Initial Experience with Oral Contrast in PET/CT: Phantom and Clinical Studies

Christian Cohade, MD[1]; Medhat Osman, MD, PhD[1]; Yuji Nakamoto, MD, PhD[1]; Laura T. Marshall, BS[1]; Jonathan M. Links, PhD[2]; Elliot K. Fishman, MD[3]; and Richard L. Wahl, MD[1]

[1]Division of Nuclear Medicine, Russell H. Morgan Department of Radiology and Radiological Sciences, Johns Hopkins Hospital, Baltimore, Maryland; [2]Department of Environmental Health Sciences, Johns Hopkins School of Public Health, Baltimore, Maryland; and [3]Diagnostic Imaging Section, Russell H. Morgan Department of Radiology and Radiological Sciences, Johns Hopkins Hospital, Baltimore, Maryland

The aims of the study were to evaluate the effects of oral contrast on apparent tracer activity measured with PET/CT when using CT attenuation correction and to report our initial experience in the use of oral contrast with PET/CT. **Methods:** Phantom studies with ^{18}F activity and saline bags or syringes filled with barium or gastrografin of varying densities were performed using a PET/CT scanner (CT attenuation correction). In the study, 91 clinical patients received dilute oral contrast and were evaluated by whole-body ^{18}F-FDG PET. **Results:** A phantom experiment with CT contrast (1.3% weight/volume [w/v] barium) showed a "cold" area in the cold stomach whereas a phantom with high-density barium (98% w/v) showed an artifactual focus of intense "activity" in the cold stomach. In clinical studies, stomach and right colon were opacified by CT contrast. Maximal measured contrast density was 239 Hounsfield units. **Conclusion:** High-density barium causes overestimation of tissue ^{18}F-FDG concentration. Low-density barium does not cause significant artifacts and appears suitable for clinical use.

Key Words: PET/CT; ^{18}F-FDG; oral contrast; artifact

J Nucl Med 2003; 44:412–416

In CT scanning, the use of positive oral contrast has been shown to allow better definition of the bowel (*1–3*). Oral contrast might help in interpreting PET/CT images, allowing better discrimination between physiologic and pathologic abdominal uptake. Because artifactually increased activity in the presence of radiodense objects has been reported with CT attenuation correction (*4*), oral contrast is also a potential cause of artifacts on PET/CT in cases of overestimation of 511-keV photon attenuation and overcorrection of images. During our initial PET/CT experience, CT-corrected PET images in a patient who had consumed high-density barium for other purposes revealed an artifact of "increased" gastric activity that was unseen on the uncorrected images (Fig. 1).

The purpose of this study was to evaluate in phantom studies whether oral contrast could affect apparent PET tracer "activity" when using CT attenuation correction. We also assessed our initial clinical experience with oral contrast.

MATERIALS AND METHODS

Data Acquisition

Scanning was performed using a PET/CT scanner (Discovery LS; GE Medical Systems, Waukesha, WI). Emission data were acquired for 5-7 positions at 5 min per position and were reconstructed using CT for attenuation correction (ordered-subset expectation maximum algorithm). The parameters of the multidetector helical CT were 140 kVp, 80 mA, 0.8 s per CT rotation, pitch of 6, and 22.5 mm/s table speed. The conversion scale used to transform Hounsfield units (HU) into attenuation coefficients was described previously (*5*).

Phantom Studies

The first 2 experiments were performed with a phantom filled with 74 MBq ^{18}F activity (0.24 mCi/mL) and a saline bag filled with CT oral contrast (READY CAT barium sulfate suspension, 1.3% weight/volume [w/v]; E-Z-EM Inc., Westbury, NY) and high-density barium (E-Z-HD barium sulfate suspension, 98% w/v; E-Z-EM Inc.), respectively (to simulate a contrast-filled stomach). In the third experiment, 8 syringes filled with varying concentrations (100%, 80%, 60%, 40%, 20%, 10%, 1%, and 0%) of MD-Gastroview (Mallinckrodt Inc., St. Louis, MO) were placed in a cylindric phantom containing 74 MBq ^{18}F activity diluted with water (0.35 mCi/mL).

In all experiments, CT was performed, followed by emission and transmission scanning with ^{68}Ge (3 min per position). Two datasets of PET images with ^{68}Ge and CT-based correction and 1 without attenuation correction were reviewed by an experienced nuclear medicine physician using eNTEGRA software (ELGEMS, Haifa, Israel). Images were reviewed for abnormal uptake in the region of the stomach present on the attenuation-corrected images

Received May 24, 2002; revision accepted Oct. 4, 2002.

