET data were sampled to produce sinograms emulating 10-, 6-, 4-, 2-, 1-, and 0.5-min acquisitions. There was no difference between the CT scans for the two systems.

The key findings of this superb study are summarized below: (1) all 153 target lesions in 44 patients were identified in both scanners, with no observed difference. (2) The LAFOV PET/CT scan time that yielded equivalent target lesion integral activity (count statistics) to the 16.06 min SAFOV scan was 1.63 ± 0.19 min. When comparing ^{18}F- vs ^{68}Ga-based tracers for the LAFOV system, ^{18}F performed better (~ 1.5 vs ~ 2.3 min), which is expected since ^{18}F has much better decay characteristics for PET imaging than ^{68}Ga. (3) Signal-to-noise ratio (SNR) was the highest for long-duration (i.e., 10 min) LAFOV images, and equivalency between the LAFOV and SAFOV (16.06 min scan) was seen at 1.83 ± 1.00 min. (4) Target lesion-to-background ratio (TBR) was slightly better on the LAFOV at 10 min (mean value 2.27 ± 0.02) than the SAFOV (mean value 2.06 ± 0.02), although there was no statistically significant difference. (5) Ten-minute LAFOV PET images showed superior quality than 16.06 min SAFOV images, while those that showed equivalent quality (as the 16.06 min SAFOV PET images) had average scan times of about 1.5–2 min on the LAFOV scanner. Importantly, 0.5-min acquisitions on the LAFOV system did provide visualization of all target lesions and demonstrated acceptable quality for diagnostic purposes. (6) To achieve equivalent lesion measured integral activity as the SAFOV reference (16.06 min scan in CBM), if the LAFOV examination is maintained at 10 min, an approximately sixfold reduction in the injected tracer dose could be used, which can lead to ~ sixfold lower equivalent radiation dose (< 1 mSv vs. ~ 5 mSv for standard PET tracer dose). It is worth noting that these results were achieved on the LAFOV PET/CT scanner using a maximum ring difference (MRD) of 85. There is further potential to reduce imaging time and/or injected radioactivity with the ultra-high sensitivity mode (which has a MRD of 322, available now but not available at the time of this study), which has higher sensitivity (≥ 150 cps/kBq) than the LAFOV Biograph Vision Quadra scanner (≥ 70 cps/kBq) but the same time resolution.

One cannot talk about this LAFOV PET/CT scanner without mentioning the uEXPLORER PET/CT scanner (United Imaging Healthcare Co., Ltd.). In May 2018, the first total-body PET scanner was built by a consortium with aid from several industrial collaborators, which has a 194 cm axial FOV for PET imaging [4, 7]. Of note, the time resolution of the uEXPLORER PET/CT scanner was 430 ps, and the sensitivity based on the NEMA NU-2 phantom was ~ 190 cps/kBq (70-cm length) and ~ 150 cps/kBq (200-cm length) respectively [8]. In November 2018, the first human images from the uEXPLORER scanner were presented at a total-body PET workshop, which were acquired at the Department of Nuclear Medicine, Zhongshan Hospital, Fudan University (Shanghai, China) [4]. Within a short period of time, a series of studies were reported to investigate the potential and future clinical applications of this total-body scanner [4, 9–20]. In one recent study, it was concluded that a fast PET protocol with a 30–45 s acquisition time in the uEXPLORER PET/CT can provide equivalent image quality as the conventional digital uMI 780 PET/CT (United Imaging Healthcare Co., Ltd.) with longer clinical acquisition settings.

There is likely no room for even faster PET scans, which will not be patient-friendly except in some very unusual circumstances (for example, a patient cannot hold still for more than 1 min due to certain diseases). Several reports (including this work [5]) showed that 1-min PET scan or low-dose PET scan had the same diagnostic performance as a typical 5–10 min PET scan with typical injected radiopharmaceutical dose. With the capability of acquiring superb quality PET images (e.g., HD or 4 K) using the LAFOV PET/CT scanner and 10 min (or longer) scan time, it will be very important to investigate whether higher quality PET images will lead to better clinical performance (e.g., diagnostic accuracy and detection of more lesions) than a standard PET scan. That is a critical question to answer, which is eagerly awaited by many in the field of nuclear medicine and molecular imaging, and we look forward to the findings in the near future. If the answer is no, it may dampen the enthusiasm for such LAFOV PET/CT scanner, just like a luxury car does not get one to the destination faster than a normal family car, which is much more affordable and cost-effective for the majority of the human population.

