Limitations of CT During PET/CT

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Our aim was to determine the diagnostic limitations of low-dose, unenhanced CT scans performed for anatomic reference and attenuation correction during PET/CT. **Methods:** The Radiology Information System at our oncologic hospital was queried during the 9-mo period from July 2002 to April 2003 for patients with PET/CT scans and diagnostic enhanced CT within 2 wk of each other. One radiologist interpreted the CT portion of the PET/CT (CT^p) unaware of the PET results and the associated enhanced diagnostic CT (CT^d). A medical student compared this interpretation with the official report of the CT^d and listed all discrepancies between reports. A separate radiologist compared CT^p and CT^d images and classified true discrepant findings as due to lack of intravenous contrast, arm-position artifact, lack of enteric contrast, low milliamperage (mA), and quality of lung images. **Results:** Among 100 patients, the most common malignancies were lymphoma ($n = 37$), cancer of the colorectum ($n = 31$), and esophageal cancer ($n = 15$). Among 194 true discrepancies in which findings were missed at CT^p, causes were as follows: (a) lack of intravenous contrast (128/194, 66%), (b) arm-down artifact (17/194, 9%), (c) quality of lung images (26/194, 13%), (d) lack of enteric contrast (15/194, 8%), and (e) low mA (8/194, 4%). Discrepancies were seen most commonly in detecting lymphadenopathy and visceral metastases. **Conclusion:** Most missed findings on the unenhanced CT portion of the PET/CT scans were due to technical factors that could be altered. Discrepant findings would have led to altered management in only 2 patients, suggesting a role for limited repeat imaging to reduce radiation and use of valuable resources.

Key Words: PET/CT; diagnostic CT; limitations of CT

Diagnostic CT scanning has been the mainstay of oncologic imaging over the past 25 y. By the end of the 1990s, ^{18}F-FDG PET/CT was developed, offering the first opportunity to combine metabolic and anatomic information leading to a powerful new combined-modality imaging examination.

Methodologic and technical differences between the CT performed for anatomic localization and attenuation correction (CT^p) and a typical diagnostic CT scan (CT^d) include arm position (frequently down for CT^p), suspended respiration (vs. quiet breathing for CT^p), use of enteric contrast (variable in CT^p) and intravenous contrast materials (not typically used in CT^p), and levels of microamperage·seconds (mA·s) of radiation (much lower in CT^p).

The limitations of the CT^p are partly intuitive, based on the increased accuracy of CT using oral and intravenous contrast agents noted early on in the development of CT protocols (*1*). The functional information provided by PET when correlated with the CT anatomic information, in some clinical scenarios, served to overcome expected limitations incurred with the absence of intravenous or oral contrast. This has been most obvious in patients with lymphoma, where nodal disease status is not well predicted by size or morphology on CT as much as by metabolic activity on ^{18}F-FDG PET; thus, diagnostic CT scans have added little useful information beyond the anatomic coregistration provided (*2*). This has led to a proposed change in diagnostic approach, at least in lymphoma, wherein ^{18}F-FDG PET might be thought of as the only imaging test required. Aside from these direct investigations in patients with lymphoma, and the theoretic limitations of these low-dose, localizing, unenhanced CT scans, little practical data are available with regard to the limitations of this CT^p and the advantage of diagnostic CT in addition to PET/CT for other types of malignancies. Might a similar shift in diagnostic strategy with limited additional scanning be possible in patients with other types of malignancies?

The goal of this investigation was to document limitations of CT^p more specifically and to assist imaging specialists who may be less familiar with these limitations. By documenting the limitations in various organ systems and for various tumor types, we aimed to outline the advantages of either PET/CT with intravenous contrast or, if appropriate, suggest the need for limited additional diagnostic contrast-enhanced CT. Specifically, we aimed to elucidate what findings could be missed if only CT^p were performed in patients with various malignancies and how, if at all, this might affect their clinical course.

MATERIALS AND METHODS

Patients

This was a retrospective study approved by our institutional review board. Patient consent was deemed unnecessary.

We queried our Radiology Information System (Quadris, version 981218; ADAC HealthCare Information Systems) over a 9-mo period (July 2002 to April 2003) to find PET/CT scans performed consecutively at our institution. Inclusion criteria were patients with cancer who also had a diagnostic CT scan of the abdomen with or without the pelvis or chest with intravenous and oral contrast material also performed at our institution in patients of any age within 2 wk before or after the PET/CT.