For correspondence or reprints contact: Richard L. Wahl, MD, Division of Nuclear Medicine, Russell H. Morgan Department of Radiology and Radiological Sciences, Johns Hopkins Hospital, 601 N. Caroline St., Room 3223, Baltimore, MD 21287-0817.

E-mail: rwahl@jhmi.edu

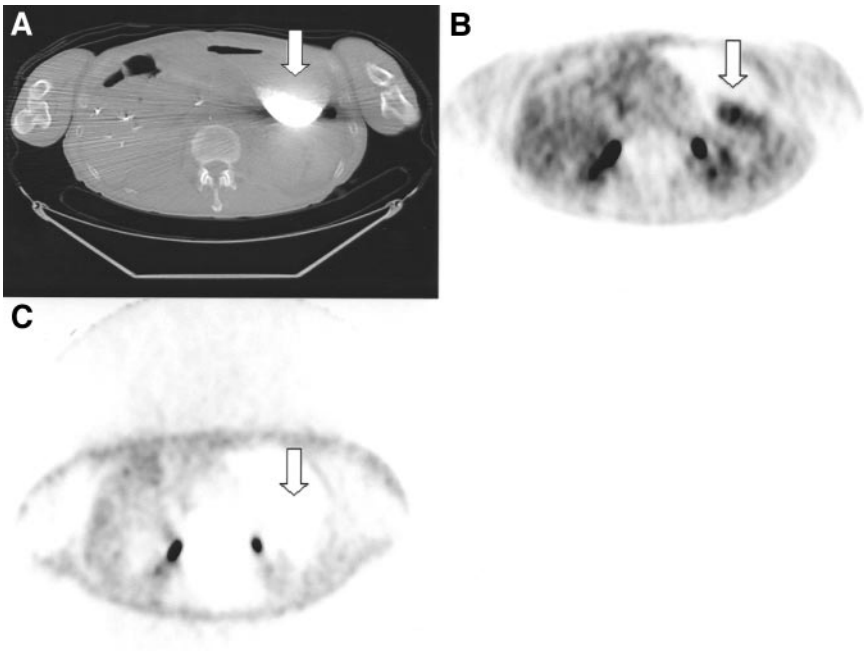

FIGURE 1. Sixty-year-old man with rising CA19-9 level and history of pancreatic cancer after therapy was evaluated by ^{18}F-FDG PET for suspected tumor. Patient had ingested barium for upper gastrointestinal study 1 week before PET/CT study without additional contrast being administered. CT (A; arrow) showed residual, dense barium in distended stomach consistent with high-grade gastric outlet stenosis. CT attenuation-corrected PET emission images (B; arrow) showed area of increased activity in stomach corresponding to barium retention on CT (max CT Hounsfield units = 3,071). However, no increased uptake was seen in gastric lumen in nonattenuation-corrected images (C; arrow). SUV_{LEAN} for high-activity gastric artifact was 5.31 maximum and 3.81 mean.

and absent on the noncorrected images. For the third experiment, a 1.91-cm^2 region of interest (ROI) was used to measure the "activity" and contrast density for each syringe.

Patient Studies

A total of 108 clinical patients were evaluated retrospectively by whole-body ^{18}F-FDG imaging after oral contrast utilization was initiated. Patients received 2 bottles (450 mL per bottle) of CT contrast (barium suspension; 1.3%) at least 10 min before receiving a 555- to 740-MBq ^{18}F-FDG intravenous injection, followed by another bottle of contrast 40 min later.

Image Analysis

One experienced reader performed image analysis using eNTEGRA software. Patient compliance with contrast ingestion and quantity of contrast were reviewed. The extent of bowel opacification was categorized as absent, partial, or adequate on the CT images. For the first 30 patients receiving oral contrast, density of contrast in the digestive tract was measured in HU using a manually drawn ROI. The maximum diameter in millimeters of the gastric lumen, evaluated in a transverse section of the midportion of the stomach, was then measured for CT and PET images. PET window levels were adjusted for each patient to those used for clinical interpretation (liver activity set to moderate gray intensity). A soft-tissue window (minimum = − 250 HU; maximum = +250 HU) was used for CT. The possible effect of oral contrast ingestion on neck muscle uptake was evaluated in 2 groups of 20 patients (with and without contrast) by measuring metabolic activity in several neck muscles using a circular ROI (6-pixel area).