Currently, there is no head-to-head comparison between the 106 cm (Siemens Healthineers, USA) and 194 cm (United Imaging Healthcare Co., Ltd., China) LAFOV PET/CT systems. Both scanners have generally met the performance expectations for such an expensive system. The smaller footprint of the 106 cm LAFOV scanner may allow for easier clinical installation. Since we do not have detailed figures for cost comparison between the two systems, we cannot comment on this aspect, which will certainly be a major consideration when a hospital/institution decides on which system to procure. Another consideration is that bed movement will be needed for the 106-cm LAFOV system to scan the entire body, which may not be necessary for the 194-cm uEXPLORER system. There could be some error or artifacts caused by bed motion. However, such issues could/should be readily corrected with the modern state-of-the-art systems.

In the work of [5], attenuation correction was performed using low-dose non-enhanced CT data. Although the CT dose was not specifically stated, the effective radiation dose associated with this type of low-dose CT scan is approximately 2–3 mSv, which is significantly lower than a typical diagnostic body CT exam and the CT component of a typical modern PET/CT exam (~5–10 mSv) [21–23]. With the constant advancements of CT tube and detector technologies [24], as well as artificial intelligence (AI)-based CT dose reduction technologies (e.g., TrueFidelity Deep Learning Image Reconstruction from GE Healthcare [25, 26] and Advanced Intelligent Clear-IQ Engine from Canon Medical Systems USA Inc. [27–29]), it is very likely that the CT component of LAFOV PET/CT exam will be further reduced to the sub-mSv level in the near future, which means the entire whole-body PET/CT exam with a low dose of injected PET tracer can be achieved below 2 mSv. This will provide unprecedented possibilities for a variety of clinical scenarios such as longitudinal PET/CT scans of (cancer) patients to monitor the therapeutic response [30–32], routine PET/CT scans of non-cancer patients [33–36], and repeated scans in pediatric patients [37], among others.

Many aspects of the LAFOV PET/CT scanner deserve to be further explored in the future. For example, PET/CT scans with low tracer dose could provide important insight for first-in-human studies of novel tracers by enabling non-invasive whole-body pharmacokinetic analysis in all tissues. This is especially important for ^{11}C-/^{18}F-based tracers that require elaborate and lengthy syntheses, which may have low radiochemical yields and consequently are not amenable to human studies using a conventional PET/CT scanner. We look forward to future studies of many novel PET tracers in the metastatic cancer setting. In addition, PET/CT scans at later time points may offer important information, such as differentiating cancer from inflammation based on dual-time-point ^{18}F-FDG PET scans. In a recent study, the same group from Bern, Switzerland, reported that late acquisition ^{68}Ga-PSMA-11 PET/CT using the LAFOV system resulted in improvements in TBR and SNR for clinical diagnosis of recurrent prostate cancer, with only modest impairment in subjective visual imaging quality [38]. For future systematic and routine studies in these areas, scanner performance may not be the limiting factor. Instead, logistics and throughput will be the major considerations especially in medical centers with a high daily clinical workload.

Currently, LAFOV PET/CT scanners are much more expensive than SAFOV PET/CT and only available at a few major medical centers around the world. LAFOV PET is still in its early days, analogous to PET scanners in the 1970s when they were first reported [39, 40]. With continued development and optimization of the PET/CT scanner, as well as cost reduction, we believe LAFOV PET/CT scanners will become widely available in the future, just like PET/CT scanners have replaced PET scanners more than a decade ago [41, 42]. Without any doubt, LAFOV PET/CT scanners hold tremendous potential for becoming an indispensable tool for humankind's ultimate victory over cancer, as well as catalyzing more preclinical/clinical applications in various disciplines (e.g., pediatric disorders, peripheral vascular diseases, tracking of transplanted cells, development of novel pharmaceuticals and radiopharmaceuticals, global disease assessment) [11, 34, 43–46].

Funding The authors are financially supported by the National Natural Science Foundation of China (No. 81630049 and 82030052), the University of Wisconsin—Madison, and the National Institutes of Health (P30CA014520).

Declarations

Conflict of interest Weibo Cai is a scientific advisor, stockholder, and grantee of Focus-X Therapeutics, Inc. All other authors declare no conflict of interest.