PET/CT

All patients fasted for at least 6 h before imaging. All images were obtained with a dedicated PET/CT system that operates in 2-dimensional mode, has an axial field of view of 15.5 cm, and has an axial slice thickness (resolution) of 4.2-mm (full width at half maximum) intensity at the center of the field of view (Discovery LS; GE Healthcare). Images were acquired after intravenous injection of 555 MBq (15 mCi) ^{18}F-FDG and a 45- to 60-min uptake period and were reconstructed with a 28-subset, 2-iterations algorithm, 128×128 matrix, and CT-based attenuation coefficient. For anatomic localization and attenuation correction, CT (CT^p) was performed without intravenous iodinated contrast. Oral contrast, diatrizoate meglumine/sodium ([MD-Gastroview; Mallinckrodt] in 1,000 mL sterile water with raspberry ice Crystal Light, 2.26 g [Kraft Foods, USA]) or 2.1% (w/v) barium sulfate suspension, 2.0% (w/w) (Readi-Cat 2; EZ EM), was administered to 13 patients, 45 min before scanning. Scanning parameters included 120–140 kVp (kilovoltage peak), 64 average mA·s, 5-mm slice thickness, and 4.25-mm table increment. Patients were scanned supine with their arms at their sides during quiet respiration.

Diagnostic CT (CT^d)

Within 2 wk before or after PET/CT, CT^d was performed on a multislice helical scanner with either 4- or 8-detector rows using 140 kVp, variable mA·s depending on body habitus (average = 290 mA·s), beam pitch 0.9375–1.375, 0.5- to 0.8-s tube rotation speed, and 5-mm slices (Lightspeed and Lightspeed Ultra; GE Healthcare). Oral contrast, 1,000 mL, was administered 45–60 min before scanning (diatrizoate meglumine and diatrizoate sodium solution [Gastroview]; Mallinckrodt). In patients who received oral contrast immediately before for CT^p, 8–16 oz additional contrast was administered to fill the stomach. Nonionic intravenous contrast, 150 mL, was administered at a rate between 1.5 and 4.0 mL/min, depending on venous access and scan type (Omnipaque 300; GE Healthcare).

Image Analysis

One body imager with >10-y experience in interpreting body CT interpreted the CT^p unaware of the images and report of the associated PET scan and the comparison CT^d performed within 2 wk. Results were directly transcribed by a medical student. All studies were visualized on a PACS (Centricity PACS 2.1; GE Healthcare), using the scroll function and with liberal use of variable window/level settings to overcome the limitations of the lack of intravenous contrast.

Subsequently, the medical student compared the transcribed official report of the CT^d with the interpretation of the matching CT^p and listed discrepant findings by anatomic region and organ system, noting the finding, date of the scan, and image number. Patient demographics and primary malignancy were also recorded.

