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REVIEW Open Access

Peritoneal deposits: PET/CT the keen observer

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Abstract

Background The peritoneum is the largest serous membrane in the body, it is a preferred site for metastasis of primary malignancies like mesothelioma. Accurate monitoring of tumor response to chemotherapy and detection of tumor recurrence is critical in management planning. CT is the gold standard for the detection of peritoneal deposits. PET scans are performed on patients with a variety of malignancies.

Results The study included 70 patients, 36 females, and 34 males. The age ranged from 5 to 76 years. 59 patients presented to the PET CT unit with known 1ry tumor while 11 patients presented with metastasis of unknown 1ry. Lymphoma followed by colon were the commonest sites for the primary tumor with 15 and 13 patients for each respectively. Breast came in the 3rd place followed by endometrial carcinoma with 12 and 6 patients respectively. Bronchogenic carcinoma came after with 4 patients. Then melanoma, cervical, ovarian, and NET with 2 patients for each. One case had HCC. After performing the PET CT scan we detect the primary neoplastic process for 8 patients out of the 11 previously unknown cases and 3 cases being the unknown origin. These 8 patients were found to be 3 cases with 1ry breast lesions, 2 cases with ovarian masses, and the last 3 cases were colonic, HCC, and lymphoma. 60 of the patients included had peritoneal deposits while 10 were free. Ten patients were reviewed, finding 8 patients were free on CT and PET images, while 2 patients had avid spots. These spots were reviewed turning to be normal bowel activity. Visibility of the peritoneal deposits on CT images was observed, 33 patients had deposits that were not visualized on CT, and 27 were visible. The avid peritoneal deposits were observed. Fifty-eight patients had avid deposits while two patients had non-avid deposits. Fifty-five patients had high-grade avidity deposits while 3 patients had low-grade avidity deposits.

Conclusions Evaluation of peritoneal malignancies with PET/CT is rewarding adding substantially to CT scanning alone.

Keywords PET/CT, CT, And peritoneal deposits

Background

- The peritoneum is a large serosal membrane that lines the abdominal cavity from the inside and covers the intra-abdominal structures. It is divided into two layers the parietal and visceral layer. In males, it forms a closed sac while in females it is perforated laterally by the fallopian tubes [1].
- The peritoneum is a favorable site for neoplastic lesions from primary (such as mesothelioma) and secondary malignancies with the latter representing the majority. Colo-rectal carcinoma and gynecological neoplastic masses are the most common primary malignancies among males and females respectively which usually give metastasis to the peritoneum.
- The presence of peritoneal deposits represents a very powerful prognostic factor. It alters the tumor stag-

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ing and therefore alters the treatment plan, disease prognosis, and outcome as well as the patient's quality of life [2].

- Routes of spread are direct invasion for nearby organs, intra-peritoneal seeding, lymphatic spread, and hematogenous spread [3]. Proper early detection of the peritoneal deposits and their number is crucial as the low-volume disease might be suitable for preoperative cytoreduction [4]. Peritoneal deposits, however, can remain occult for some time especially if too small or in challenging sites (hidden between the abdominal viscera) because the imaging procedures can be variable in their detection of the deposits [5].
- Conventional enhanced CT used to be the preoperative gold standard for the detection of peritoneal deposits, depending on factors such as proper technique (good opacification of the bowel, timing of contrast injection, and good machine). Other factors concerning the peritoneal deposit such as the size, site, and morphology of the deposit. Some factors might hinder the ability of the CT to detect peritoneal metastasis such as the presence of ascites, and paucity of intra-abdominal fat, deposits that are too small or hidden between bowel loops [6].
- In our facility, we prefer staging of primary tumors using the aid of 18F-FDG PET scans to identify the lesions suspicious for peritoneal deposits based on their FDG avidity which corresponds to CT findings of peritoneal disease [6].

Patients and methods

Our study was a prospective one carried out on 70 patients (36 females, and 34 males), who had PET/CT scans done to them at our hospital whether for initial staging of a pathologically proven primary tumor, postoperative re-staging, or therapy response assessment whether during or after treatment completion, depending on clinical, laboratory or conventional imaging, findings to detect the presence or absence of peritoneal deposits. The scan procedures were fully explained, and the informed consent was signed by the patients at the time of the scan. The study was conducted from august 2021 to august 2022.

Reference standard

The reference gold standard to ensure the accuracy of the imaging findings included mainly histopathology results if available and the response of the peritoneal metastatic lesions (diagnosed by the PET CT scan) to therapy in the follow-up scans.

Imaging protocol

An Integrated PET/CT scanner is utilized. (Ge (American) discovery 5 rings CT 16 slice). This dedicated system integrates a PET scanner with a multi-section helical CT scanner and permits the acquisition of co-registered CT and PET images in one session.

Patient preparation

Pre-scan

All patients were informed to fast at least 6 h before the scan with good hydration, diabetic patients were informed to take their medication (oral pills or insulin injections) at least four hours before the scan, available recent serum creatinine Laboratory test, and avoid vigorous exercise the day before the scan. They were also informed to have a low carbohydrate, high fat, and protein diet two days before the scan.

