



# Comparison of image quality and lesion detection between digital and analog PET/CT

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## Abstract

**Objective** The purpose of this study was to compare image quality and lesion detection capability between a digital and an analog PET/CT system in oncological patients.

**Materials and methods** One hundred oncological patients (62 men, 38 women; mean age of  $65 \pm 12$  years) were prospectively included from January–June 2018. All patients, who accepted to be scanned by two systems, consecutively underwent a single day, dual imaging protocol (digital and analog PET/CT). Three nuclear medicine physicians evaluated image quality using a 4-point scale (−1, poor; 0, fair; 1, good; 2, excellent) and detection capability by counting the number of lesions with increased radiotracer uptake. Differences were considered significant for a  $p$  value  $< 0.05$ .

**Results** Improved image quality in the digital over the analog system was observed in 54% of the patients ( $p = 0.05$ , 95% CI, 44.2–63.5). The percentage of interrater concordance in lesion detection capability between the digital and analog systems was 97%, with an interrater measure agreement of  $\kappa = 0.901$  ( $p < 0.0001$ ). Although there was no significant difference in the total number of lesions detected by the two systems (digital:  $5.03 \pm 10.6$  vs. analog:  $4.53 \pm 10.29$ ;  $p = 0.7$ ), the digital system detected more lesions in 22 of 83 of PET+ patients (26.5%) ( $p = 0.05$ , 95% CI, 17.9–36.7). In these 22 patients, all lesions detected by the digital PET/CT (and not by the analog PET/CT) were  $< 10$  mm.

**Conclusion** Digital PET/CT offers improved image quality and lesion detection capability over the analog PET/CT in oncological patients, and even better for sub-centimeter lesions.

**Keywords** Digital PET/CT · Analog PET/CT · Lesion detection capability · Image quality

## Introduction

The state of the art of PET/CT consists of digital detectors with higher detection capability, which may enhance the diagnostic performance [1], lesion assessment and quantification of burden disease [2]. The higher detection of digital systems compared to analog systems lies in the different scintillator element coupling technology. In analog systems, multiple scintillation crystals are coupled to multiple detectors, while in

digital systems each scintillation crystal is coupled to a single detector. This 1:1 counting coupling of digital systems provides an enhanced time-of-flight (TOF) and lower dead time, as well as higher timing and spatial resolution [3–6]. These properties may potentially have a significant clinical impact, and translate to greater accuracy in the staging and treatment monitoring of oncological diseases. Therefore, the aim of our study was to compare image quality and lesion detection capability between digital and analog PET/CT systems in oncological patients.