Studies with human participants or animals This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Cherry SR, Badawi RD, Karp JS, Moses WW, Price P, Jones T. Total-body imaging: transforming the role of positron emission tomography. Sci Transl Med. 2017;9:eaaf6169. https://doi.org/10.1126/scitranslmed.aaf6169.
2. Cherry SR, Jones T, Karp JS, Qi J, Moses WW, Badawi RD. Total-body PET: maximizing sensitivity to create new opportunities for clinical research and patient care. J Nucl Med. 2018;59:3–12. https://doi.org/10.2967/jnumed.116.184028.
3. Vandenberghe S, Moskal P, Karp JS. State of the art in total body PET. EJNMMI Phys. 2020;7:35. https://doi.org/10.1186/s40658-020-00290-2.
4. Badawi RD, Shi H, Hu P, Chen S, Xu T, Price PM, et al. First human imaging studies with the EXPLORER total-body PET scanner. J Nucl Med. 2019;60:299–303. https://doi.org/10.2967/jnumed.119.226498.
5. Alberts I, Hünermund JN, Prenosil G, Mingels C, Bohn KP, Viscione M, et al. Clinical performance of long axial field of view PET/CT: a head-to-head intra-individual comparison of the biograph vision quadra with the biograph vision PET/CT. Eur J Nucl Med Mol Imaging. 2021;48:2395–404. https://doi.org/10.1007/s00259-021-05282-7.
6. Casey ME, Osborne DR. Siemens Biograph Vision 600. In: Zhang J, Knopp MV, editors. Advances in PET: the latest in instrumentation, technology, and clinical practice. Chambridge: Springer International Publishing; 2020. p. 71–91.
7. Zhang X, Zhou J, Cherry SR, Badawi RD, Qi J. Quantitative image reconstruction for total-body PET imaging using the 2-meter long EXPLORER scanner. Phys Med Biol. 2017;62:2465–85. https://doi.org/10.1088/1361-6560/aa5e46.