On the day of the scan

All patients were subjected to weight, and height measuring and all metallic items (that can cause artifacts) were removed including clothes with metallic parts, and replaced by clean disposable gowns to wear. Serum glucose measurement should be below 200 mg/dl (including diabetic patients). An intravenous (I.V.) cannula was inserted in the patient's arm for the administration of 18F-FDG and the CT I.V. contrast. Patients then were seated in an isolated quiet room with dim lights and were informed to keep relaxed and avoid any muscular activity, stress, or any physical movements (including chatting with each other), especially after the radio-active tracer injection to avoid false tracer uptake. Patients who felt cold were given clean blankets to keep them warm to avoid brown fat false uptake (Figs. 1, 2, 3, 4, 5, 6).

The technique of 18F-FDG PET/CT scan

18F-FDG was injected intravenously in a dose of 0.1 mCi/kg body weight. All patients were kept in a quiet room with a warm temperature and asked to rest keeping their movements at an absolute minimum and void before imaging immediately. After injection scanning by a hybrid PET/CT scanner (GE Discovery and Philips Gemini TF (Time-of-Flight) PET/CT machines) was performed at 60 min. The patient asked to be in a supine position on the table with their arms raised above their heads and a suitable head fixation position. First, we performed a low-dose non-enhanced CT scan and then a whole-body PET scan. The study took approximately 20–30 min. typical whole-body PET/CT scanning began from the skull base and extended caudally to the level of the mid-thighs, the Porto-venous phase was taken to cover the skull bases down to the mid-thighs.

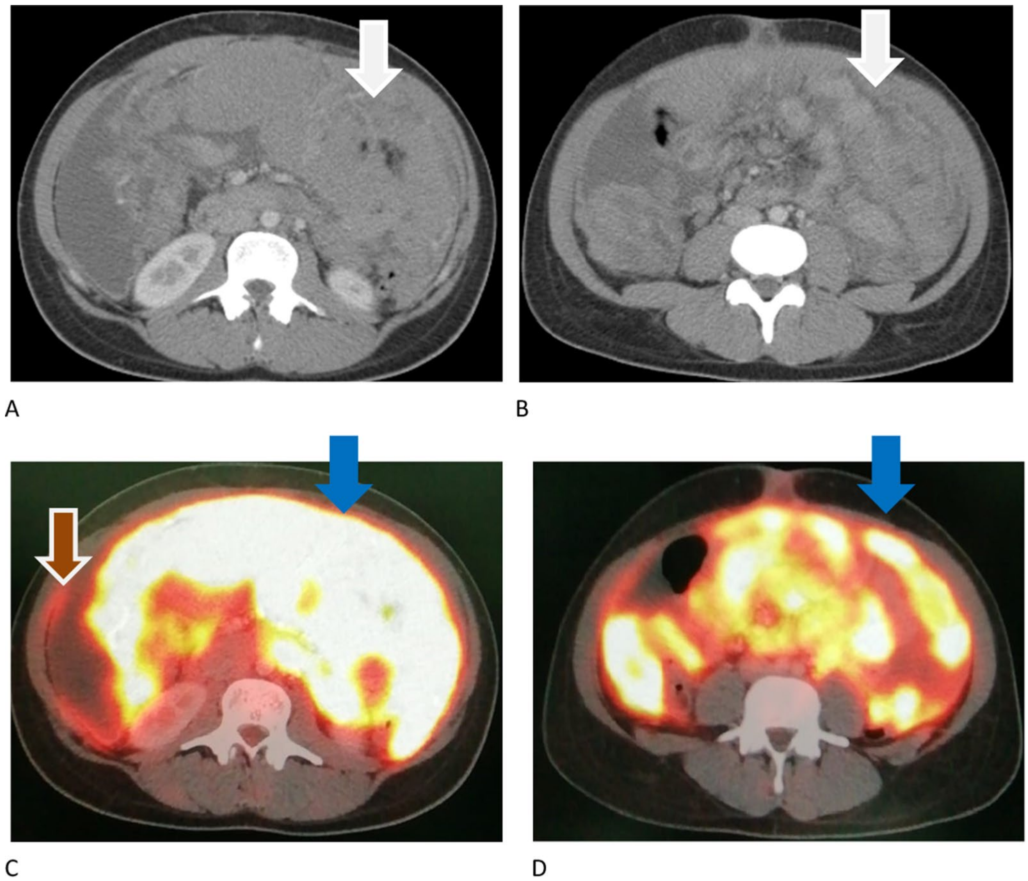


Fig. 1 **A–D** Middle age male, diagnosed with small bowel lymphoma, received CTH and was referred for re-assessment with PET CT. Conventional CT images **A**, **B** show large omental cakes occupying almost the whole abdominal cavity (white arrows). Fused images **C**, **D** revealed these lesions to be FDG avid (blue arrows). Metabolically inert ascites are also noted (brown arrow)

The total length of CT coverage was an integral number of bed positions scanned during the acquisition of PET data. (Approximately 6–7 bed positions are planned in 3D acquisition mode for scanning the entire patient with 3–5-min acquisition at each bed position.) The study was performed with the patient breathing quietly. The scanning parameters for low-dose attenuation correction CT were 120 kV, 100MA, collimator width of (64 × 0.625 mm), a pitch of 0.8, gantry rotation time of 0.5 s, and a field of view of 50 cm. The scanning parameters for high-dose diagnostic CT were 120 kV, 300MA, collimator width of (64 × 0.625 mm), a pitch of 0.8, gantry rotation time of 0.5 s, and field of view of 50 cm. The helical data were retrospectively reconstructed at a 1-mm interval. The patient was injected with about 100 ml of non-ionic iodinated contrast material using a dual syringe Medrad (Stellent) automated injector with an injection rate of about 2.5 ml/s (Tables 1, 2, 3, 4, 5, 6).

