

# Oncological Applications of FDG PET Imaging\*

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**T**echnical considerations, normal distributions of FDG and applications of FDG imaging using PET for brain tumors, colorectal cancer, lymphoma, melanoma, lung cancer and head and neck cancer have been addressed previously. This article focuses on applications of FDG PET imaging for breast cancer, pancreatic cancer, hepatocellular carcinoma and other body tumors.

## BREAST CARCINOMA

Breast carcinoma is the most common malignancy in women in North America. If diagnosed early, it is a curable disease. The estimated incidence of breast carcinoma in 1998 was 180,300 cases, and about one third of those patients will die from the disease.

### Detection of Breast Carcinoma

The initial diagnosis of breast cancer is usually made by physical examination or mammography. However, despite the important screening role of physical examination and mammography in detecting early breast cancer, mammography is difficult to interpret in women who have dense breast tissue or have undergone mastoplasty or prior biopsy. Although the sensitivity of mammography is high for the detection of breast cancer, its specificity is less than 30%, leading to a large number of biopsies for benign lesions. Breast MRI is one imaging technique that shows promise in evaluating breast lesions that are equivocal on mammography, as is functional imaging with radiopharmaceuticals such as  $^{99m}\text{Tc}$ -sestamibi and FDG.

Several studies have shown that FDG PET allows accurate detection of breast carcinoma, with sensitivity and specificity ranging from 80% to 100% (Table 1) (1–11). As with other types of tumors, false-negative results can occur when lesions are <1 cm in size (1–5) or when the tumor is

slow growing or well differentiated, as in tubular and ductal carcinoma in situ (4,8). False-positive results occur in patients with inflammatory processes in the breast or early after biopsy or surgery.

FDG PET is particularly useful in patients with small lesions, nonpalpable lesions, equivocal mammographic findings and fibrocystic disease, in which fine-needle biopsy is less reliable. FDG PET can also detect breast cancer in women after augmentation mastoplasty. Mammographic detection of cancer in these women is challenging, because of the radiodensity of the implant (12).

### Staging of Breast Carcinoma

The main site of lymphatic drainage of the breast is the axilla, and the presence of axillary node metastases is the most important prognostic factor in patients with breast carcinoma (13). The sensitivity of CT in detecting lymph node metastases in the axilla is approximately 50% (14). Axillary lymph node dissection usually is performed as a diagnostic procedure for staging, because no noninvasive techniques can reliably predict lymph node metastases. The morbidity associated with lymph node dissection is not negligible (15), and only 20% of women with noninvasive carcinoma have axillary nodal metastases (16). Because of earlier detection of breast cancer, the proportion of axillary nodal metastases is decreasing, and most patients are candidates for outpatient breast salvage procedures performed with local anesthesia.

Several studies have shown that PET can detect axillary lymph node metastases with relatively high sensitivities and specificities (Table 2) (2–6,9,17–20). In a study of 50 patients, Adler et al. (18) found that the sensitivity and negative predictive value were 95%, the specificity 66% and the accuracy 77%. They concluded that axillary dissection was not necessary in patients with negative PET findings, because of the low risk of axillary metastases. Patients with positive PET findings should undergo axillary dissection to confirm the presence and number of involved lymph nodes. This approach would have saved \$2300 per individual in this group of patients. The anticipated limitation of this approach is that 5% of women with microscopic lymph node metastases not detected by PET would be understaged. Therefore, for staging early breast carcinoma, identification and sampling of the sentinel lymph node may be the procedure of choice.

However, an advantage of FDG PET is the capability to

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**TABLE 1**  
Detection of Breast Carcinoma: Summary of Literature

Authors	Year	No. of patients	PET		
			Sensitivity (%)	Specificity (%)	Accuracy (%)
Wahl et al. (2)	1991	12	100		
Tse et al. (3)	1992	14	80	100	
Adler et al. (5)	1993	35	96	100	
Hoh et al. (6)	1993	20	88	83	
Dehdashti et al. (7)	1995	32	88	100	
Avril et al. (8)	1996	72	92	97	
Schiedhauer et al. (9)	1996	30	91	86	
Palmedo et al. (10)	1997	20	92	86	90
Noh et al. (11)	1998	27			97
Total		250	80–100	83–100	90–97

detect metastases in internal mammary lymph nodes, for which routine sampling is not the current standard. In addition, as reported for other primary malignancies, PET will frequently detect unsuspected distant metastases (1,5).