8. Spencer BA, Berg E, Schmall JP, Omidvari N, Leung EK, Abdelhafez YG, et al. Performance evaluation of the uEXPLORER total-body PET/CT scanner based on NEMA NU 2–2018 with additional tests to characterize long axial field-of-view PET scanners. J Nucl Med. 2021;62:861–70. https://doi.org/10.2967/jnumed.120.250597.
9. Feng T, Zhao Y, Shi H, Zhang X, Wang G, Badawi RD, et al. Total-body quantitative parametric imaging of early kinetics of FDG. J Nucl Med. 2021;62:738–44. https://doi.org/10.2967/jnumed.119.238113.
10. Sui X, Liu G, Hu P, Chen S, Yu H, Wang Y, et al. Total-body PET/computed tomography highlights in clinical practice: experiences from Zhongshan Hospital Fudan University. PET Clin. 2021;16:9–14. https://doi.org/10.1016/j.cpet.2020.09.007.
11. Tan H, Gu Y, Yu H, Hu P, Zhang Y, Mao W, et al. Total-body PET/CT: current applications and future perspectives. AJR Am J Roentgenol. 2020;215:325–37. https://doi.org/10.2214/ajr.19.22705.
12. Zhang X, Cherry SR, Xie Z, Shi H, Badawi RD, Qi J. Subsecond total-body imaging using ultrasensitive positron emission tomography. Proc Natl Acad Sci USA. 2020;117:2265–7. https://doi.org/10.1073/pnas.1917379117.
13. Zhang X, Xie Z, Berg E, Judenhofer MS, Liu W, Xu T, et al. Total-body dynamic reconstruction and parametric imaging on the uEXPLORER. J Nucl Med. 2020;61:285–91. https://doi.org/10.2967/jnumed.119.230565.
14. Zhang YQ, Hu PC, Wu RZ, Gu YS, Chen SG, Yu HJ, et al. The image quality, lesion detectability, and acquisition time of (18)F-FDG total-body PET/CT in oncological patients. Eur J Nucl Med Mol Imaging. 2020;47:2507–15. https://doi.org/10.1007/s00259-020-04823-w.
15. Nardo L, Abdelhafez YG, Spencer BA, Badawi RD. Clinical Implementation of total-body PET/CT at University of California. Davis PET Clin. 2021;16:1–7. https://doi.org/10.1016/j.cpet.2020.09.006.
16. Zhao YM, Li YH, Chen T, Zhang WG, Wang LH, Feng J, et al. Image quality and lesion detectability in low-dose pediatric (18)F-FDG scans using total-body PET/CT. Eur J Nucl Med Mol Imaging. 2021. https://doi.org/10.1007/s00259-021-05304-4.
17. Hu P, Lin X, Zhuo W, Tan H, Xie T, Liu G, et al. Internal dosimetry in F-18 FDG PET examinations based on long-time-measured organ activities using total-body PET/CT: does it make any difference from a short-time measurement? EJNMMI Phys. 2021;8:51. https://doi.org/10.1186/s40658-021-00395-2.
18. Spencer BA, Berg E, Schmall JP, Omidvari N, Leung EK, Abdelhafez YG, et al. Performance evaluation of the uEXPLORER total-body PET/CT scanner based on NEMA NU 2–2018 with additional tests to characterize PET scanners with a long axial field of view. J Nucl Med. 2021;62:861–70. https://doi.org/10.2967/jnumed.120.250597.
19. Hu P, Zhang Y, Yu H, Chen S, Tan H, Qi C, et al. Total-body (18)F-FDG PET/CT scan in oncology patients: how fast could it be? Eur J Nucl Med Mol Imaging. 2021;48:2384–94. https://doi.org/10.1007/s00259-021-05357-5.
20. Tan H, Sui X, Yin H, Yu H, Gu Y, Chen S, et al. Total-body PET/CT using half-dose FDG and compared with conventional PET/CT using full-dose FDG in lung cancer. Eur J Nucl Med Mol Imaging. 2021;48:1966–75. https://doi.org/10.1007/s00259-020-05091-4.
21. Martí-Climent JM, Prieto E, Morán V, Sancho L, Rodríguez-Fraile M, Arbizu J, et al. Effective dose estimation for oncological and neurological PET/CT procedures. EJNMMI Res. 2017;7:37. https://doi.org/10.1186/s13550-017-0272-5.
22. Hemke R, Yang K, Husseini J, Bredella MA, Simeone FJ. Organ dose and total effective dose of whole-body CT in multiple myeloma patients. Skeletal Radiol. 2020;49:549–54. https://doi.org/10.1007/s00256-019-03292-z.
23. McCollough CH, Bushberg JT, Fletcher JG, Eckel LJ. Answers to common questions about the use and safety of CT scans. Mayo Clin Proc. 2015;90:1380–92. https://doi.org/10.1016/j.mayocp.2015.07.011.
24. McCollough CH, Chen GH, Kalender W, Leng S, Samei E, Taguchi K, et al. Achieving routine submillisievert CT scanning: report from the summit on management of radiation dose in CT. Radiology. 2012;264:567–80. https://doi.org/10.1148/radiol.12112265.
25. Greffier J, Hamard A, Pereira F, Barrau C, Pasquier H, Beregi JP, et al. Image quality and dose reduction opportunity of deep learning image reconstruction algorithm for CT: a phantom study. Eur Radiol. 2020;30:3951–9. https://doi.org/10.1007/s00330-020-06724-w.
26. Park C, Choo KS, Jung Y, Jeong HS, Hwang JY, Yun MS. CT iterative vs deep learning reconstruction: comparison of noise and sharpness. Eur Radiol. 2021;31:3156–64. https://doi.org/10.1007/s00330-020-07358-8.
27. Naganawa S, Nakamichi R, Ichikawa K, Kawamura M, Kawai H, Yoshida T, et al. MR imaging of endolymphatic hydrops: utility of iHYDROPS-Mi2 combined with deep learning reconstruction denoising. Magn Reson Med Sci. 2020. https://doi.org/10.2463/mrms.mp.2020-0082.
28. Singh R, Digumarthy SR, Muse VV, Kambadakone AR, Blake MA, Tabari A, et al. Image quality and lesion detection on deep learning reconstruction and iterative reconstruction of submillisievert chest and abdominal CT. AJR Am J Roentgenol. 2020;214:566–73. https://doi.org/10.2214/ajr.19.21809.
29. Ueda T, Ohno Y, Yamamoto K, Iwase A, Fukuba T, Hanamatsu S, et al. Compressed sensing and deep learning reconstruction for women's pelvic MRI denoising: utility for improving image quality and examination time in routine clinical practice. Eur J Radiol. 2020;134: 109430. https://doi.org/10.1016/j.ejrad.2020.109430.
30. Paul DM, Ghiuzeli CM, Rini J, Palestro CJ, Fung EK, Ghali M, et al. A pilot study treatment of malignant tumors using low-dose (18)F-fluorodeoxyglucose ((18)F-FDG). Am J Nucl Med Mol Imaging. 2020;10:334–41.
31. Borra A, Morbelli S, Zwarthoed C, Bianchi A, Bergesio F, Chauvie S, et al. Dual-point FDG-PET/CT for treatment response assessment in Hodgkin lymphoma, when an FDG-avid lesion persists after treatment. Am J Nucl Med Mol Imaging. 2019;9:176–84.
32. Bois F, Noirot C, Dietemann S, Mainta IC, Zilli T, Garibotto V, et al. [(68)Ga]Ga-PSMA-11 in prostate cancer: a comprehensive review. Am J Nucl Med Mol Imaging. 2020;10:349–74.
33. Asadollahi S, Rojulpote C, Bhattaru A, Patil S, Gonuguntla K, Karambelkar P, et al. Comparison of atherosclerotic burden in non-lower extremity arteries in patients with and without peripheral artery disease using (18)F-NaF-PET/CT imaging. Am J Nucl Med Mol Imaging. 2020;10:272–8.
34. Brandão SCS, Ramos JOX, de Arruda GFA, Godoi E, Carreira L, Lopes RW, et al. Mapping COVID-19 functional sequelae: the perspective of nuclear medicine. Am J Nucl Med Mol Imaging. 2020;10:319–33.
35. Zadeh MZ, Seraj SM, Østergaard B, Mimms S, Raynor WY, Aly M, et al. Prognostic significance of (18)F-sodium fluoride in newly diagnosed multiple myeloma patients. Am J Nucl Med Mol Imaging. 2020;10:151–60.
36. Zhang V, Borja AJ, Rojulpote C, Padmanabhan S, Patil S, Gonuguntla K, et al. Global quantification of pulmonary artery atherosclerosis using (18)F-sodium fluoride PET/CT in at-risk subjects. Am J Nucl Med Mol Imaging. 2020;10:119–26.
37. Masselli G, De Angelis C, Sollaku S, Casciani E, Gualdi G. PET/CT in pediatric oncology. Am J Nucl Med Mol Imaging. 2020;10:83–94.

