Halo Artifacts of Indwelling Urinary Catheter by Inaccurate Scatter Correction in 18F-FDG PET/CT Imaging: Incidence, Mechanism, and Solutions

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Abstract
Background Halo artifacts from a urinary catheter due to inaccurate scatter correction can cause significantly reduced tumor visibility in 18F-FDG PET/CT images. We investigated the incidence and mechanism of halo-artifact generation, and we attempted to establish appropriate scatter correction techniques to reduce artifacts.

Methods We first retrospectively reviewed patients with urinary catheters who were undergoing 18F-FDG PET/CT scans. Halo artifacts on the PET images were visually assessed with a standard scatter correction based on a tail-fitted single-scatter simulation (TF-SSS) using 4-mm voxel μ-maps (TFS 4-mm). We then performed phantom studies to reproduce the appearance of halo artifacts and evaluate scatter correction techniques regarding halo-artifact suppression. We measured the standardized uptake values (SUVs) to quantitatively assess the PET images. The scatter correction also used TF-SSS with 2-mm voxel μ-maps (TFS 2-mm) and a Monte Carlo-based single-scatter simulation (MC-SSS). Finally, we investigated whether TFS 2-mm and MC-SSS can be applied to patient data.

Results There were 61 patients with urinary catheters; in five, halo artifacts were observed in the TFS 4-mm images. The phantom study clearly demonstrated the appearance of halo artifacts. The SUVs for the TFS 4-mm and TFS 2-mm images were underestimated at the halo-artifact regions, whereas the SUV for the MC-SSS images became the true value (SUV = 1). In four of the five patients, halo artifacts were not present in the TFS 2-mm images. In all five patients, halo artifacts were absent in the MC-SSS images. The patient and phantom studies demonstrated that halo artifacts were caused by overestimates of the scatters due to mismatch by urine movement in the interval between the CT and the PET scan, or by the partial volume effect and downsizing in the converting process from the CT images to the μ-maps.

Conclusions Halo artifacts were due to the mismatch between the μ-maps and PET images, which induces the scatter correction error. With the TF-SSS, halo artifacts were improved by using a small voxel size for the μ-maps, but the artifacts remained in one case. With the MC-SSS, it was possible to accurately estimate the scatters without generating halo artifacts.

Introduction
Positron emission tomography/computed tomography (PET/CT) is useful for the assessment and management of many types of cancer including their diagnosis, staging, prognosis, and therapeutic efficacy. $^{18}$F-fluorodeoxyglucose (FDG) PET/CT in particular has become an important tool for identifying new and effective therapies in cancer treatment and for its role as an imaging biomarker [1, 2].

The main excretion pathway of $^{18}$F-FDG is through the kidneys, ureters, and bladder, and this makes it difficult to adequately visualize pelvic tumors by using filtered back-projection images because streak artifacts may appear in the pelvis. Such streak artifacts can be reduced by an iterative reconstruction algorithm [3], but when other radiotracers with renal excretion are used (e.g., $^{68}$Ga-labeled prostate-specific membrane antigen [PSMA]) [4], photopenic artifacts surround the kidneys and the bladder even in iterative reconstruction images [5, 6]. These are so-called halo artifacts and could potentially mask primary tumors and local recurrences.

The appearance of the halo artifacts is caused by inaccurate scatter correction in the most commonly used algorithm [7, 8], which is a tail-fitted single-scatter simulation (TF-SSS) [9–11]. In $^{68}$Ga-PSMA PET/CT imaging, scatter correction becomes inaccurate due to errors in both the scatter estimate by the single-scatter simulation (SSS) and the scaling factor calculation by a fitting process [7, 8]. The possibility of the artifact appearance can be reduced by oral hydration, and by suppressing the urination urge by administering of a diuretic before positron emission tomography (PET) imaging [12], and by urine drainage using an indwelling urinary catheter into the bladder. This procedure is particularly important for the identification of pelvic tumors such as colorectal and bladder cancers [13, 14].

We have observed an artifact that is different from those caused by scatter correction error in the $^{18}$F-FDG PET/CT images for patients with an indwelling urinary catheter. This artifact is a type of halo artifact that appears in the region where the urinary catheter is present. To the best of our knowledge, this artifact has not been comprehensively studied or reported. Because the artifact obliterates the true $^{18}$F-FDG uptake, the presence of a malignant tumor may not be detected, and an
accurate quantitative evaluation such as the standardized uptake value (SUV) measurements can be impossible.