A second abdominal imager with >5 y experience interpreting abdominal CT was prompted to classify each discrepant finding by performing a side-by-side comparison of CT^p and CT^d on PACS. Discrepancies were identified as 5 "true" discrepancy categories: "IV", "Lung", "Arm-down", "Enteric", and "Low mA". Other discrepancies were identified as 4 "false" discrepancy categories: "Insignificant", "Perceptive", "Interpretive", and "Patient". "IV" was defined as a discrepancy that was thought to be due to the lack of intravenous contrast used in the CT^p (e.g., nonenhancement of liver lesions, inability to distinguish lymph nodes from vessels or other structures) (Fig. 1). "Lung" was defined as a discrepancy due to either the lack of use of an edge-enhancing algorithm ("lung" kernel) to reconstruct the images (in which a nodule or focus of ground-glass opacity was unable to be resolved) or due to respiratory artifact (e.g., motion, poor inspiration, mosaic perfusion, etc.) typically seen at non−breathold CT^p (Fig. 2). "Arm-down" was defined as a focal beam-hardening artifact obscuring findings on the CT^p that were well seen on CT^d (Fig. 3). "Enteric" was defined as a finding missed due to a lack of administration of oral or rectal contrast on the CT^p (e.g., bowel, mesenteric, and nodal lesions) (Fig. 4). "Low mA" was defined as a finding not appreciated on the CT^p because of overall graininess of the image (global beam-hardening) (Fig. 5). "Patient" was defined as a change in radiographic findings that could be explained by a change in the patient's clinical condition in the time interval (0–14 d) between CT^p and CT^d (e.g., development of
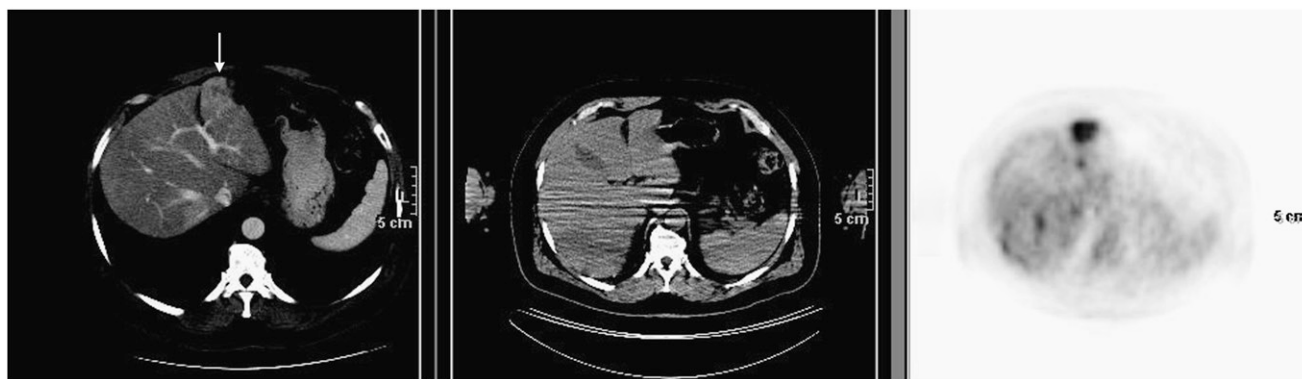
FIGURE 1. Patient with colorectal cancer with hepatic metastasis in left hepatic lobe seen on CT^d (arrow) but not on CT^p. Corresponding PET image confirms metastasis. This was considered a potentially significant finding. Treatment was not changed as it was seen on PET portion of scan.
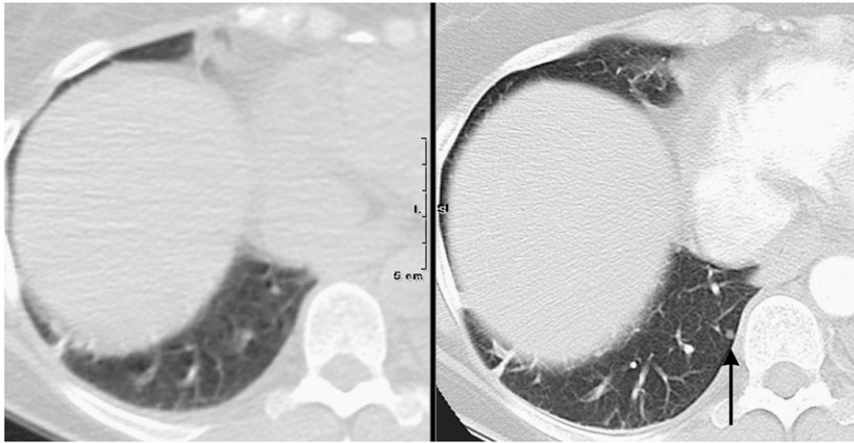
FIGURE 2. Patient with non–small cell lung cancer and increasing metastatic disease with new lung and liver (not shown) lesions. Small subpleural nodule (arrow) was not seen on CTp likely due to both breathing and non–edge-enhancing algorithm. Note that such a nodule would be unlikely to be seen on PET because of its small size, and its visualization on PET/CT would rely on better-quality lung images only. This was not considered a significant finding as generalized increase in metastatic disease was noted.

pleural effusions or lung infiltrates or ascites). "Insignificant" was defined as a clinically unimportant incidental finding (e.g., bone island or a subcentimeter renal low-density lesion too-small-to characterize mentioned in only 1 report, either CTd or CTp, etc.). "Perceptive" difference was defined as an abnormality that was present on both CTp and CTd but was not mentioned in the review of CTp because of oversight. "Interpretive difference" was defined as an abnormality that was present on CTp and CTd but was of a more subjective nature and interpreted differently (e.g., prostate enlargement, cardiomegaly, splenomegaly, or adrenal thickening).

Further analysis consisted of review of the official PET scan report, PET images as needed, and the electronic medical record for clinical notes, laboratory values, surgical and biopsy results, and follow-up imaging results for 36 mo.

On the basis of this chart review of all true discrepancies, the following were determined by one attending physician and the radiology resident (medical student at beginning of project): (i) which discrepant findings were of potential clinical significance (e.g., could change the cancer stage or treatment [based on the accepted approach for staging and treatment at the authors' institution] because of increase or decrease in existing disease or new disease appearing or could require intervention because of infection, hemorrhage, or bowel, biliary, or renal obstruction or deep venous thrombosis, aneurysm, fracture, etc.); (ii) which potentially significant discrepant findings, determined by CTd to have been overlooked on CTp, were diagnosed nonetheless on the basis of PET findings; (iii) which potentially significant findings were missed both on CTp and PET but seen on CTd; (iv) which patients, among group iii, incurred a change in management. A change in management was defined as a change in type, dose, or schedule of administration of chemotherapy or radiotherapy, cessation or commencement of the same plan or a new plan for surgery, excisional biopsy, or a change in extent or approach of surgery, or cancellation of surgery. Change in management could also include performance of an invasive procedure, commencement or cessation of anticoagulation, antibiotics, and other nononcologic medical or surgical treatment.