38. Alberts I, Prenosil G, Mingels C, Bohn KP, Viscione M, Sari H, et al. Feasibility of late acquisition [68Ga]Ga-PSMA-11 PET/CT using a long axial field-of-view PET/CT scanner for the diagnosis of recurrent prostate cancer-first clinical experiences. Eur J Nucl Med Mol Imaging. 2021. https://doi.org/10.1007/s00259-021-05438-5.
39. Phelps ME, Hoffman EJ, Mullani NA, Ter-Pogossian MM. Application of annihilation coincidence detection to transaxial reconstruction tomography. J Nucl Med. 1975;16:210–24.
40. Ter-Pogossian MM, Phelps ME, Hoffman EJ, Mullani NA. A positron-emission transaxial tomograph for nuclear imaging (PETT). Radiology. 1975;114:89–98. https://doi.org/10.1148/114.1.89.
41. Beyer T, Townsend DW, Czernin J, Freudenberg LS. The future of hybrid imaging-part 2: PET/CT. Insights Imaging. 2011;2:225–34. https://doi.org/10.1007/s13244-011-0069-4.
42. Townsend D, Beyer T, Czernin J. 20 years of PET/CT: a conversation with David Townsend and Thomas Beyer. J Nucl Med. 2020;61:1541–3. https://doi.org/10.2967/jnumed.120.257725.
43. Kung BT, Seraj SM, Zadeh MZ, Rojulpote C, Kothekar E, Ayubcha C, et al. An update on the role of (18)F-FDG-PET/CT in major infectious and inflammatory diseases. Am J Nucl Med Mol Imaging. 2019;9:255–73.
44. Wei W, Ehlerding EB, Lan X, Luo QY, Cai W. Molecular imaging of β-cells: diabetes and beyond. Adv Drug Deliv Rev. 2019;139:16–31. https://doi.org/10.1016/j.addr.2018.06.022.
45. Wei W, Rosenkrans ZT, Liu J, Huang G, Luo QY, Cai W. ImmunoPET: concept, design, and applications. Chem Rev. 2020;120:3787–851. https://doi.org/10.1021/acs.chemrev.9b00738.
46. Saboury B, Morris MA, Nikpanah M, Werner TJ, Jones EC, Alavi A. Reinventing molecular imaging with total-body PET, part II: clinical applications. PET Clin. 2020;15:463–75. https://doi.org/10.1016/j.cpet.2020.06.013.