Herein, we retrospectively evaluated the patients with urinary catheters who were undergoing $^{18}$F-FDG PET/CT scans, in order to determine the presence and incidence of halo artifacts and provide clinical examples. To clarify the mechanism underlying the artifacts, we performed phantom studies simulating $^{18}$F-FDG PET/CT imaging with urinary catheters, and we propose steps to take to eliminate the halo artifacts by considering the $\mu$-map voxel size and scatter correction algorithm. We also investigated whether this approach can be applied to clinical patient data. The study was conducted to better understand the halo artifact and to establish an appropriate method to correct the scatters in order to reduce the halo artifacts generation in the $^{18}$F-FDG PET/CT imaging of patients with an indwelling urinary catheter.

Materials And Methods
A Gemini TF PET/CT scanner (Philips Healthcare, Cleveland, Ohio) was used for all imaging [15]. The coincidence and energy windows were used at their fixed setting of 3.8 nsec and 460–665 keV, respectively. The acquisition was in three-dimensional mode only.

Patient Study 1
We retrospectively analyzed patient data to identify characteristics of artifact generation and to investigate the incidence of artifacts. The evaluations included all of the whole-body $^{18}$F-FDG PET/CT data of the patients with indwelling urinary catheters who were scanned at our institution during the period from June 2013 to January 2020.

The PET/CT scans were performed following our standard protocol. $^{18}$F-FDG (4.5 MBq/kg) was injected after a $\geq$ 6-hr fast by the patient, although oral hydration with glucose-free water was allowed. For each patient, computed tomography (CT) was performed for attenuation and scatter corrections, and then a PET scan was performed from the mid-femur or toes to the top of the head. The PET acquisition time was 1–2 min/bed position.

For the PET image reconstruction, the three-dimensional blob-based iterative list-mode ordered-subset expectation maximization algorithm with time-of-flight information was used under the
following conditions: iterations, 3; subsets, 33; blob increment, 2.0375 voxels; blob radius, 2.5 voxels; blob shape parameter alpha, 8.3689; relaxation parameter, 0.7. All PET images were corrected for attenuation and scatter by using μ-maps converted from the CT images and resampled to isotropic 4-mm voxels, which matched the μ-maps. The scatter correction algorithm was TF-SSS (TFS 4-mm) [11, 16], which is the default setting in this scanner. Images with attenuation correction but non-scatter-correction (NSC) were also reconstructed. The image matrix size was 144 × 144 pixels for the 576-mm field of view (FOV). All reconstructions were performed offline using Philips PET reconstruction software. The parameters for the CT imaging were as follows: tube voltage, 120 kVp; tube current, 200 mAs; FOV, 600 mm.

In the visual assessment of halo-artifact generation, by comparing PET images without attenuation/scatter corrections and the CT images, we determined whether motion artifacts by the patient's arms, diaphragm, or urinary catheter were present, and we excluded such artifacts from the evaluation. Images with the urinary catheter located outside of the transverse PET FOV were also excluded. We defined cold regions of consecutive zero-valued voxels that were present in the PET images with urinary catheters shown on the CT images as halo artifacts if their appearance on the scatter-corrected PET images was inconsistent with the NSC images. The evaluation was performed by a single reader using the IntelliSpace Portal (version 5.0.0.20030; Philips Healthcare). We also obtained sinograms of the prompt, scatter, random, and μ-map to measure their radial profiles.

**Phantom Study**

To verify the mechanism of the halo artifacts and to devise improvements to eliminate the halo artifacts, we conducted an experiment to reproduce halo artifacts by using a body phantom of the National Electrical Manufacturers Association (NEMA) with the spherical inserts removed and with urinary catheters.

Referring to the findings of Patient study 1, we identified the following two appearance patterns of halo artifacts.

One pattern was observed in the cases in which there were the urine shifts between the CT imaging and the subsequent PET imaging. This shift may have arisen as the urine in the urinary catheter...
flowed downwards from the upper part of the urinary catheter after the CT imaging. This pattern (hereafter called the 'urine shift pattern') corresponds to the scenario in which urine is not present in the CT scan but appears in the PET scan (CT−/PET+) as in the phantom diagram of Fig. 1A. For comparison, we also set regions at which urine appears in the CT scan but not in the PET scan (CT+/PET−), or no urine was present in the CT and PET scans (CT−/PET−), or urine was present in the CT and PET scans (CT+/PET+).