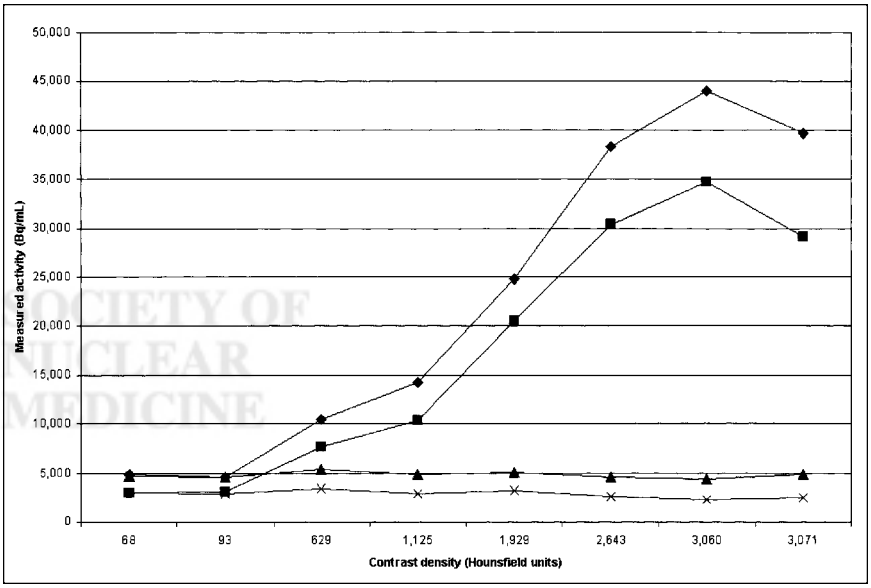

FIGURE 2. Phantom with syringes filled with variable concentrations of gastrografin, plotted as measured emission data activity (in Bq/mL) versus measured contrast density by CT (in Hounsfield units [HU]). Maximum (◆) and mean (■) measured activity with CT attenuation correction, and maximum (▲) and mean (✕) measured activity with ^{68}Ge attenuation correction are displayed. Drop in measured activity is observed for high-density contrast. In this region, "real density" is >3,071 HU, but the PET/CT system plateaus at this level. Thus, overcorrection in presence of high-density contrast also has plateau corresponding to 3,071 HU density. However, because of increased true attenuation as result of increasing "real" density, measured counts decrease, resulting in drop in curve.

TABLE 1
Extent of Bowel Opacification by Oral Contrast

Opacification	Stomach	Small bowel	Right colon	Transverse colon	Descending colon	Rectosigmoid
Adequate	88	90	80	64	31	13
Partial	0	0	2	2	7	9
Absent	3	1	9	25	53	69

Data are expressed as number of imaging studies in which opacification was achieved.

RESULTS

Phantom Studies

The first experiment with CT oral contrast (1.3% w/v) showed a cold area in the region of contrast in the nonradioactive stomach for all 3 sets of images. The maximum density in the stomach was 182 HU.

The second experiment with high-density contrast showed a cold area in the region of the nonradioactive stomach in the noncorrected and ^{68}Ge-corrected images. The CT-corrected images, however, showed an artifactual focus of intense "activity" with a maximal density measured at 3,071 HU in the nonradioactive stomach.

In the third experiment, ^{68}Ge-corrected and noncorrected images showed the cold syringes in a uniform background. The CT attenuation correction produced similar expected "cold"-appearing images of the syringes containing 0% and 1% contrast, but the higher concentrations showed increasing levels of activity, with intense artifacts at >60% concentration (not shown). Figure 2 shows that the measured activity is progressively overestimated with CT attenuation correction at high HU using the commercial software.

Patient Studies

Of the 108 patients (84%), 91 received oral contrast. Of these, 75 patients received the full regimen of contrast and 16 received only part of the contrast because of inability to drink the entire volume. Seventeen did not receive any contrast because of the study indication (head and neck cancer [$n = 11$]) or refusal ($n = 6$). Details on bowel opacification are reported in Table 1. Measured oral contrast density in the digestive tract is reported in Table 2.

The diameter of the stomach lumen measured on CT was significantly different (59.8 ± 20.6 mm) from that measured on PET emission images with CT attenuation correction (43.8 ± 23; $P < 0.000001$). Muscle activity tended to be higher in patients who received oral contrast than in those without contrast (Table 3). A systematic review of the diagnostic utility of oral contrast in enhancing the interpretation of PET/CT images (Fig. 3) will be reported subsequently. No obvious foci of artifactual "uptake" resulting from CT-based attenuation correction in the presence of CT oral contrast were found. There were thus no false-positive interpretations related to such potential artifacts.