Statistical data analysis

By using the statistical package SPSS version 25 the data were coded and entered. It was summarized using descriptive statistics: frequencies were stated as numbers of percentages and observations for categorical variables. Measures of central tendency for parametric numerical variables are calculated by means and standard deviations. For assessment of the relationship between categorical variables, inferential statistical analyses were performed using chi-squared tests with contingency tables for expected and observed values as well as testing for correlation using the spearman-rho test. All tests are considered statistically significant at a p-value equal to or less than 0.05. Using contingency tables, diagnostic performance indices including specificity, sensitivity, negative, and positive predictive values, and overall accuracy were calculated. Data was presented by bar charts, graphs, and tables as well as pie charts.

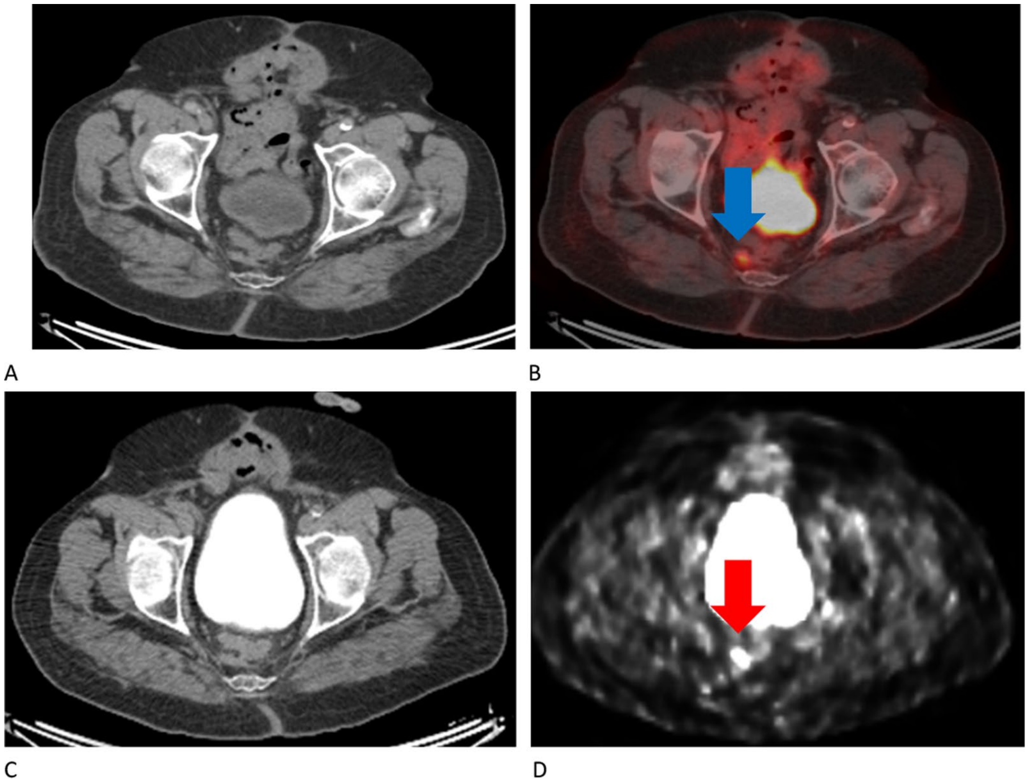


Fig. 2 **A–D** A 40-year-old male patient, with a known case of cancer colon, underwent surgical resection, referred for metastatic workup before therapy. In the early scan (**A**, **B**); the fused image revealed operative bed small low-grade FDG avid nodular thickening involving the right aspect of the pre-sacral fascia which was not obvious in the conventional CT images (blue arrow). A delayed scan was obtained (**C**, **D**), and revealed an increase in the FDG avidity of the lesion keeping with its neoplastic nature and confirming residual tumoral tissue at the operative bed (red arrow)

Results

Our study included 70 patients, 36 (51.4%) females, and 34 (48.6%) males. The age ranged from 5 to 76 years a median age of 45 years (16.77%). 59 (84.3%) patients presented to our PET CT unit with a known primary tumor while 11 (15.7%) patients presented with metastasis of unknown primary. The site of the primary tumor of the 59 patients was recorded. We found that lymphoma followed by colon were the commonest sites for the primary tumor with 15 (25.4%) and 13 (22%) patients for each respectively. Breast came in third place followed by endometrial carcinoma with 12 (20.3%) and 6 (10.2%) patients respectively. Bronchogenic carcinoma came after with 4 patients (6.8%). Then melanoma, cervical, ovarian, and NET with 2 patients (3.4%) for each. One case (1.7%) had HCC. After performing the PET CT scan we were able to detect the primary neoplastic process for 8 patients out of the 11 previously unknown cases (72.7%) and 3 cases remained of unknown origin (27.3%). These 8 patients were found to be 3 cases with primary breast lesions (37.5%), 2 cases with ovarian masses (25%), and the last three cases were colonic, HCC, and lymphoma with one case for each (12.5%). 60 (85.7%) of the patients included in our study had peritoneal metastatic deposits while 10 (14.3%) patients were free. Those 10 patients were reviewed carefully. We found that 8 (80%) patients were free on CT and PET images, while 2 (20%) patients had FDG avid spots. These spots were reviewed again; both turned out to be normal bowel activity. The visibility of the peritoneal deposits (in the positive patients) on conventional CT images was observed. 33 patients (55%) had deposits that were not visualized on CT while 27 (45%) were visible. The peritoneal deposits FDG uptake was observed. 58 patients (96.7%) had deposits that were FDG avid (active) while only two patients (3.3%) had non-FDG avid deposits (inert). The avidity of FDG uptake of the metabolically active deposits was recorded. Fifty-five patients (94.8%) had high-grade FDG avid deposits while 3 patients (5.2%) had low-grade FDG avid deposits.