RESULTS

PET/CT and diagnostic CT scans of 100 patients (62 male, 38 female; average age, 55.6 y; range, 4–83 y) were reviewed. All PET/CT scans were full-body scans. Diagnostic CT scans encompassed the chest, abdomen, and pelvis (n = 85); the chest and abdomen only (n = 10); and the abdomen and pelvis only (n = 5). Malignancies included the following: lymphoma (n = 37); colorectal cancer (n = 31); esophageal cancer (n = 15); 2 each of cholangiocarcinoma, lung cancer, neuroblastoma, and soft-tissue sarcoma; and 1 each of breast, gallbladder, gastric, hepatocellular, pancreatic, prostate, unknown primary cancers, and myelodysplastic syndrome and melanoma.

Thirteen patients received oral contrast on CTp (13%). Twenty-eight patients underwent CTd after PET/CT (28%; average, 5.3 d), 22 underwent CTd before PET/CT (22%; average, 2.6 d), and 50 underwent CTd on the same day.

There were 482 total discrepancies between the interpretation of the CTp and the dictated report of the CTd. The average number of discrepancies per scan was = 4.8 (range, 0–17). There were 288 discrepancies that did not
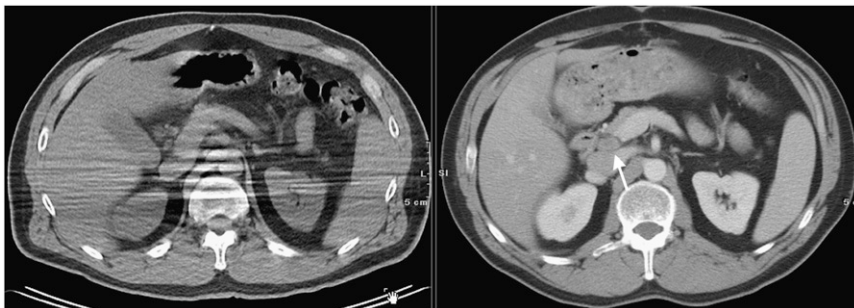
FIGURE 3. Patient with colorectal cancer with portacaval lymphadenopathy (arrow) obscured by localized beam-hardening artifact from arm-down position. This was not considered a significant finding as it was unchanged and was seen on PET.

FIGURE 4. Patient with lymphoma and nodules in terminal ileum (arrow). These are not appreciated on CT^p without benefit of oral contrast. This finding was considered clinically significant as it could represent extranodal spread of lymphoma. It was proven to be Crohn disease after colonoscopy and surgical removal.

represent true discrepant findings between the CT^p and the CT^d scans, including 110 perceptive differences, 86 interpretive differences, 84 insignificant differences, and 8 changes in patients' clinical conditions. There were 194 true discrepancies (80 patients), with an average of 2.4 per patient (range, 1–8) (Table 1; Fig. 6). Sixty discrepancies (31%) were judged to be potentially significant.

Twenty-six (43%) of these 60 discrepant findings, though missed on CT^p, were diagnosed in 22 patients on the PET scan portion of the PET/CT in patients with colorectal cancer ($n = 8$), lymphoma ($n = 7$), esophageal cancer ($n = 3$), and 1 each of cholangiocarcinoma, gallbladder cancer, neuroblastoma, and pancreatic carcinoma.

Thirty-four potentially significant findings missed on PET and on CT^p but seen on CT^d were noted in 24 patients with colorectal cancer ($n = 10$), lymphoma ($n = 7$), esophageal cancer ($n = 3$), and 1 each of cholangiocarcinoma, neuroblastoma, lung, and gastric cancer (Table 2). These occurred in lymph nodes ($n = 8$), viscera ($n = 22$), and soft tissues ($n = 4$). As can be seen in Table 2, the vast majority of these discrepancies were caused by the lack of intravenous contrast. This obscured the true size or number of hypo- and hypervascular liver metastases or of biliary

dilatation or obscured the recognition of lymph nodes. Other reasons included focal beam-hardening from the arm-down position obscuring liver lesions or lymph nodes, obscuration of lung nodules from a smooth lung algorithm, and obscuration of bowel wall thickening or luminal masses from lack of oral contrast.