#### Detection of Recurrent or Metastatic Breast Carcinoma

In a study of 75 patients with suspected recurrent or metastatic disease, Bender et al. (21) found that FDG PET detected 6 local recurrences, 8 lymph node metastases and 7 bone metastases not seen on CT or MRI. In another study of 57 patients, the sensitivity and specificity of FDG PET in detecting tumor recurrence was 93% and 79%, respectively (22). False-positive results included muscular uptake, thyroiditis, blood-pool activity, radiation pneumonitis, osteoarthritis and intestinal activity. False-negative results were mostly from bone metastases. Cook et al. (23) compared FDG PET with bone scintigraphy in 23 patients who had skeletal metastases from breast cancer. They concluded that FDG PET was superior to bone scintigraphy in detecting osteo-

**TABLE 2**  
Staging of Breast Carcinoma: Summary of Literature

Authors	Year	No. of patients	PET		
			Sensitivity (%)	Specificity (%)	Accuracy (%)
Wahl et al. (2)	1991	12	100		
Tse et al. (3)	1992	10	57	100	
Nieweg et al. (4)	1993	5	100		
Adler et al. (5)	1993	20	90	100	
Hoh et al. (6)	1993	14	67	100	
Shiedhauer et al. (9)	1996	30			94
Utech et al. (17)	1996	124	100	75	
Adler et al. (18)	1997	50	95	66	77
Crippa et al. (19)	1998	68	85	91	89
Smith et al. (20)	1998	50	90	97	
Total		383	57–100	66–100	77–94

lytic metastases that had a poorer prognosis. Osteoblastic metastases had lower FDG uptake and were frequently undetectable by PET.

#### Monitoring Therapy of Breast Carcinoma

Studies on small numbers of patients suggest that FDG PET can detect decreased tumor metabolism before any change in size is apparent on anatomic imaging in patients responding to therapy but not in nonresponding patients (24,25). If these data are confirmed in larger series of patients, predicting tumor responsiveness to therapy would avoid unnecessary toxicity and expense in nonresponsive patients.

#### PANCREATIC CARCINOMA

Pancreatic ductal adenocarcinoma is the fourth leading cause of death in the United States and is increasing in incidence. The preoperative diagnosis, staging and treatment of pancreatic cancer remain challenging even for experienced clinicians, and the prognosis is extremely poor.

Pancreatic cancer often is first diagnosed by sonographic or CT findings, including the presence of low-attenuation pancreatic masses and dilatation of the pancreatic duct or biliary tree. CT is the most common diagnostic imaging modality used in the preoperative diagnosis of pancreatic cancer. This technique can also assess vascular involvement and invasion of adjacent organs (26–28). Unfortunately, interpretation of the CT scan is sometimes difficult in cases of mass-forming pancreatitis or questionable findings, such as enlargement of the pancreatic head without definite signs of malignancy. The diagnosis of lymph node metastases is also difficult with CT because these are small. Other anatomic imaging modalities, including sonography, endoscopic retrograde cholangiopancreatography and MRI, have similar limitations. Although CT-guided fine-needle biopsy may provide a tissue diagnosis, this technique may suffer from significant sampling error (29).

The difficulty in making a preoperative diagnosis is associated with two types of adverse outcomes. First, less aggressive surgeons may abort attempted resection because of lack of a tissue diagnosis. This is supported by the significant rate of reoperative pancreaticoduodenectomy performed at major referral centers (30–32). A second type of adverse outcome generated by failure to obtain a preoperative diagnosis occurs when more aggressive surgeons inadvertently resect benign disease. This is notable particularly in patients who present with suspected malignancy but in whom CT shows no associated mass. This has been reported to occur in up to 55% of patients in some series (33).