Discussion

Four ways are known for metastatic neoplasm dissemination throughout the peritoneum involving spreading along the peritoneal ligaments, omentum and mesentery, lymphatic extension, seeding through the ascites, and hematogenous spread. Omentum was the frequent

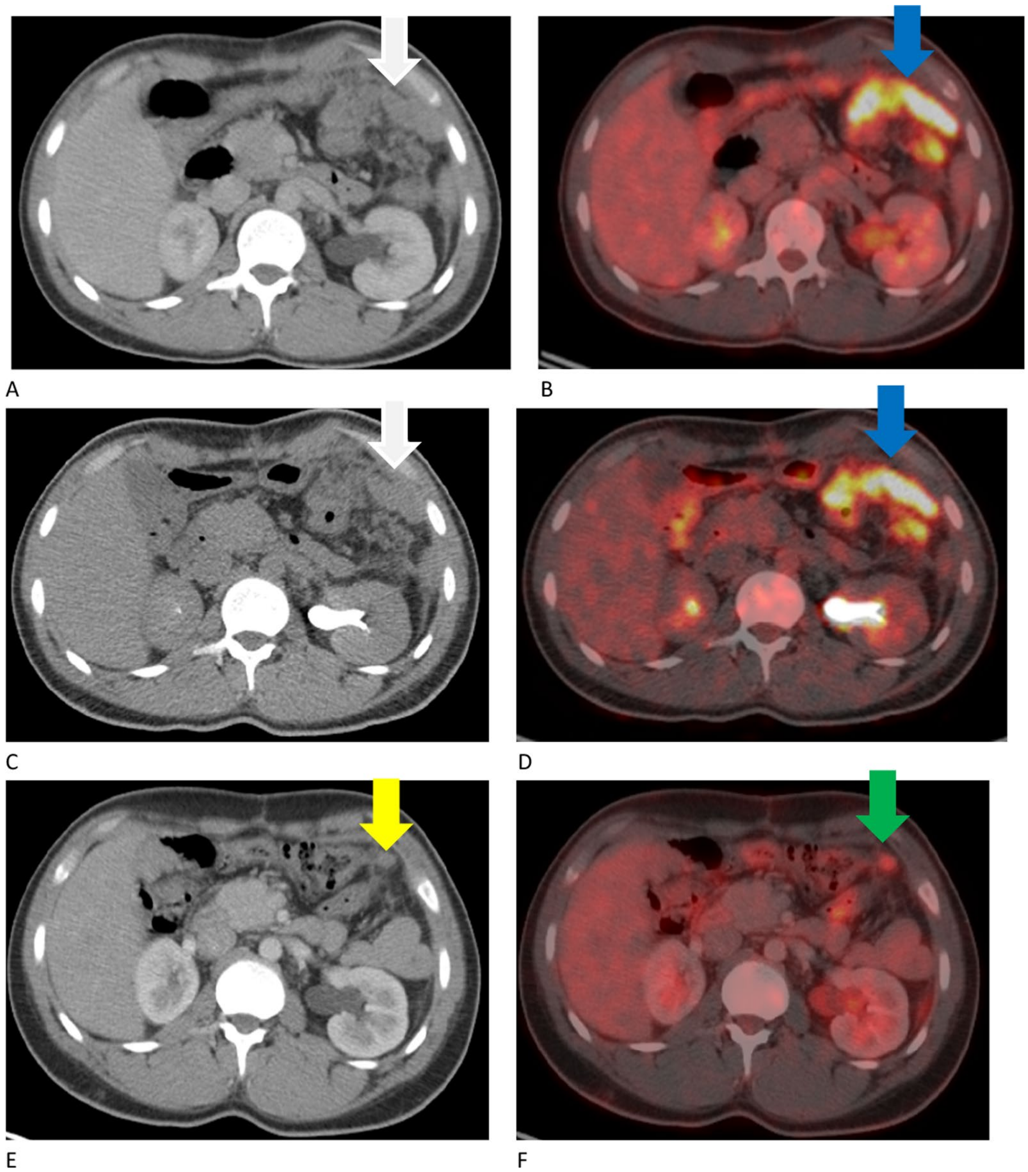


Fig. 3 **A–F** A 25-year-old male patient, with a known case of cancer colon, underwent surgical resection referred for metastatic workup before therapy. In the early scan (**A**, **B**); there is an FDG avidity at the left hypochondrial region between the small bowel loops (white arrow in the conventional CT images and blue arrow in fused images). (Collapsed small bowel or deposit) Delayed images were obtained (**C**, **D**); revealing persistent FDG avidity is still noted at the same site with an increase in the metabolic activity denoting its neoplastic nature (peritoneal deposit) (white arrow in the conventional CT images and blue arrow in fused images). The patient received CTH and a follow-up PET CT scan was done 3 months later (**E**, **F**); revealing a dramatic response with marked morphological and metabolic regression of the peritoneal deposit denoting a favorable response to therapy (yellow arrow in the conventional CT images and green arrow in fused images)