TABLE 2
Contrast Density Measured in Bowel in Patients Receiving CT Oral Contrast

Parameter	Stomach	Small bowel	Right colon
Maximum	167.4 ± 8.9 (142–187)	156.6 ± 28 (100–209)	142.1 ± 46.2 (39–239)
Mean	135.2 ± 7.7 (120–157)	104.1 ± 23.4 (64–148)	80.7 ± 34.7 (14–152)

Results are expressed as Hounsfield units (mean ± SD). Values in parentheses are ranges. Scans from first 30 patients receiving oral contrast are included for these measurements. Maximum measured density was 239 in right colon.

DISCUSSION

The clinical case example and the phantom experiments clearly showed that high-density oral contrast can produce an artifact of apparent increased tracer uptake. The radiodensity of this dense barium is near that of metallic objects, which also can produce artifacts of increased activity on emission PET if CT-corrected emission data are used (*4*). These artifacts are likely caused by the energy differences

TABLE 3
Muscle Uptake (SUV_{lean}) Maximum With and Without Oral Contrast

Muscle	SUV_{max} without oral contrast	SUV_{max} with oral contrast	2-tailed *P* test
Right mylohyoid	3.89	3.55	0.52
Left mylohyoid	3.5	3.59	0.85
Right cricoarytenoid	2.36	3.63	*0.03
Left cricoarytenoid	2.04	3.12	0.07
Interarytenoid	2.32	3.17	*0.05
Right strap muscle	1.38	1.75	0.1
Left strap muscle	1.21	1.63	*0.01

*$P < 0.05$.

Two groups of patients were compared; the first 20 patients having received oral contrast and the last 20 patients imaged before oral contrast was introduced into routine clinical practice, excluding 2 patients with head and neck cancer, 1 with thyroid cancer, and 3 with previous neck irradiation.

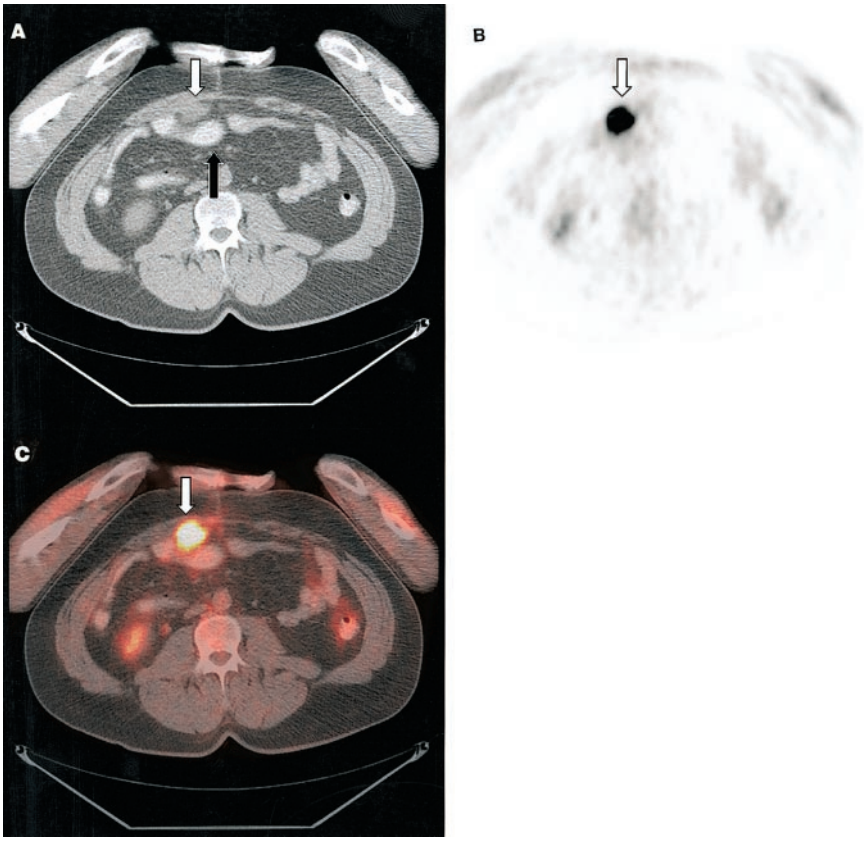

FIGURE 3. Example of clinical value of oral contrast in patient with resected colorectal carcinoma evaluated with ^{18}F-FDG PET for suspected recurrence. (A) Transverse CT image shows transverse colon with contrast (white arrow) and soft-tissue-density lesion adjacent to anterior abdominal wall (black arrow). (B) PET images with CT attenuation correction show focus of intense uptake in anterior abdomen (white arrow). (C) Fused PET/CT image shows that focus of uptake corresponds to soft-tissue mass (white arrow) and not to bowel. Diagnosis of peritoneal tumor implant was made. Patient underwent chemotherapy.