The second pattern was observed in the cases in which the urinary catheter was arranged in an arc (hereafter referred to as the 'tube curve pattern') and urine is present throughout the urinary catheter. Here, the urinary catheter was placed in a semicircle with a radius of 10 cm at a position 5 cm away from the NEMA body phantom (Fig. 1B). The urinary catheter and the NEMA body phantom were filled with 150 kBq/mL and 3.0 kBq/mL of 18F-FDG solution, respectively. The SUV inside the NEMA body phantom was adjusted to 1. The PET data were acquired at two bed positions (2 min/bed position).

The PET images were reconstructed under the same conditions as those in Patient study 1, with the following two additional conditions: (1) TF-SSS using 2-mm voxel μ-maps (TFS 2-mm) and (2) Philips' own scatter correction method based on a Monte Carlo-based SSS (MC-SSS) using 4-mm voxels μ-maps (MCS 4-mm). The Discussion section and previous studies provide detailed descriptions of the MC-SSS algorithm [17, 18]. The CT imaging parameters were the same as those in Patient study 1.

Sinograms were evaluated as in Patient study 1. We manually set the volume-of-interest for the entire NEMA body phantom to measure the SUV for each slice.

Patient Study 2
Here we applied two image reconstruction settings added in the phantom studies to cases in which halo artifacts appeared. We investigated the presence/absence of halo artifacts using the same evaluations as in Patient study 1.

Results
Patient Study 1
Of the 3,633 whole-body 18F-FDG PET/CT cases at our institute, we identified 61 patients with urinary catheters. Table 1 summarizes the demographics of these patients. Of the 61 patients, five (8.2%)
had halo artifacts caused by the urinary catheter in TFS 4-mm images.

Table 1
Background of the 61 patients with urinary catheters

| Characteristics                  | Description                  |
|----------------------------------|------------------------------|
| Age, yrs                         | 61 (17–87)                   |
| Males/females                    | 32/29                        |
| Body weight, kg                  | 57 (28–90)                   |
| Blood sugar, mg/dL               | 117 (67–157)                 |
| 18F-FDG injection dose, MBq      | 254 (128–415)                |
| Diagnosis, no. of patients:      |                              |
| Malignant lymphoma               | 17                           |
| Brain tumor                      | 10                           |
| Spinal tumor                     | 10                           |
| Bladder cancer                   | 6                            |
| Fever of unknown origin          | 6                            |
| Colorectal cancer                | 2                            |
| Lung cancer                      | 2                            |
| Extramammary Paget disease       | 2                            |
| Cancer of unknown primary origin | 2                            |
| Kidney cancer                    | 1                            |
| Ovarian cancer                   | 1                            |
| Laryngeal cancer                 | 1                            |
| Subcutaneous tumor               | 1                            |

Data are the number or average (range).

Figures 2 and 3 illustrate two representative cases. In both cases, the scatters were overestimated (Fig. 4A,B), and thus a halo artifact was identified on the TFS 4-mm images, but no halo artifacts were present on the NSC images.

Reviewing the µ-maps of the two cases, urinary catheters were absent on the 4-mm voxel µ-maps. The urine in the catheter was not visible in the CT image (yellow arrow in Fig. 2A), and not present on the µ-maps (Fig. 2B). However, the PET images showed the urine (red arrows in Fig. 2C). This suggests that there is a mismatch between the µ-maps and the PET images, and this mismatch may be ascribed to the urine in the urinary catheter having shifted in the interval between the CT imaging and the PET imaging (urine shift pattern). Figure 3 shows the presence of a urinary catheter and urine in both the CT and PET images (red arrows in Fig. 3A,C), but the urinary catheter and urine are absent in the 4-mm voxel µ-map (Fig. 3B), leading to the mismatch between the µ-maps and the PET images. This mismatch occurred for a case with the urinary catheter placed in an arc (blue arrow in Fig. 3C). Four cases including the one illustrated in Fig. 3 showed a similar phenomenon, i.e., the tube curve pattern.