site, the regions around the liver and spleen as well as the small pelvis. Fluid in the right infra-colic space down to the small bowel mesentery to the confluence of the mesentery with the colon. In the left infra-colic spaces, fluid flow is often stopped by the sigmoid mesocolon before it flows into the pelvis [7, 8]. Most of the lesions presented as nodular multiple plaques and swelling as well as diffuse infiltrations into the para-colic fat tissue [9, 10]. In describing the characteristics of FDG images, abnormally peritoneal metastasis reveal intense focal, circumscribed spots of uptake corresponding to nodular peritoneal deposits or diffusely uniform FDG uptake corresponding to diffuse peritoneal disease [7, 8] and also nodular or curvilinear uptake along the liver surface [10]. A vertical straight line may be seen on sagittal sections, demarcating the boundary between diffusely increased activity in

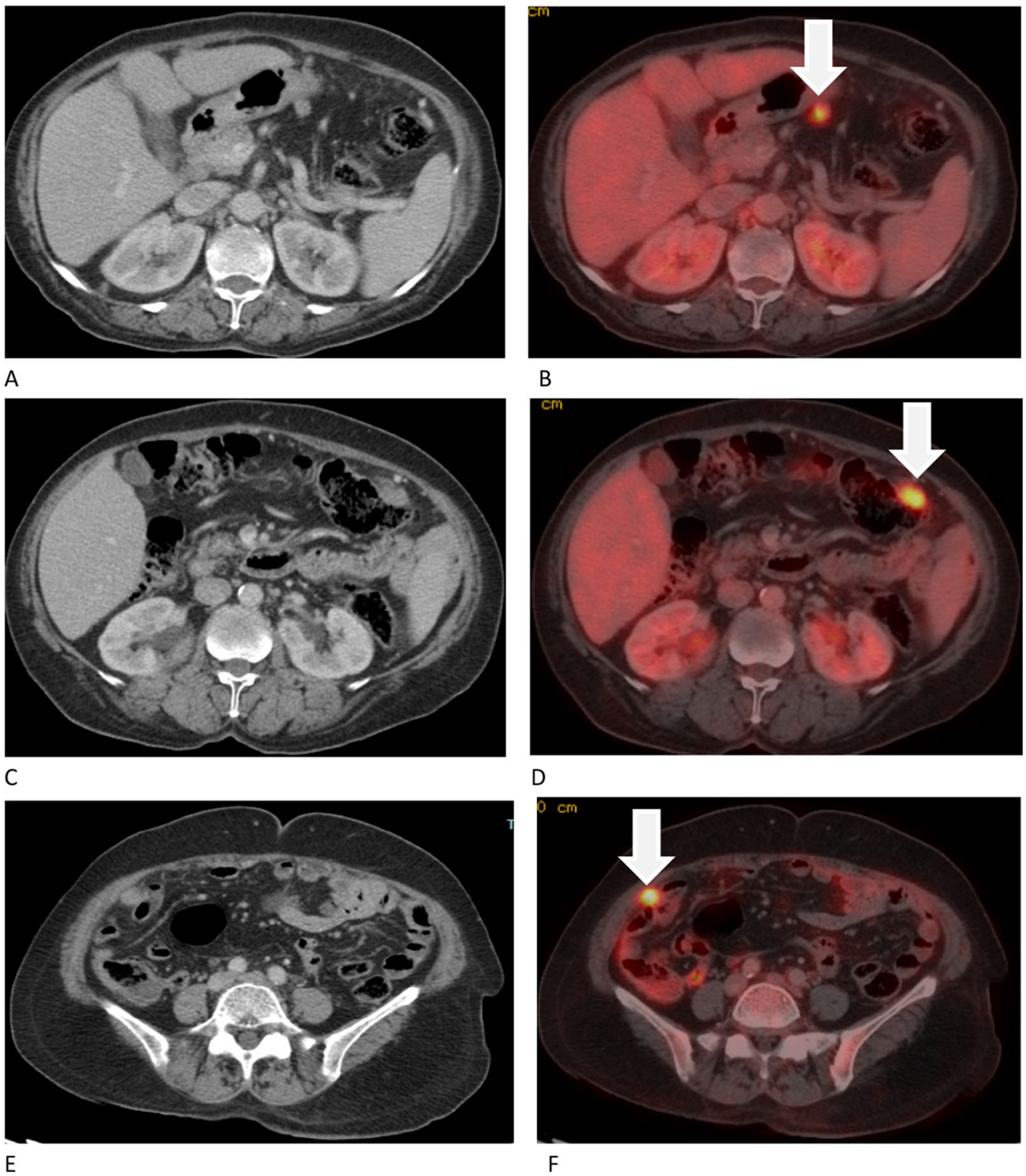
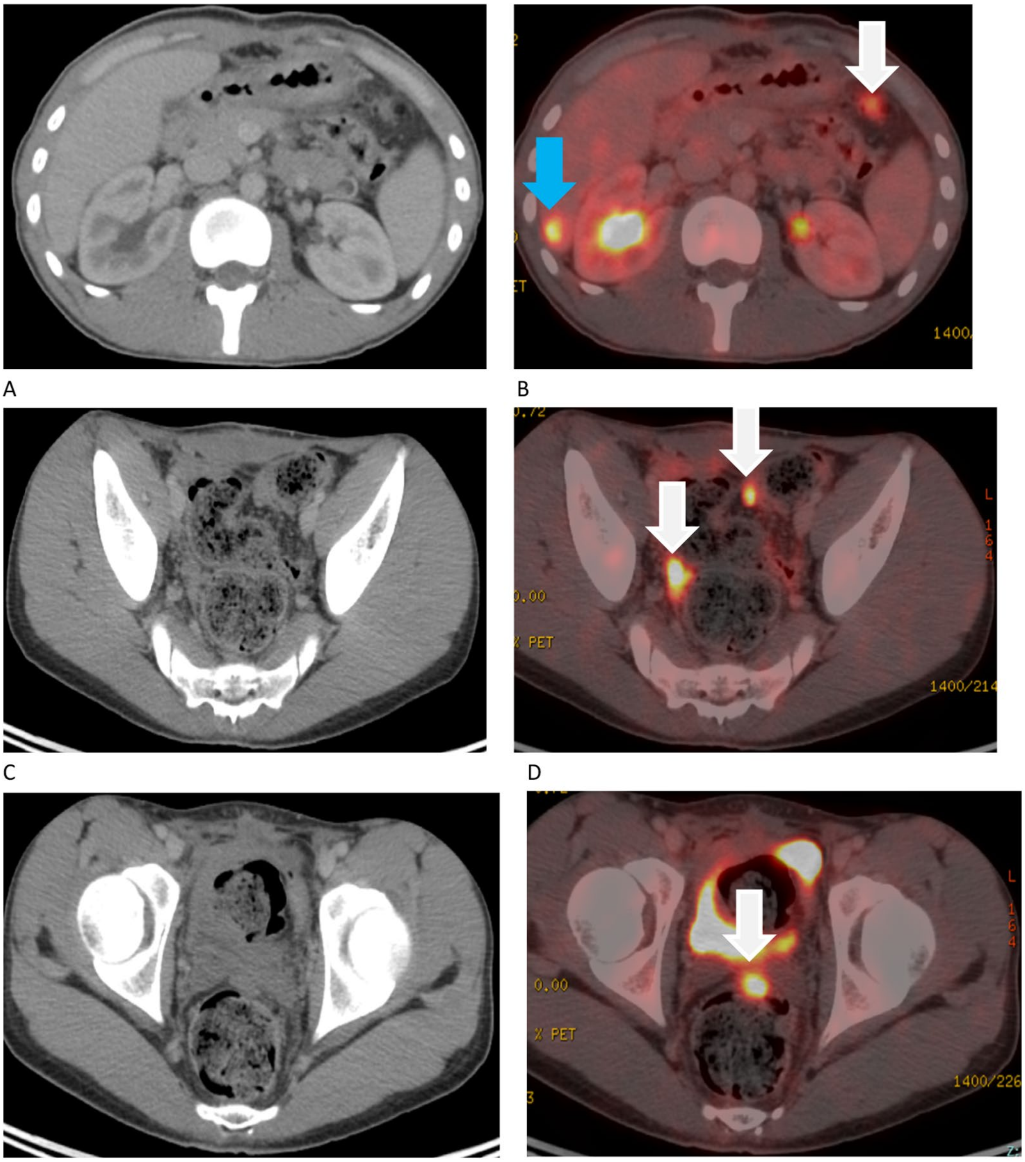