between photons used for CT scanning and the 511-keV photons used for ^{68}Ge transmission scanning. The use of low-energy photons for transmission imaging results in increased attenuation coefficients in the presence of materials of high atomic number (metallic objects, high-density contrast material) compared with the use of high-energy 511-keV photons. This increased attenuation for low-energy x-rays is caused by an increased probability of photoelectric interaction of low-energy photons with material of high atomic number. Mathematic algorithms ideally should scale the attenuation coefficients obtained with low-energy photons to the energy level of 511-keV photons. However, it appears that current and widely applied commercial scaling algorithms are not appropriate for high-density materials, causing an overestimation of attenuation coefficients in their presence and thus an overcorrection of the emission data that then produces an artifact of increased apparent tracer activity. The third phantom experiment shows that the CT attenuation correction algorithm produces an increasing overcorrection of the emission activity in the presence of increasing density of high-atomic-number contrast materials (Fig. 2). The overestimation of tracer activity begins to appear for materials as the measured density rises between 93 and 629 HU. The exact concentration threshold at which artifacts of increased activity can be expected will vary according to the material used for contrast and its quantity. No studies showed obvious artifacts from using oral CT contrast with 1.3% barium, as commonly used in CT contrast studies.

The density of CT oral contrast, with a maximum of 239 HU registered in patients, appears to be low enough not to produce a significant artifact. Therefore, artifacts of increased activity caused by CT oral contrast seem unlikely and were not observed in this study. However, if the concentration of the oral contrast in the lumen increases markedly as a result of significant water reabsorption, it is possible that artifacts of increased apparent tracer uptake will be observed. A limited time of around 1 h between CT oral contrast administration and CT acquisition may have limited water reabsorption and artifacts in our clinical patients.

The extent of gut opacification was adequate for most of the stomach, small bowel, and right colon but was adequate less frequently for the transverse, descending, and rectosigmoid colon. Nonopacification of the left colon is a lesser problem, because colon identification is often straightforward. Opacification of the small bowel is more relevant, because without contrast it is not always easy to delineate from other abdominal structures.

The size of the gastric lumen was smaller when measured by PET than by CT. A spatial misregistration could occur in this situation, and corrections for attenuation will be less accurate. Our comparison of contrast and noncontrast patient groups showed that muscle uptake in the head and neck

is not substantially different globally in the contrast and noncontrast PET study groups. However, to avoid increased muscle uptake, we are not currently using oral contrast in head and neck cancer.

The diagnostic impact of oral contrast on PET/CT interpretation was not systematically evaluated in this study, because only contrast-enhanced CT was performed. However, oral contrast enhancement clearly facilitates small bowel identification, and qualitatively makes image interpretation easier with PET/CT.

CONCLUSION

Phantom studies demonstrated artifacts of increased apparent ^{18}F-FDG uptake using CT-corrected PET if dense contrast was present. Phantom and patient studies using clinically practical CT oral contrast did not demonstrate such artifacts. CT oral contrast use has been implemented in clinical PET/CT practice and appears valuable in some instances.

REFERENCES

1. Hamm B. Contrast materials for cross-sectional imaging of the abdomen. *Curr Opin Radiol.* 1992;4:93–104.
2. Gore R. Cross-sectional imaging of the colon. In: Gore R, Levine MS, Laufer I, eds. *Textbook of Gastrointestinal Radiology.* Philadelphia, PA: W.B. Saunders; 1994:1051–1063.
3. Megibow AJ, Bosniak MA. Dilute barium as a contrast agent for abdominal CT. *AJR.* 1980;134:1273–1274.
4. Goerres GW, Hany TF, Kamel E, von Schulthess GK, Buck A. Head and neck imaging with PET and PET/CT: artefacts from dental metallic implants. *Eur J Nucl Med Mol Imaging.* 2002;29:367–370.
5. Nakamoto Y, Osman M, Cohade C, et al. PET/CT: comparison of quantitative tracer uptake between germanium and CT transmission attenuation-corrected images. *J Nucl Med.* 2002;43:1137–1143.