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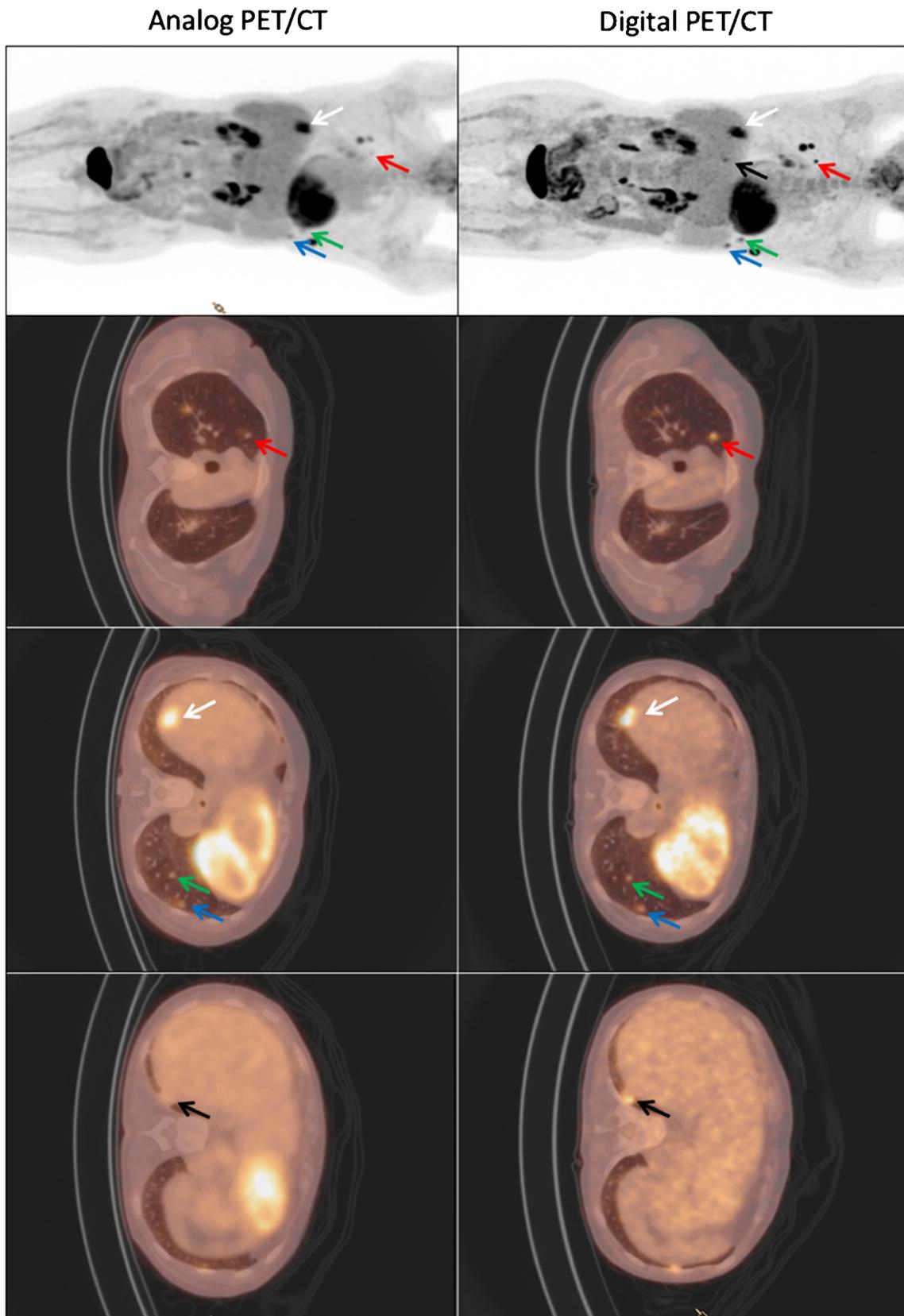
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## Materials and methods

### Patients, imaging protocol and PET/CT acquisition

This prospective study was conducted from January to June of 2018 and included the first 100 consecutive oncological



patients (62 men, 38 women; mean age of  $65 \pm 12$  years) who were referred to the Nuclear Medicine Department of the

Hospital de la Santa Creu i Sant Pau (Barcelona) for an initial assessment or treatment monitoring by PET/CT, and who

◀ **Fig. 1** A 57-year-old man who underwent follow-up 18F-FDG PET/CT after chemotherapy for colorectal cancer. The analog PET/CT was performed first and the digital PET/CT was performed thereafter. The digital system showed lung (red, green, blue and black arrows) and liver metastases (segment VIII; white arrow). The analog system detected the lung and liver metastasis. The lung nodule located in the lower right lobe was observed in the CT component of both systems (digital and analog) with an improved radiotracer uptake in the digital PET (black arrow)

accepted to be scanned by two systems in the same imaging session after a single radiotracer injection. Of these 100 patients, 31 patients were diagnosed with lung cancer, 17 with breast cancer, 12 with lymphoproliferative disorders (LPDs), eight with colorectal cancer, seven with cancer of unknown origin, six with prostate cancer, four with melanoma, three with osteosarcoma, two with oropharyngeal cancer, two with ovarian cancer, two with multiple myeloma, two with malignant pleural tumor, one with urothelial cancer, one with pancreas cancer, one with cholangiocarcinoma and one with hepatocellular carcinoma.