Chart review of these 34 cases indicated that most discrepant lesions were not pursued because of the widespread disease in these patients such that treatment would not have been altered. However, discrepant findings would have led to a change in management in 2 patients (2/46 patients, 4%). The changes consisted of the performance of a cystoscopy in a patient with lymphoma to work up a mass missed on the CT and PET portions of the PET/CT near the bladder. The mass seen on CT^d was worrisome for lymphoma versus bladder cancer (patient was a smoker). Cystoscopy was normal, and after chemotherapy (being given for lymphoma anyway) the mass shrunk, indicating that it was probably lymphoma. In a second patient with lymphoma, colonoscopy and surgical removal of the neoterminal ileum was required to diagnose the cause of the nodules (Crohn disease) in the ileum not seen on the CT or PET portions of the PET/CT due to the lack of oral contrast but well seen
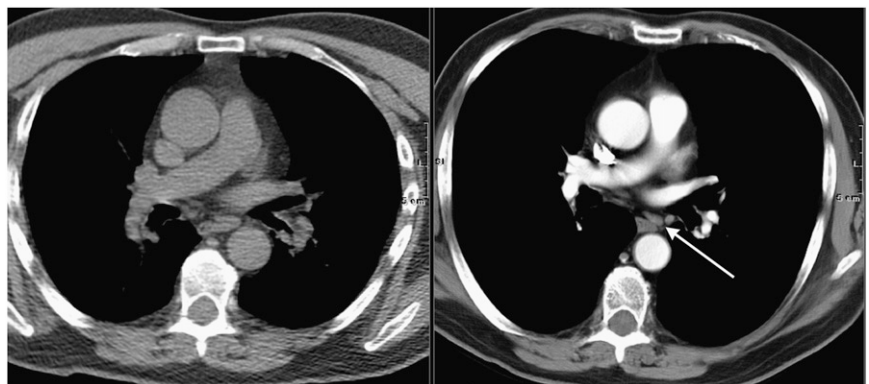
FIGURE 5. Patient with esophageal carcinoma. Small regional lymph node (arrow) is suggestive of metastases because of location (not size). It is difficult to resolve from esophagus itself because of overall beam-hardening. This was not considered significant as liver and bone lesions were seen on PET.

TABLE 1
Discrepancies Between CT^p and CT^d ($n = 482$)

Discrepancy	Category	No. of discrepancies	Percentage of true discrepancies
True		194	
	IV	128	66
	Lung	26	13
	Algorithm	14	7
	Respiratory	12	6
	Arm-down	17	9
	Enteric	15	8
	Low mA	8	4
False		288	
	Interpretive	86	30
	Insignificant	84	29
	Perceptive CT^p	78	27
	Perceptive CT^d	32	11
	Patient change	8	3

on CT^d. Thus, the change in management of the 2 patients was due to use of invasive diagnostic examinations ($n = 2$) and the need for an operation ($n = 1$) (Fig. 7).

With respect to hepatic versus extrahepatic discrepancies for the 3 most common malignancies, colorectal cancer showed a fairly even distribution of overall true and potentially significant discrepancies between hepatic and extrahepatic sites; lymphoma and esophageal cancer showed a predominance of true and potentially significant discrepancies in extrahepatic over hepatic sites (Tables 3 and 4).

Pelvic region discrepancies were found in only 13 patients. Six were deemed potentially significant, of which 3

were noted on PET. One finding led to the need for an additional procedure (change in management) (Table 5).

DISCUSSION

The development of whole-body PET scanners using readily available tracers such as ^{18}F-FDG represented a tremendous contribution to the diagnostic armamentarium of cancer imaging. However, the metabolic information provided by ^{18}F-FDG uptake alone did not provide adequate image resolution to afford accurate anatomic localization of diseased areas. This prompted the development of combined PET/CT scanners (*3*), packaging multislice helical scanners (e.g., 16- to 64-row detector scanners) with whole-body PET scanners), and allowing high-quality multiplanar reformatted isotropic data for fusion with PET. Although the CT portion of the scan was used mainly for anatomic coordination and for rapid attenuation correction, it became apparent that it might contain valuable information, especially if oral and or intravenous contrast were administered. Controversy with regard to the administration of oral or intravenous iodinated contrast material exists due to technical, economic, workflow, and radiation safety concerns. In our institution, if diagnostic CT is desired, it may be done on the same machine for patient convenience just after the completion of the PET/CT with a dynamic injection of intravenous contrast. Oral contrast is routinely given for the localizing CT to assist in the localization of abnormalities within or adjacent to bowel. However, several institutions have also begun to administer intravenous contrast material with the PET/CT for the localizing scan to allow the "localizing" CT to become
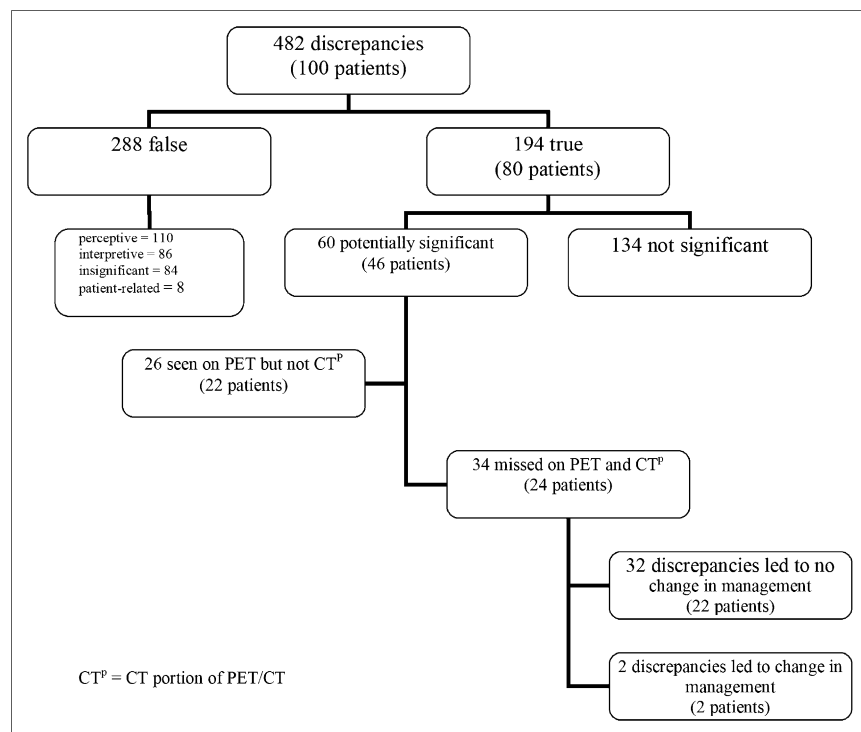
FIGURE 6. Box diagram outlining results of analysis of PET/CT scans by discrepancy and patient.