Fig. 4 A–F A 50-year-old female patient, with a known case of ovarian tumor, underwent TAHBSO, received CTH, and was referred for follow-up. PET CT fused images revealed multiple variable-sized FDG avid peritoneal deposits scattered in the abdominal cavity, some of them are very small and hidden between the bowel loops and were not obvious in the conventional CT images (white arrows)

the peritoneum and low activity in the retroperitoneum [11]. only lesions with sufficient malignant cells to change the glucose metabolism can be detected.

Our study included 70 patients, 36 (51.4%) females, and 34 (48.6%) males. The age ranged from 5 to 76 years a median age of 45 years (16.77%). 59 (84.3%) patients presented to our PET CT unit with a known primary tumor while 11 (15.7%) patients presented with metastasis of unknown primary. The site of the primary tumor of the 59 patients was recorded. We found that lymphoma followed by colon were the commonest sites for the primary tumor with 15 (25.4%) and 13 (22%) patients for each respectively. Breast came in third place followed by endometrial carcinoma with 12 (20.3%) and 6 (10.2%) patients respectively. Bronchogenic carcinoma came after with 4 patients (6.8%). Then melanoma, cervical, ovarian, and NET with 2 patients (3.4%) for each. One case (1.7%) had HCC. After performing the PET CT scan we were able to detect the primary neoplastic process for 8 patients out of the 11 previously unknown cases (72.7%) and 3 cases remained of unknown origin (27.3%). These 8 patients were found to be 3 cases with primary breast lesions



A B C D E F

Fig. 5 **A–F** A 15-year-old child, with a known case of lymphoma, was referred for follow-up. PET CT images revealed multiple variable-sized FDG avid peritoneal deposits scattered in the abdominal cavity between the bowel loops and at the pre-rectal fascia and were not obvious in the conventional CT images (white arrows). Also, an FDG avid hepatic focal lesion is seen at segment VI which is not visualized in the conventional CT images (blue arrow). The case was reported Deauville score of 5b as these lesions were new ones in news sites

(37.5%), 2 cases with ovarian masses (25%), and the last three cases were colonic, HCC, and lymphoma with one case for each(12.5%).