After a single radiotracer intravenous injection of either 18F-FDG or 18F-FluoroCholine (doses calculated depending on body weight, approximately 3.7 MBq per kg), all patients consecutively underwent a single-day, dual imaging protocol with two PET/CT systems (digital and analog). 18F-FDG was administered to 94 patients and 18F-FluoroCholine to the remaining six patients. All patients fasted for at least 6 h before the intravenous administration of 18F-FDG. The dual imaging protocol was consecutively acquired on a Philips digital VEREOS and a Philips analog GEMINI TF PET/CT system. The first PET/CT was performed 60 min after the intravenous injection of the radiotracer, and the second PET/CT was performed thereafter (mean time delay:  $50 \pm 14$  min). In patients referred for an initial assessment, the digital PET/CT was performed first, while in patients who were referred for treatment monitoring, the analog PET/CT was performed first, as the previous scan had been performed with this system. In 58 patients, the analog PET/CT was initially performed and the digital PET/CT thereafter. In the remaining 42 patients, the PET/CT was performed the other way around. All patients were verbally informed and signed a written consent form. The study was approved by the institutional ethical board.

Acquisition and reconstruction parameters were those employed in standard clinical protocols for both systems. The CT was obtained before the PET scan. The CT components of both scanners consisted of a 64-slice helical multidetector, and CT acquisition parameters were similar for both systems: 120kVp, tube current modulation, pitch of 0.828 and 3 mm slice thickness (with slice increment of 1.5 mm). No intravenous or oral contrast was used. CT reconstruction was performed according to the recommended clinical settings for each device, i.e. iDose iterative reconstruction for the digital system and filtered back projection for the analog system. Subsequently, the PET dataset was acquired. The active PET field of view (FOV) for both systems was 57.6 cm. The matrix size for the digital system was  $288 \times 288$  with a 2-mm voxel, while it was  $144 \times 144$  with a 4-mm voxel for the analog system. The axial FOV was 16.4 cm for the digital system and 18 cm for the analog system. Two minute/bed position and list-mode time of flight (TOF) acquisition were used in both systems. 3D-ordered subset expectation maximization (3D-OSEM) algorithm was used for PET image reconstruction, using two iterations, ten subsets, and PSF resolution recovery in the digital system and three iterations, 33 subsets in the analog PET system.

## Image analyses

### Qualitative and quantitative analyses

Images were reviewed using the Philips IntelliSpace Portal workstation v8.0. The digital PET/CT and analog PET/CT studies were opened in the workstation and linked automatically for their simultaneous assessment. All lesions with increased radiotracer uptake from the different body regions (including primary tumors, lymph nodes and distant suspected metastasis) were included in the qualitative assessment. All studies were assessed independently of which PET/CT (digital or analog) was performed first. Image quality was assessed by three experienced nuclear medicine physicians using a 4-point scale (−1, poor; 0, fair; 1, good; 2, excellent). In addition, to assess the detection capability the three experienced nuclear

**Table 1** Comparison of lesion detection capability between digital and analog PET/CT

Method of detection		Analog PET/CT			Total
		PET-	PET + with lesions	PET + with more lesions	
Digital PET/CT	PET	17	0	0	17
	PET + with lesions	3	61	0	64
	PET + with more lesions	0	19	0	19
Total		20	80	0	100

medicine physicians evaluated the digital and analog PET/CT datasets by counting the number of lesions with increased radiotracer uptake.

### Statistical analysis

The interrater agreement and quantitative analysis was assessed using the Cohen's kappa coefficient [ $\kappa$ ] and proportions of confidence intervals (CI). Normal distribution of the number of lesions detected by PET/CT was assessed by the Kolmogorov-Smirnov test. Continuous variables are presented as mean  $\pm$  standard deviation (SD). Comparison of image quality between digital PET/CT and analog PET/CT was performed using chi-squared test for categorical variables. Total number of lesions detected by digital PET/CT and analog PET/CT was compared using Student t-test for paired continuous variables. Differences were considered significant for a probability value ( $p$  value)  $<0.05$ . The IBM SPSS Statistics V25 software package was used for all statistical analysis.