Newer imaging modalities may improve the accuracy of the preoperative diagnosis of pancreatic adenocarcinoma and avoid these adverse outcomes. A summary of previously published series involving FDG PET in the preoperative diagnosis of pancreatic carcinoma is presented in Table 3 (34–42). In eight studies including a total of 561 patients, the overall performance of PET in differentiating benign from

**TABLE 3**  
Detection of Pancreatic Carcinoma: Summary of Literature

Authors	Year	No. of patients	PET		
			Sensitivity (%)	Specificity (%)	Accuracy (%)
Bares et al. (35)	1994	40	92	84	90
Stollfuss et al. (36)	1995	73	95	99	93
Inokuma et al. (37)	1995	46	94	82	85
Kato et al. (38)	1995	24	93	78	87
Friess et al. (39)	1995	80	94	88	91
Ho et al. (40)	1996	16	100	67	86
Zimny et al. (41)	1997	106	85	84	85
Delbeke et al. (42)	1998	65	92	85	91
Total		561	85–100	67–99	85–93

malignant lesions showed a sensitivity of 85%–100%, a specificity of 67%–99% and an accuracy of 85%–93%, and most of the studies suggested improved accuracy for PET when compared with CT. These results are similar to the findings in our series, with a sensitivity of 92% and a specificity of 85% for FDG PET compared with 65% and 62%, respectively, for CT (42). One must keep in mind, however, that these studies suffer from biases. For example, the CT data are not acquired prospectively, and the quality of the CT images may vary among different institutions. Together, these series support the conclusion that FDG PET may represent a useful adjunctive study in the evaluation of patients with suspected pancreatic cancer.

The rate with which FDG PET results may lead to alterations in clinical management clearly depends on the specific therapeutic philosophy of the evaluating surgeon. In our center, we advocate pancreaticoduodenectomy only for patients with potentially curable pancreatic cancer. We take an aggressive approach to resectioning, including en bloc retroperitoneal lymphadenectomy and selective resection of the superior mesenteric–portal vein confluence when necessary. Although certain patients with chronic pancreatitis may also benefit from pancreaticoduodenectomy, most patients with nonmalignant biliary strictures are treated optimally without resection. In our series of patients, the application of FDG PET in addition to CT altered the surgical management in up to 41% of the patients: 27% by identifying pancreatic carcinoma and 14% by identifying unsuspected distant metastases or by clarifying the benign nature of lesions equivocal on CT (42). In this regard, FDG PET may allow selection of the optimal surgical approach.

In addition to the evaluation of PET for suspected primary pancreatic adenocarcinoma, we have examined the usefulness of PET for assessment of tumor response to neoadjuvant therapy and evaluation of possible tumor recurrence after resection (43). FDG PET successfully predicted histologic evidence of chemoradiation-induced tumor necrosis in all four patients who had at least a 50% reduction in tumor standardized uptake value (SUV) after chemoradiation. Among these patients, none showed a measurable change in

tumor diameter as assessed by CT. Definitive conclusions about the role of FDG PET in assessing treatment response will require evaluation in a larger group of patients. However, given the poor track record of CT in assessing histologic response to neoadjuvant chemoradiation, the potential usefulness of FDG PET in this capacity deserves further investigation.

Most reports on the clinical use of FDG PET for pancreatic malignancy have emphasized the identification of recurrent nodal or distant metastatic disease. Of the eight patients evaluated for possible recurrence in our series, all were noted to have significant new regions of FDG uptake and all proved to have metastatic pancreatic adenocarcinoma (43). This technique may be particularly useful when CT identifies an indistinct region of change in the bed of the resected pancreas that is difficult to differentiate from postoperative or postradiation fibrosis. In addition, we have found FDG PET to be useful in the evaluation of new hepatic lesions that may be too small to perform a biopsy on. In this setting, we have used FDG PET documentation of recurrence instead of biopsy as the basis for additional tumor-directed therapy.