Phantom Study
We developed an experimental approach to accommodate the phenomenon that occurred in Patient
Figure 5 shows phantom images that simulate the mismatch due to urine shift. The region with the mismatch between the CT images (µ-maps) and the PET images identified in Patient study 1 corresponds to the second urinary catheter region from the left in Fig. 5. No $^{18}$F-FDG solution was added to the urinary catheter showing in the CT image, and this urinary catheter was not visualized in the µ-maps. However, the PET images showed the $^{18}$F-FDG solution, suggesting that there is the mismatch between the µ-maps and the PET images, as in Patient study 1.

The TFS 4-mm image of this pattern overestimated the scatters (Fig. 4C), resulting in the presence of halo artifacts. The SUV was < 0.5 and was underestimated here (slices 30–100 in Fig. 6A). Halo artifacts also appeared in the TFS 2-mm image. The urinary catheter was not shown in the 2-mm voxel µ-map, causing the mismatch and the scatters to be overestimated. By contrast, in the MCS 4-mm image, the scatters were correctly estimated (Fig. 4C) and no artifact appeared, resulting in a correct evaluation of the SUV (Fig. 6A). No artifact appeared in other regions (CT-/PET-, CT+/PET-, CT+/PET+) with the scatters accurately estimated, and the SUV at these regions was 1 (Fig. 6A, Supplemental Fig. 1).

Figure 7 provides phantom images that simulate the mismatch caused by the tube curve. The region of the arc-shaped urinary catheter appears in the CT image but not on the 4-mm voxel µ-map. This resulted in mismatch with the PET image. The TFS 4-mm image overestimated the scatters (Fig. 4D), resulting in the presence of halo artifacts. The SUV was close to zero and was underestimated here (slices 110–180 in Fig. 6B). By contrast, no halo artifact appeared in the TFS 2-mm image. Here the urinary catheter was clearly depicted in the 2-mm voxel µ-map, and the scatters were correctly evaluated without any mismatch (Fig. 4D). In the MCS 4-mm image, the scatters were also correctly evaluated (Fig. 4D), and no halo artifact appeared. Since there was no halo artifact, the SUVs for the TFS 2-mm and MCS 4-mm images became 1 in all catheter regions (Fig. 6B).

Patient Study 2
We investigated whether the artifacts could be improved by TFS 2-mm and MCS 4-mm images in cases in which halo artifacts had appeared in the TFS 4-mm images.
In the urine shift pattern, the urinary catheter was not depicted in the 2-mm voxel μ-map (Fig. 2B), and there was a mismatch between the μ-maps and the PET images as with the TFS 4-mm images. The result was that the scatters were overestimated, and the halo artifact remained (Figs. 2C, 4A).

In the tube curve pattern, the urinary catheter was depicted in the 2-mm voxel μ-map, and this eliminated the mismatch (Fig. 3B). The result was that the scatters were correctly evaluated, and no halo artifact appeared here (Figs. 3C, 4B).

The MCS 4-mm image also correctly evaluated the scatters in both patterns, and there were no halo artifacts (Figs. 2C, 3C, 4A,B).

Discussion

We have described halo artifacts caused by an indwelling urinary catheter in 18F-FDG PET/CT imaging that can potentially complicate tumor assessments in artifact-hampered regions. The results of our patient and phantom studies demonstrated that scatter correction errors are a cause of halo artifacts. It was established that the halo artifacts appear in the TF-SSS images when there is a urine-detection mismatch between the μ-maps and the PET images. The halo artifacts were improved when the μ-map voxel size was reduced, but the halo artifacts remained in one case. With the MC-SSS method, it was possible to conduct accurate scatter correction without generating halo artifacts in all cases, indicating that it is possible to improve the accuracy of the diagnoses of tumor presence and quantitative analyses.

The scatter correction algorithm currently used in PET/CT scanners is the TF-SSS method. An SSS is an analytical method to estimate the scatter contribution derived from the activity distribution and attenuation map. However, the scatter contribution from multiple scatters and activities located outside the FOV are not considered. The scaling factor that is estimated using the tail part on the scatter sinogram is assumed to include only the contribution of scatter. The scatter contribution determined by the SSS is compensated by scaling it to match the measured sinogram [11]. The tail part on the sinogram is identified by a mask from the μ-maps. Therefore, obtaining accurate scatter corrections by the TF-SSS depends on whether it is possible to accurately detect the tail part on the μ-maps. As shown in this study, the identification of the tail part is inaccurate when there is a mismatch...
between the μ-maps and PET images. Consequently, errors occur in the fitting process, and the scatters will be overestimated.