## Results

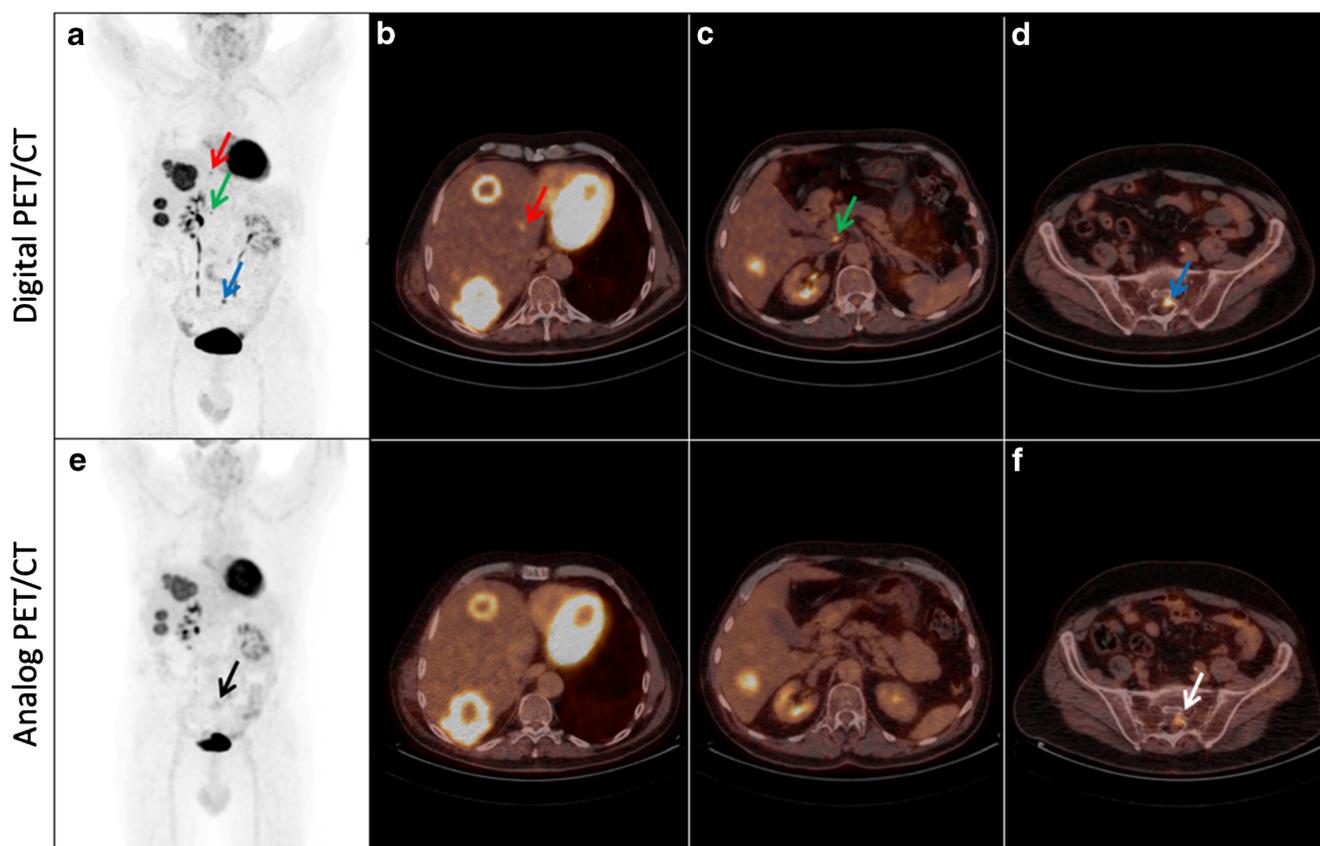
### Qualitative and quantitative analyses

#### Image quality

There were significant differences in image quality between the digital PET/CT and the analog PET/CT using a 4-point scale analysis ( $X^2 [2, N = 200] = 76, p < 0.001$ ). In 54 patients (54%), image quality was better in the digital PET/CT than in the analog PET/CT ( $p = 0.05$ , 95% CI, 44.2–63.5) (Fig. 1). In the remaining 46 patients, image quality did not significantly differ between both systems.

#### Lesion detection capability

The percentage of interrater concordance in lesion detection capability between the digital and analog systems was 97%, with an interrater measure agreement of  $\kappa = 0.901$  ( $p < 0.0001$ ).