Discrepant organ	No.	Malignancy	Description	Category
Lymph nodes	8			
Chest	3	Lymphoma	Paratracheal node, 0.7 cm	IV
		Neuroblastoma	Paratracheal node, 0.7 cm	IV
		Neuroblastoma	Bilateral axillary nodes, largest 1.3 × 0.9 cm	Arm
Abdomen	3	Colorectal	Periportal node, 2.8 × 1.4 cm	IV
		Gastric	Perigastric node, 0.8 cm	IV
		Neuroblastoma	L paraaortic node, 0.6 cm	IV
Pelvis	2	Neuroblastoma	L common iliac, 0.7 × 0.5 cm/R external iliac nodes, 0.6 × 0.5 cm	IV
		Colorectal	Sigmoid mesenteric nodes, 0.5 cm	mA
Viscera	26			
Lung	2	Lung	Nodule, 0.6 cm	Lung algorithm
		Colorectal	Bilateral nodules, largest 0.7 cm	Lung algorithm
Liver	16	Colorectal	Size discrepancy in hepatic metastases	IV
		Colorectal	Segment 4, 2.5 × 1.5 cm	IV
		Colorectal	Segment 5, 1.7 × 0.7 cm	Arm
		Colorectal	Segment 8, 1 × 0.6 cm	Arm
		Colorectal	New mild biliary dilatation	IV
		Lymphoma	Increased biliary dilatation	IV
		Esophageal	Segment 5, 1.2 × 1.2 cm	IV
		Colorectal	Segment 3, 0.9 × 0.3 cm	IV
		Colorectal	Increased severe R biliary dilatation	IV
		Cholangiocarcinoma	Segment 6/hepatic dome, subcentimeter lesions	IV
		Lung	Segment 7, 2.7 × 2.3 cm	Arm
		Lung	Segment 2, subcentimeter hypervascular foci	IV
		Colorectal	Scattered lesions, largest 2.8 × 1.8 cm	IV
		Esophageal	Segment 2, subcentimeter lesion	IV
		Esophageal	Segment 7/8, 1.9 × 1.1 cm hypervascular lesion	IV
		Esophageal	Segment 6, subcentimeter hypervascular lesion	IV
Kidney	1	Lymphoma	Slight delay in L kidney excretion	IV
Bowel	3	Lymphoma	Soft tissue in gastric antrum	Oral
		Lymphoma	Filling defects in terminal ileum*	Oral
		Esophageal	Gastric fundal thickening	Oral
Soft tissue	4			
Peritoneum		Colorectal	Peritoneal carcinomatosis	Resp. Art.
Chest		Colorectal	Subcutaneous nodules	mA
Chest		Lymphoma	Postmediastinal soft tissue	IV
Pelvis		Lymphoma	Prevesical, 6.3 × 3.3 cm soft-tissue mass*	IV

*Management was changed in this case.
Resp. Art. = respiratory artifact.

"diagnostic" and to avoid the necessity of a repeat examination with its additional radiation, cost, and use of valuable and potentially limited resources. In fact, attenuation correction tables have been created for contrast-enhanced CT scans (4). This would seem to be the most economical protocol overall from the standpoint of time and radiation exposure, although there are reports that the intravenous contrast can result in an overestimation of the standardized uptake value (SUV) arising from elevated CT attenuation in areas of focal intravenous contrast accumulation, such as the vessels or parenchymal organs. The amount of the SUV overestimation is not significant in tumor (2,4–9). Several other investigators have recently confirmed the feasibility of using intravenous contrast in various types of modified injection protocols allowing combined diagnostic CT with PET (10–12).

Oral contrast may affect the CT-based attenuation (2,13,14). The resulting attenuation-corrected PET activity can be overestimated by as much as 20%, but with an average of 4.4% with standard dilutions of positive oral contrast (13,15). Many centers either withhold oral contrast or administer a neutral density oral contrast to help distend and identify the intestines, without interfering with attenuation mapping (16).