Conventional CT images were reviewed and 27(38.6%) patients had peritoneal deposits while the rest 43(61.4%) were considered free. Then the PET CT fused images were reviewed to detect the peritoneal deposits based on their FDG uptake. 58 patients (96.7%) had deposits that were FDG avid (active) while only two patients (3.3%) had non-FDG avid deposits (inert). The avidity of FDG uptake of the metabolically active deposits was recorded. 55 patients (94.8%) had high-grade FDG avid deposits while 3 patients (5.2%) had low-grade FDG avid deposits, We considered the lesions showing SUV max higher than the SUV average of the liver; to be active lesions while those with SUV max values lower than the SUV average of the liver were considered inert. So, 60 (85.7%) of the patients included in our study had peritoneal metastatic

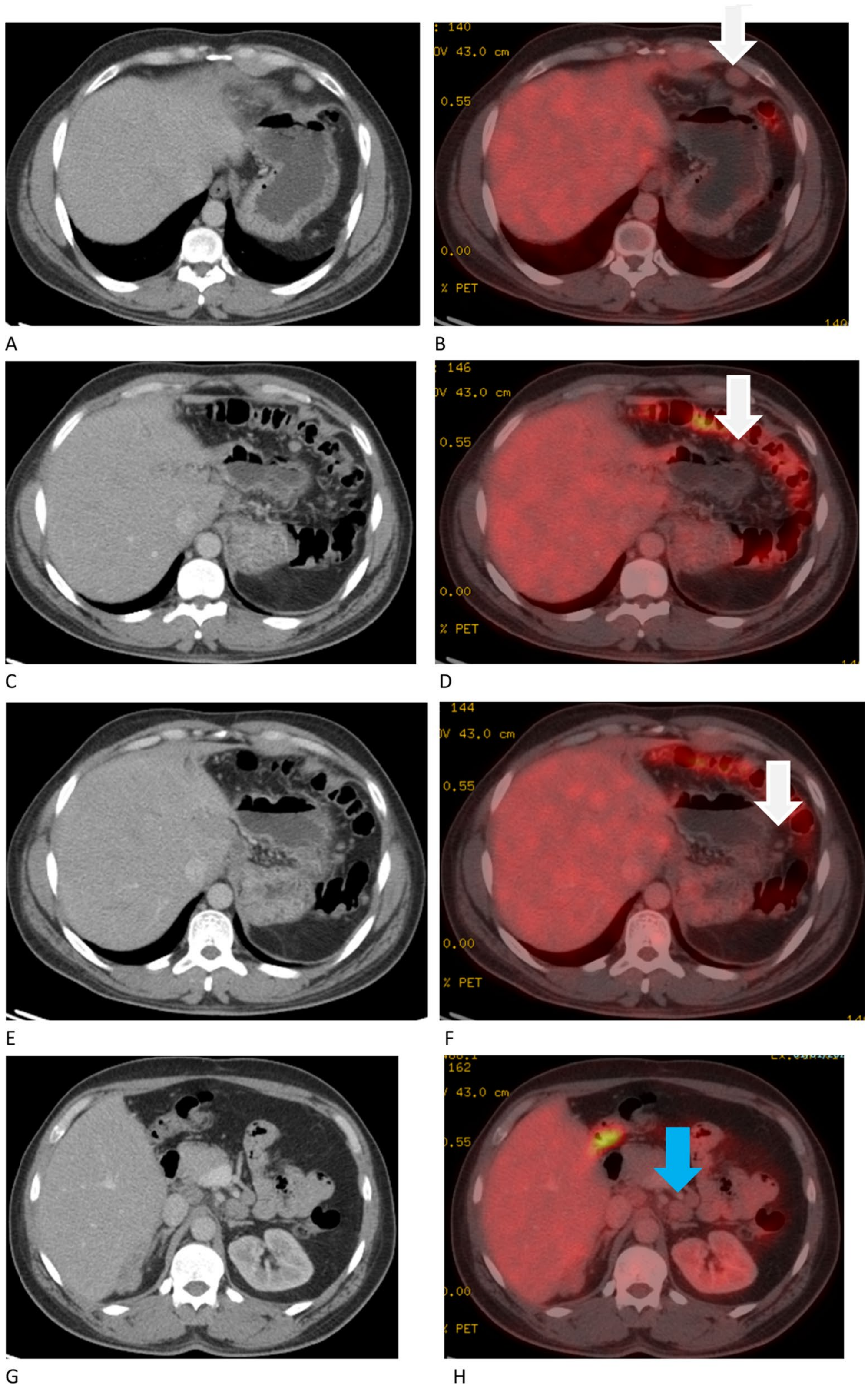


Fig. 6 A–F A 43-year-old male patient, with a known case of neuroendocrine tumor, underwent surgical resection, referred for metastatic workup and follow-up after the operation. Conventional CT images and fused PET CT images (**A**–**D**) revealed multiple variable-sized metabolically inert peritoneal deposits scattered in the abdominal cavity (white arrows). Two non-FDG avid retro-pancreatic lymph nodes are also seen (**G**, **H**) (blue arrow)