**Fig. 2** A 66-year-old man who underwent follow-up 18F-FDG PET/CT after chemotherapy for metastatic small cell lung cancer (SCLC). The analog PET/CT was performed first and the digital PET/CT was performed thereafter. (a) The digital MIP PET image showed multiple liver metastasis and three foci of increase 18F-FDG uptake (red, green and blue arrows) which corresponded to (b) liver metastasis (red arrow), (c) interportocaval lymph node (green arrows) and (d) sacral bone metastasis

(blue arrow) in the fused axial slices. All these lesions with 18F-FDG uptake were sub-centimeter. (e) The analog MIP PET images detected multiple liver metastases and a lightly sacral diffuse FDG uptake (black arrow) which corresponded to (f) bone metastasis (white arrow) in the fused axial slices. The sub-centimeter liver metastasis (b; red arrow) and interportocaval lymph node (c; green arrow) were not detected by the analog system

In 80 of 100 patients, both PET/CT (digital and analog systems) detected lesions (PET+) (Table 1). In 61 of the 80 PET+ patients, both systems detected the same number of lesions. In the remaining 19 of the 80 PET+ patients, the digital system detected more lesions than the analog system. Moreover, the digital system was positive in three patients in whom the analog system did not detect lesions (PET-). Therefore, 20 patients using the analog system and 17 patients using the digital system were considered PET-.

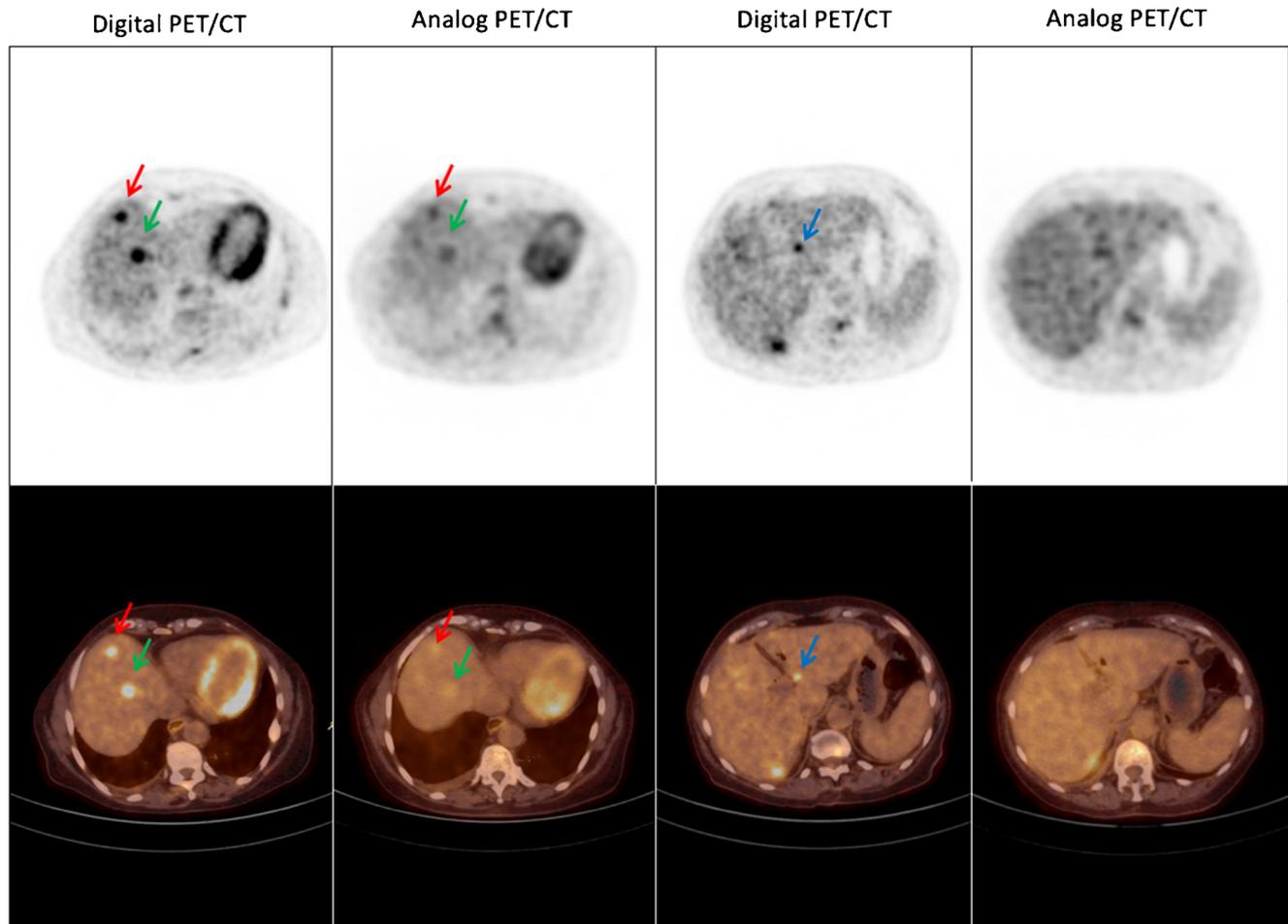
There were no significant differences in the total number of lesions detected by each system (digital:  $5.03 \pm 10.6$  vs. analog:  $4.53 \pm 10.29$ ;  $p = 0.75$ ). In 22 of the 83 PET+ patients (26.5%), the digital PET/CT detected more lesions compared to the analog PET/CT ( $p = 0.05$ , 95% CI, 17.9–36.7) (Fig. 2).