Studies comparing staging information gained from PET/CT with diagnostic CT have shown that, for esophageal and colorectal cancer, impact on patient care from more accurate staging can occur in 20%−30% of cases

FIGURE 7. A 63-y-old man with lymphoma and mass above bladder with low standardized uptake value, not prospectively identified on PET or CT[p] but well seen on CT[d]. Note lower bladder volume on PET/CT.

(17,18). Some studies have even suggested that in tumors such as lymphoma and gastrointestinal stromal tumor, little or no additional information is gained with diagnostic CT after performance of PET/CT (2,19–21). As such, at least for lymphoma, the possibility that only PET/CT is necessary without any additional diagnostic CT was posited. This shift in clinical approach is intriguing and needs further delineation, especially for other tumor types.

Though such issues are still unsettled, we attempted to assess the actual diagnostic limitations in a group of oncologic patients undergoing PET/CT by comparing the findings with the subsequent diagnostic CT. Our goal was to determine limitations of CT[p] and to determine whether the current method of performance of PET/CT was optimal or could be improved. Finally, we aimed to assess whether all patients benefited from additional diagnostic full-body CT scans and, if not, which types of patients might need only limited, if any, additional scanning.

In our group of patients, the major cause for discrepant findings between PET/CT and diagnostic CT was the lack of intravenous contrast material. This most often led to undetected liver metastases or poor lymph node recognition and most often was apparent in patients who were likely to have liver metastases and undergo PET/CT—that is, patients with colorectal cancer. Some metastases could be seen on PET/CT if a wide window/level was applied to the CT image or if the metastases were large or metabolically active enough to be seen on PET. If further experience confirms that the intravenous contrast bolus can be given without interfering with CT attenuation mapping or tumor activity assessment, there should be no reason to perform duplicate CT scans and incur extra radiation and use extra time and resources unnecessarily. Work in progress suggests that PET/CT can be performed with intravenous contrast, despite earlier fears.

The second most common limitation of PET/CT compared with diagnostic CT in our group of patients occurred in the category of missed lung findings, either due to the occurrence of motion artifact from quiet respiration compared with breath-hold diagnostic CT or, surprisingly, due

to the easily correctable reconstruction kernel used when displaying lung images. Although faster scanners with more detectors are being integrated, this will not overcome the motion artifacts from the quiet breathing technique used to match the PET acquisition.

The third most common reason for discrepant findings was the arm-down position used for all patients during PET/CT to allow comfort during prolonged PET and also used for the CT portion to avoid shifting anatomy and interference with anatomic coregistration. This resulted in a beam-hardening artifact most severe in the same horizontal plane in which the arms were resting. Development of faster more efficient collimator crystals could ideally allow for more rapid, arm-up PET as is done in routine diagnostic CT. Fortunately, the majority of our patients are now able to undergo arm-up positioning during the entire PET and CT acquisition.

Occasionally, a lack of oral contrast caused discrepant findings. However, it should be noted that 87% of cases were done without oral contrast, and the vast majority of discrepancies in these cases were unrelated to the lack of oral contrast. Thus, oral contrast seems to make little difference, probably because intestinal abnormalities are uncommon overall or because of the ease of identifying the intestines in all but the slimmest of patients.

The final category, accounting for only 4% of discrepancies, was the use of low mA·s for PET/CT. This was the reason that findings were thought to have been missed in only 4% of scans. This interesting, incidental observation is in keeping with suggestions in the literature that excessive doses of radiation are used routinely in CT scans and are unnecessary for diagnostic images (22–24).

A large number of discrepancies in this study were accounted for by perceptive, interpretive, or insignificant differences between the scans that did not represent true differences between the scans. Reader variability is common in interpretation of imaging studies, especially for such entities as abnormal lymph nodes at or around the 1-cm size, as well as enlargement of organs such as the prostate, heart, and spleen, for which differing values are

TABLE 3
Hepatic vs. Extrahepatic Findings (of 194 True Discrepancies)

Malignancy	Total no. of discrepancies	Hepatic (%)	Extrahepatic (%)
Colorectal	72	29 (40)	43 (60)
Lymphoma	48	7 (15)	41 (85)
Esophageal	25	9 (36)	16 (64)
Lung	8	4 (50)	4 (50)
Gastric	8	2 (25)	6 (75)
Cholangiocarcinoma	7	5 (71)	2 (29)
Neuroblastoma	7	2 (29)	5 (71)
Gallbladder	5	4 (80)	1 (20)
Pancreatic	4	3 (75)	1 (25)

Data are expressed as number or number with percent in parentheses.

published. The seemingly large number of perceptive errors (most often multiple errors in only a few patients) we encountered consisted of 78 findings missed on retrospective review of CT^p and 32 findings on the official report of CT^d. A sampling of these showed that despite the experience of the readers, these "nontrue" discrepancies were perhaps due to haste in reading cases or reader fatigue (e.g., a small subpleural lung nodule or a small inconspicuous liver lesion or heterogeneous body density) or differences in what radiologists consider important to mention in a report (e.g., a calcified subcarinal lymph node or cholelithiasis or a tiny kidney calculus without obstruction). We believe that these discrepancies can be found in any study involving inter- or intraobserver variability and do not reflect actual image-quality limitations such as we found in our other well-defined categories.