Table 1 Demographic data for the studied group

	N/Mean	%/SD	Median (IQR)	Range
Sex				
Male	34	48.6%		
Female	36	51.4%		
Age	43.83	16.77	45 (35–57)	(5–76)

Table 2 59 patients presented to our PET CT unit with known primary tumor while 11 patients presented with metastasis of unknown primary

	N	%
Known 1ry tumor		
Unknown	11	15.7
Known	59	84.3

Table 3 Site of the primary tumor in the patients

	N	%
Site of 1ry (*N* = 59)		
Endometrial	6	10.2
Cervical	2	3.4
Ovarian	2	3.4
NET	2	3.4
Colon	13	22
Breast	12	20.3
Lymphoma	15	25.4
HCC	1	1.7
Bronchogenic	4	6.8
Melanoma	2	3.4

deposits while 10 (14.3%) patients were free. Those 10 patients were reviewed carefully. We found that 8 (80%) patients were free on CT and PET images, while 2 (20%) patients had FDG avid spots on PET CT fused images. These spots were reviewed again; both turned out to be normal bowel activity. The visibility of the peritoneal deposits on conventional CT images was re-assessed again (in all patients). Thirty-three patients (47.1%) had deposits that were not visualized on CT while 27 (38.6%) were visible and 10 (14.3%) were free from peritoneal deposits.

Table 5 Type of the primary tumor discovered during the scan for the patients presenting with unknown primary

Type of Tumor on CT (*N* = 8)	Breast	3	37.5%
	Colon	1	12.5%
	HCC	1	12.5%
	Lymphoma	1	12.5%
	Ovary	2	25.0%

Table 6 Peritoneal metastasis visibility on CT

	N	%
Visible on CT		
Visible	27	45.0
Not visible	33	55.0

So according to the conventional CT criteria only we had 27 true positive patients, 33 false negative patients, and 10 true negative patients. When we added the PET CT criteria eventually we had 58 true positive patients, 2 false positive patients, 8 true negative patients, and 2 false negative patients, and. These results were interpreted and we were able to calculate the Accuracy, sensitivity, and specificity for both conventional CT and PET CT. Conventional CT had percentages of 52.85% accuracy, 45% sensitivity, and 100% specificity for the peritoneal deposits. PET CT had 94.3% accuracy, 96% sensitivity, and 80% specificity. Wang and Chen. et al28 made a systemic review in detecting peritoneal metastasis of gastric cancer. They meta-analyzed 4 PET-only studies. This resulted in low pooling sensitivity of 28% and high pooling specificity of 97% in detecting PC of gastric cancer. Joon Seok Lim, MD1 Myeong-Jin Kim, MD1 study found by analyzing the original preoperative reports, showing that CT had a higher sensitivity (76.5% vs 35.3%), a lower specificity (91.6% vs 98.9%), with an equal accuracy (89.3%) when compared with the PET imaging. The higher sensitivity of CT in the clinical setting of peritoneal carcinomatosis will help physicians to avoid unnecessary surgery in patients with peritoneal metastasis. The higher specificity of PET suggests it may be helpful in equivocal cases on CT, as well as avoiding missing the chance for performing curative surgery. Turlakow et al. have reported the superior sensitivity of PET to CT for their patients who had various malignancies [7]. Tanaka et al. demonstrate PET

Table 4 Number of patients whose primary tumor was detected after the scan

Type of Tumor on CT for unknown primary patients (*N* = 11)	Discovered after the scan	8	72.7%
	Unknown	3	27.3%

sensitivities are superior to CT for the evaluation of peritoneal recurrence of the colorectal tumor [12]. Different known limitations of PET imaging are associated with the relatively lower sensitivity or diagnostic performance for the preoperative detection of peritoneal metastasis [8]. The first is the spatial resolution of 4–5 mm or higher so small seeded peritoneal nodules may be missed with 18F-PET imaging, the low spatial resolution of PET imaging because of the physical characteristics of the PET scanner and the number of enrolled studies and the number of patients with every specified cancer was small and limited. So further studies with a larger sample size are needed to statistically confirm our results.

Conclusions

Detecting the peritoneal deposits with 18F-FDG PET/CT is rewarding and adds substantially to CT scanning. When a peritoneal biopsy is either unavailable or inappropriate it is a useful diagnostic tool. The high specificity and high positive ratio provide the reliability of 18F-FDG PET /CT to detect peritoneal deposits [13]. PET/CT may be beneficial to surgeons when selecting appropriate patients to perform laparoscopy or laparotomy.

Abbreviations

PET/CT	Positron emission tomography and computed tomography
FDG	Fludeoxyglucose (18F)
Primary	1Ry

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Author contributions
NNA: Reviewing literature, data collection, write and revise the manuscript, HTAMY: Reviewing literature, data analysis, perform statistical manuscript editing prepare figure and tables. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was prospective study. This study was approved by the Research Ethics Committee of the Faculty of Medicine at Ain shams University in Egypt. All patients included in this study gave written informed consent to participate by their clinical and radiological data in this review.

Consent for publication
All patients included in this research gave written informed consent to publish the data contained within this study.

Competing interests
The authors declare they have no competing interests.

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