Of these 22 patients in whom the digital PET/CT increased the number of lesions detected as compared to the analog PET/CT, six patients were diagnosed with lung cancer, four with colorectal cancer, four with breast cancer, three with LPDs, three with prostate cancer, one with

melanoma and one with sarcoma. In these 22 patients, all lesions detected by the digital PET/CT (and not by the analog PET/CT) were  $< 10$  mm with improved radiotracer uptake; eight were located in the lung, eight in the lymph nodes, six in the liver (Fig. 3), four in bones, one in seminal vesicle, one in the right breast and one in the skin. Additionally, disease stage was modified in seven of these 22 patients (32%) (Table 2).

## Discussion

The aim of this study was to compare image quality and lesion detection capability between a digital PET/CT and an analog PET/CT system in oncological patients. It has been suggested that image quality and detection capability of digital PET/CT is higher due to better spatial and timing resolutions, lower dead time and dynamic count rate range [1, 3, 4, 7].



**Fig. 3** An 81-year-old woman who underwent follow-up 18F-FDG PET/CT after chemotherapy for breast cancer. The analog PET/CT was performed first and the digital PET/CT was performed thereafter. The digital system axial images showed increased focal 18F-FDG uptake in liver

metastases located in segments IVa (red arrow), VIII (green arrow) and III (blue arrow). The analog system detected focal 18F-FDG uptake in segments IVa (red arrow) and VIII (green arrow), and a diffused liver radiotracer uptake in segment III (blue arrow)