This study had some limitations. Our patients are from a tertiary cancer center that, on average, could have more advanced disease than the overall population of patients undergoing PET scans elsewhere. As such, additional metastases that were detected in this group on CT^d but not on CT^p may have made little difference to the overall stage or treatment. Second, in certain instances it was

TABLE 4
Hepatic vs. Extrahepatic Findings (of 60 Potentially Significant Discrepancies)

Malignancy	Total no. of discrepancies	Hepatic (%)	Extrahepatic (%)
Colorectal	23	12 (52)	11 (48)
Lymphoma	16	3 (19)	13 (81)
Esophageal	7	3 (43)	4 (57)

Data are expressed as number or number with percent in parentheses.

difficult to determine whether the lack of intravenous contrast or beam-hardening artifact (or both?) was the cause of the discrepant readings in some cases of obscured liver metastases. Possibly, an even greater number of discrepancies were due to the lack of intravenous contrast, only adding to the importance of using intravenous contrast. Finally, the reading of CT^p in a study setting as opposed to the reading of CT^d in a clinical setting may introduce a bias that results in a more accurate reading of CT^p compared with CT^d. The likely effect of this would be a greater number of discrepancies—for example, missed liver lesions seen only after careful windowing performed here in the controlled readout session.

Although a larger study with cost/benefit analysis would be optimal, our study suggests that CT could be tailored during PET/CT in the following manner: (i) Patients with colorectal cancer and other epithelial primary malignancies will probably need full-body diagnostic scans because about one half of discrepancies occurred in sites outside of the liver, including small peritoneal implants and small lung nodules; (ii) For patients with lymphoma in whom nodal disease predominates and in which size estimates fail to predict disease on CT, our results parallel those in the literature, suggesting that the CT^p scan that accompanies the PET scan may be adequate; (iii) For all patients if repeat CT^d scanning is to be done, it could be limited to the chest and abdomen as little additional information seems to be gained from the pelvic portion of CT^d scans; (iv) Although tailored strategies may be ideal, a more empiric and simple approach would be for all patients to undergo enhanced PET/CT as recent literature indicates that this is increasingly feasible.

CONCLUSION

In summary, we found that most discrepancies between the unenhanced, localizing, low-dose CT and the subsequent diagnostic CT were due to the lack of intravenous contrast, which obscured liver metastases and lymph node recognition. Easily altered technical factors could overcome the limitations of overall grainy images (low mA·s), focal beam-hardening (arm-down position), and poor-quality lung images (use of a non–edge-enhanced algorithm). Nonetheless, discrepant findings would have led to altered management in only 2 patients, suggesting that limited repeat imaging may be feasible and would have the added benefit of reducing radiation and use of valuable resources. Because workflow and economic concerns are part of our daily practice, those institutions that prefer to use unenhanced CT in PET/CT could do so confidently, particularly because past studies on lymphoma patients and our study suggest a limited need for follow-up scans using diagnostic CT. For those centers in which it is logistically feasible, conversion to the use of a normal mA·s dose, with oral and intravenous contrast-enhanced CT in PET/CT, could overcome all potential discrepancies and provide the additional

TABLE 5
Thirteen Pelvic Discrepancies Among 194 True Discrepancies

Malignancy	Discrepant finding	Discrepant category	Significant	Seen on PET
Colorectal	Bladder diverticulum	mA		
Colorectal	Thickened bladder	IV		
Colorectal	<5-mm sigmoid mesenteric nodule	Oral	Yes	
Colorectal	Residual tumor	Oral	Yes	Yes
Colorectal	Rectal soft tissue	Oral	Yes	Yes
Colorectal	Sigmoid and transverse colon thickening	Oral		
Colorectal	Enhancing mass in postoperative bed	IV	Yes	Yes
Lymphoma	Prominent ovarian vein	IV		
Lymphoma	Prevesical soft-tissue mass	IV	Yes*	
Lymphoma	Pelvic ascites	Oral		
Lymphoma	Uterine lobulation	IV		
Neuroblastoma	L common and R external iliac adenopathy	IV	Yes	
Breast	Leiomyomas	IV		

*Management change in this case = performance of cystoscopy to exclude bladder primary abnormality.

advantage of reducing patient radiation exposure, patient and institutional cost, and use of valuable and limited resources.

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