When the scatter estimate exceeds the measured prompts, many pixels on the sinogram have negative values. In general, in an iterative reconstruction algorithm, negative values are converted to zero values due to sinogram non-negativity constraints. This is the cause of low SUVs in PET images with halo artifacts.

An MC-SSS is a combination of the SSS with the technique of scaling the results of the SSS using the scaling factor calculated by a Monte-Carlo simulation [17, 18]. In the calculation of this scaling factor, only the ratio of the total scattered events and the total true plus scattered events is required. Because there is no need to identify the tail part on the μ-maps, this technique results in an absence of artifacts even with a mismatch between the μ-maps and PET images.

It has been reported that artifacts in $^{15}$O-gas brain PET imaging are caused by a phenomenon similar to that observed herein [18]. This arises from the mismatch between the μ-maps and PET images when the patient's face mask that is used to collect exhaled breath containing $^{15}$O-gas has 'disappeared' from the μ-maps [18]. The urinary catheters examined in the present study are made of a material that is very similar to the face mask: 1-mm-thick vinyl chloride. Thin materials with low attenuation coefficients (e.g., face mask and urinary catheter) tend to disappear on the μ-maps. Since μ-maps are smoothed by downsizing to match the PET voxel size and by Gaussian filtering [19], the μ-maps are affected by the partial volume effect.

In the tube curve pattern, the urinary catheter was not depicted on the 4-mm voxel μ-maps (Figs. 3B, 7B). This may be because the urinary catheter could have disappeared during the downsizing process when the urinary catheter is positioned three-dimensionally in an oblique direction with respect to the data matrix. In the 2-mm voxel μ-maps, the influence of the partial volume effect is reduced, and the urinary catheter would be depicted.

In the TFS 4-mm images of the urine shift pattern, we found that the SUV was slightly underestimated at the slice positions 150–180 (Fig. 6). The reason for this underestimation could be because there
was a mismatch between the µ-maps and PET images due to spillover from the CT+/PET + region to locations without the urinary catheter (slices 165-180).

Additional tests using other PET/CT scanners may be necessary, but the halo artifact will appear because the scatter correction algorithm used by many other vendors is the TF-SSS. Since the urine shift pattern is based on a mechanism that does not depend on the voxel size of the µ-map, it is reasonable to assume that the halo artifacts will appear on other PET/CT scanners. The appearance of halo artifacts in the tube curve pattern depends on the voxel size of the µ-maps. However, few details of the conversion process from the CT image to the µ-map have been published, and the halo artifacts may appear with any PET/CT scanner.

A feasible method to prevent the appearance of halo artifacts in the TF-SSS images is to make the scanners recognize that the body contour and the urinary catheter are located in the same spatial position by attaching the urinary catheter to the patient's skin surface (Supplemental Fig. 2). However, even with this method, a further artifact due to an accumulation of a sufficient amount of urine may interfere with the tumor detection [3]. An additional problem remains; the medical staff attaching the urinary catheter will be exposed to radiation.

The appearance of halo artifacts due to urinary catheters is rare, but our present findings indicate that the influence of image defects due to halo artifacts is significant, as the artifacts can make it impossible to diagnose tumors. In clinical settings, it would be possible to diagnose the presence of a tumor at the region where halo artifacts have appeared by referring to NSC images. However, with NSC images quantitative values such as the SUV cannot be measured. Scatter makes linearity between the image count and the true radioactivity concentration decrease. Therefore, scatter correction by an accurate estimation of scatters is essential for quantitative PET images [20]. Providing PET images that are improved by scatter correction for halo artifacts will reduce the likelihood of false-negative diagnoses of tumors and will contribute to accurate quantitative analyses.

Conclusion

Halo artifacts arose due to a mismatch between the µ-maps and PET images, and this mismatch induces errors in the scatter correction. With the TF-SSS method, the halo artifact was improved when
the μ-map voxel size was reduced, but the artifacts remained in one case. With the MC-SSS method, it was possible to conduct an accurate scatter correction without generating halo artifacts in all cases, suggesting that it is possible to improve the accuracy of both diagnoses of tumor presence and quantitative analyses.