**Table 2** Patients, PET/CT and lesion characteristics where the digital and analog PET/CT systems differed

Patient	Age (years)	Gender (male = 1; female = 2)	Radiotracer	Tumor	Referral category (1 = staging/initial diagnosis; 2 = follow up)	Time of acquisition in digital Vereos PET/CT	Time of acquisition in analog Gemini PET/CT	Time delay (min)	Total lesions detected by digital Vereos PET/CT	Total lesions detected by analog Gemini PET/CT	$\Delta$ Lesions detected between digital PET/CT vs. Analog PET/CT	Disease stage change (Yes = 1; No = 2)	Lesion localization
1	83	1	FDG	Lung	2	13:35	12:55	0:40	1	0	1	2	Skin
2	73	1	FDG	LPDs	1	17:31	16:51	0:40	1	0	1	2	Lung
3	77	1	Choline	Prostate	2	13:48	13:07	0:41	4	3	1	1	Bone
4	79	1	Choline	Prostate	1	13:36	13:01	0:35	2	1	1	1	Seminal vesicle
5	71	2	FDG	Lung	2	12:53	12:03	0:50	4	2	2	1	Lung
6	81	2	FDG	Breast	2	10:34	10:02	0:32	9	6	3	2	Liver
7	59	1	FDG	Lung	2	20:06	19:16	0:50	8	5	3	2	Lung/lymph node
8	46	1	FDG	Sarcoma	1	12:47	13:28	0:41	12	7	5	2	Lung
9	49	1	FDG	Melanoma	2	10:35	9:45	0:50	2	1	1	1	Lung/Bone
10	57	2	FDG	Lung	1	18:43	18:16	0:27	1	0	1	1	Liver
11	82	1	FDG	Colorectal	2	17:11	15:35	1:36	3	2	1	2	Lymph node
12	74	1	FDG	Breast	2	17:24	16:37	0:47	3	2	1	1	Lymph node
13	58	1	FDG	LPDs	2	18:43	19:18	0:35	13	3	10	2	Lymph nodes
14	77	2	FDG	Breast	2	17:39	16:00	1:39	56	50	6	2	Liver/Lymph nodes/Bone
15	66	1	FDG	Lung	2	18:14	17:03	1:11	9	7	2	2	Liver/Lymph node
16	57	1	FDG	Colorectal	2	10:00	8:54	1:06	4	2	2	2	Lung/Bone
17	63	2	FDG	LPDs	1	18:23	18:56	0:33	8	5	3	2	Lymph nodes
18	50	2	FDG	Breast	1	12:38	13:30	0:52	4	3	1	2	Breast
19	65	1	FDG	Colorectal	2	16:45	15:32	1:13	4	3	1	2	Liver/lung
20	76	1	Choline	Prostate	2	14:07	12:59	1:08	2	1	1	1	Liver
21	84	1	FDG	Colorectal	2	11:34	10:41	0:53	4	3	1	2	Lung
22	55	1	FDG	Lung	2	16:58	15:52	1:06	4	3	1	2	Lymph node

Indeed, these results indicate better image quality in the digital system as compared to the analog system, and are congruent with previous published reports [1, 3–6]. They might be attributed to the enhanced detector system performance; in the analog system, multiple crystals are coupled to multiple detectors, while in the digital system each crystal is coupled to a single detector (1:1 coupling). In the digital PET/CT, each detector contains thousands of single photon avalanche diodes (ADPs) coupled to a digital photon counter (DPC). The enhanced system performance can detect individual scintillating photons and directly produce a binary count, increasing the count rate and reducing the dead time of the system. Therefore, the combination of the DPC with the 1:1 direct coupling together with the enhanced TOF improves the timing and volumetric resolutions of the digital system over the analog system.

Although there was no significant difference in the total number of lesions detected by the two systems, the digital system detected more lesions in 22 of the 83 PET+ patients (26.5%). All lesions detected by the digital but not by the analog system were at the sub-centimeter level. These lesions were located in different organs including liver and lung. The superior lesion detection capability of the digital system changed the disease stage in seven of these 22 patients (32%). In addition, in four of these 22 patients whose dual PET/CT protocol started with the digital system, we observed the highest difference in the number of lesions detected between both systems. Therefore, the enhanced lesion detection capability of the digital PET/CT may be related to better contrast recovery coefficients of the digital system over the analog system and not only to different radiotracer clearance over time before image acquisition. This finding is supported by our previous results recently reported in relation to higher maximum standard uptake value (SUV) of the target lesions on the digital PET/CT independently of the order sequence of PET/CT acquisition [8]. The better target-to-background contrast provided by the digital system might be a potential advantage in the characterization of sub-centimeter lesions in organs such as the liver (Figs. 1 and 3).

Similarly, Nguyen et al. reported an improvement in the detection of lesions in five of 21 patients (24%) leading to an upstaging in two of the five patients (40%) [1]. Our results further support the advantage of digital PET in the characterization of small lesions (sub-centimeter). In addition, image quality and lesion detection capability are in line with those observed by the National Electrical Manufacturers Association test (NEMA NU2–2012), where contrast recovery coefficients were superior for the digital PET/CT (ranging from 54.3% [10 mm sphere] to 83.9% [22 mm sphere]) compared to the analog PET/CT (ranging from 23% [10 mm sphere] to 62% [22 mm sphere]). The enhanced contrast recovery coefficients for the digital PET/CT are attributed to the timing resolution and the enhanced TOF capability [6, 9–11]. However, the spatial resolution for the digital PET/CT over the analog PET/CT did not demonstrate significant changes

(4.2 mm to 5.5 mm and 4.8 mm to 5.2 mm, respectively) [6, 9, 12]. Furthermore, differences in image quality may also relate to optimization of the reconstruction parameters such as the combination of PSF and TOF [13].