Abbreviations

PET/CT
positron emission tomography/computed tomography; FDG:fluorodeoxyglucose; PSMA:prostate-specific membrane antigen; TF-SSS:tail-fitted single-scatter simulation; SSS:single-scatter simulation; PET:positron emission tomography; SUV:standardized uptake value; CT:computed tomography; TFS 4-mm:tail-fitted single-scatter simulation using 4-mm voxel μ-maps; NSC:non-scatter-correction; FOV:field of view; NEMA:National Electrical Manufacturers Association; TFS 2-mm:tail-fitted single-scatter simulation using 2-mm voxel μ-maps; MC-SSS:Monte Carlo-based single-scatter simulation; MCS-4mm:Monte Carlo-based single-scatter simulation using 4-mm voxels μ-maps

Declarations

Ethics approval and consent to participate

This retrospective study was approved by the Ethics Committee of Hokkaido University Hospital (IRB No. 019-0277) in accordance with 1964 Helsinki declaration and its later amendments or comparable ethical standards. All images were anonymized prior to the analysis. Therefore, the requirement to obtain written informed consent was waived and patients were able to opt out of participation on our hospital website.

Consent for publication

Only anonymized data is published, and therefore no consent was obtained. See paragraph above.

Availability of data and material

The datasets used and/or analyzed in this study are available from the corresponding author on reasonable request.

Competing interests

This work was supported in part by, and the Windows-PC for the reconstruction for the PET images at the Hokkaido University was funded through a sponsored research agreement with Philips Healthcare.
DS and PM are employee of Philips Japan and Philips Healthcare, respectively. Only non-Philips employees have control of any data that might present a conflict of interest for employees. All other authors have no conflict of interest to disclose.

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Authors’ contributions
Guarantors of integrity of entire study: TS; Study concepts/study design or data analysis/interpretation: KM, NN, JK, YM, KeK, OM, KH, UT, KoK, TS; Manuscript drafting or manuscript revision for important intellectual content: all authors; Clinical studies: KM, NN, JK, YM, KeK, OM, KH, KoK; Experimental studies: KM, NN, JK, YM; All authors read and approved the final manuscript.

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Figures
Figure 1

The phantom studies. Urine shift pattern (A). Tube curve pattern (B).
Figure 2

Representative PET images of a patient (urine shift pattern). CT image (A), 4-mm and 2-mm voxel μ-maps (B), PET images with non-scatter-correction (NCS), TFS 4-mm, TFS 2-mm and MCS 4-mm (C). Yellow arrowhead: urinary catheter. Red arrowheads: urine in the urinary catheter. Blue arrowheads: halo artifacts.
Representative PET images of a patient (tube curve pattern). CT image (A), 4-mm and 2-mm voxel $\mu$-maps (B), PET images with non-scatter-correction (NSC), TFS 4-mm, TFS 2-mm and MCS 4-mm (C). Red arrowheads: urinary catheter with urine. Blue arrowhead: halo artifact.
Figure 4

Sinogram profiles on halo-artifact regions from a randoms-corrected emission sinogram (thick black solid line), transmission sinogram mask (thin black solid line: 4-mm voxel, thin black dotted line: 2-mm voxel), and scatter sinogram (red solid line: TFS 4-mm, green solid line: TFS 2-mm, blue solid line: MCS 4-mm). Patient data are shown in A and B. Phantom data are shown in C and D. A and C are the urine shift pattern. B and D are the tube curve pattern.
Figure 5

Sagittal images of a phantom (urine shift pattern). CT image (A), 4-mm and 2-mm voxel μ-maps (B), PET images with non-scatter-correction (NCS), TFS 4-mm, TFS 2-mm and MCS 4-mm (C). Yellow arrowhead: urinary catheter in a CT-/PET+ region. Red arrowheads: 18F-FDG solution in a urinary catheter in a CT-/PET+ region.
Figure 6

Average SUV per slice of phantom images for the urine shift pattern (A) and the tube curve pattern (B). The origin (x-axis) of the slice position corresponds to the left limit of the phantom in sagittal images from Figs. 5C and 7C. Red line: TFS 4-mm, green line: TFS 2-mm, blue line: MCS 4-mm. Black dots in B show the tube angle defined in Fig. 1B.
Sagittal images of a phantom (tube curve pattern). CT image (A), 4-mm and 2-mm voxel μ-maps (B), PET images with non-scatter-correction (NCS), TFS 4-mm, TFS 2-mm and MCS 4-mm (C). Red arrowheads: 18F-FDG solution in the urinary catheter.

Supplementary Files
This is a list of supplementary files associated with this preprint. Click to download.

Supplemental Figure1.tif
Supplemental figure2.tif