One of the limitations of our study is the highly heterogeneous sample including patients with different primary tumors, disease stages and treatment protocols. Further research should address comparisons focused on a more homogeneous sample. A second limitation is the different image reconstruction used in each system, which might have influenced the image quality. However, we intended to compare both PET/CT devices under the standard and generally employed clinical settings.

## Conclusion

Our findings indicate that the digital PET/CT offers improved image quality over the analog PET/CT. Additionally, lesion detection capability of digital PET/CT is superior to the analog PET/CT in oncological patients. For sub-centimeter lesions, the lesion detection capability is increased even further by the digital system, especially in organs with heterogeneous appearance and background activity such as the liver.

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## Compliance with ethical standards

**Conflict of interest** All authors declare no conflict of interest.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

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## References

1. Nguyen NC, Vercher-Conejero JL, Sattar A, et al. Image quality and diagnostic performance of a digital PET prototype in patients with oncologic diseases: initial experience and comparison with analog PET. *J Nucl Med*. 2015;56:1378–85.
2. Wright C, Binzel K, Zhang J, et al. Advanced functional tumor imaging and precision nuclear medicine enabled by digital PET technologies. *Contrast Media Mol Imaging*. 2017:5260305. <https://doi.org/10.1155/2017/5260305>.

3. Frach T, Prescher G, Degenhardt C, et al. The digital silicon photomultiplier: principle of operation and intrinsic detector performance. *IEEE Nucl Sci Symp Conf Rec.* 2009:1959–65.
4. Degenhardt C, Prescher G, Frach T, et al. The digital silicon photomultiplier: a novel sensor for the detection of scintillation light. *IEEE Nucl Sci Symp Conf Rec.* 2009:2383–6.
5. Slomka PJ, Pan T, Germano G. Recent advances and future progress in PET instrumentation. *Semin Nucl Med.* 2016;46(1):5–19.
6. Rausch I, Ruiz A, Valverde-Pascual I, et al. Performance evaluation of the Philips Vereos PET/CT system according to the NEMA NU2–2012 standard. *J Nucl Med.* 2018: Oct 25. pii 118.21554.
7. Degenhardt C, Rodrigues P, Trindade A, et al. Performance evaluation of a prototype positron emission tomography scanner using digital photon counters (DPC). *IEEE Nucl Sci Symp Conf Rec.* 2012:2820–4.
8. Fuentes-Ocampo F, Paillahueque G, Lopez-Mora DA, et al. Digital vs. analog PET/CT: intrapersonal SUV comparison of target lesions and reference regions. *Eur J Nucl Med Mol Imaging.* 2018;45(Suppl 1):S212–3 **OP-658**.
9. Surti S, Kuhn A, Werner ME, et al. Performance of Philips Gemini TF PET/CT scanner with special consideration for its time-of-flight imaging capabilities. *J Nucl Med.* 2007;48:471–80.
10. Rausch I, Cal-González J, Dapra D, et al. Performance evaluation of the biograph mCT flow PET/CT system according to the NEMA NU2-2012 standard. *EJNMMI Phys.* 2015;2:26.
11. Suljic A, Tomse P, Jensterle L, et al. The impact of reconstruction algorithms and time of flight information on PET/CT image quality. *Radiol Oncol.* 2015;49:227–33.
12. Miller MGJ, Jordan D, Laurence T, et al. Initial characterization of a prototype digital photon counting PET system. *J Nucl Med.* 2014;55:658.
13. Karp JS, Surti S, Daube-Witherspoon ME, et al. Benefit of time-of-flight in PET: experimental and clinical results. *J Nucl Med.* 2008;49:462–70.