As with any imaging modality, FDG PET has identifiable limitations in the evaluation of pancreatic cancer. First, this functional imaging modality obviously cannot replace anatomic imaging in the assessment of local tumor resectability. Second, theoretic concerns have been raised about the limitations of this modality in a population of patients with a significant rate of glucose intolerance (44–46). Low SUVs and false-negative FDG PET scans have been noted in hyperglycemic diabetic patients, presumably because of increased competition for glucose uptake. The true impact of serum glucose levels on the accuracy of FDG PET in pancreatic cancer remains controversial. Friess et al. (39) and Ho et al. (40) noted no variation in the accuracy of FDG PET on the basis of serum glucose levels. Conversely, Zimny et al. (41) noted significant difficulties in the interpretation of FDG PET in diabetic patients.

Both glucose and FDG are used avidly by cellular mediators of inflammation. Inokuma et al. (37) and Ho et al. (40) have reported false-positive findings in the face of inflammatory changes in the pancreas.

Overall, FDG PET appears to be a sensitive and specific adjunct to CT when applied to the preoperative diagnosis of pancreatic adenocarcinoma. We have found this imaging modality to be of particular use in patients with suspected pancreatic cancer in whom CT fails to identify a discrete tumor mass (Fig. 1). By providing preoperative documentation of pancreatic malignancy in these patients, one may undertake laparotomy with purely therapeutic intent, and the risk of aborting resection because of diagnostic uncertainty is minimized. FDG PET is also useful in the clarification of CT-occult metastatic disease (Fig. 2), avoiding nontherapeutic resections in this group of patients.

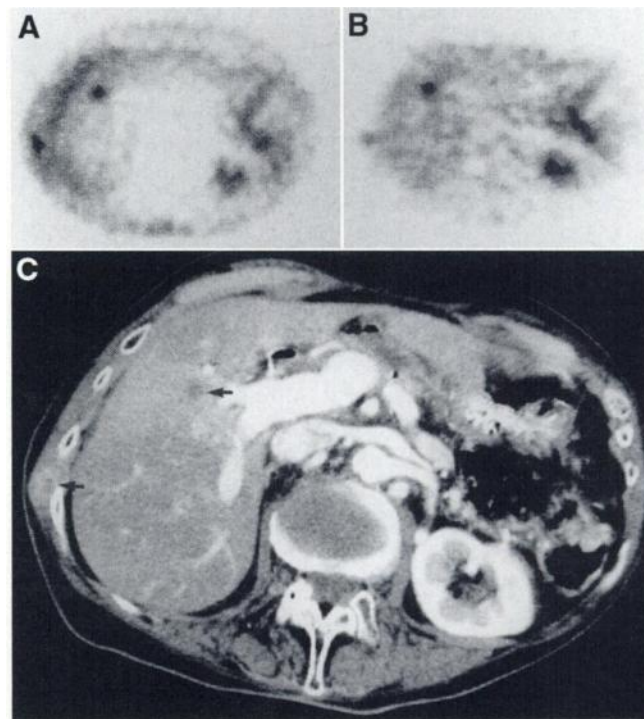


**FIGURE 1.** An 88-y-old woman who presented with obstructive jaundice. CT of abdomen shows biliary drain in place (A) but no definite lesion in presumed location of head of pancreas, which is difficult to identify (B). Fine-needle biopsy was nondiagnostic. (C and D) Corresponding FDG PET images without attenuation correction show increased FDG uptake corresponding to head of pancreas consistent with pancreatic carcinoma (D). Uptake along biliary drain (C) is probably related to inflammatory changes and should not be mistaken for metastasis. Patient underwent Whipple's operation, and 2.5-cm carcinoma was found in head of pancreas.

### HEPATOCELLULAR CARCINOMA

Hepatocellular carcinomas commonly arise in the setting of cirrhosis. The diagnostic issues of conventional imaging include differentiating hepatocellular carcinoma from cirrhosis and other benign liver diseases and assessing the response to therapy.

The liver is known to have enzyme glucose-6-phosphatase activity. Although experimental studies have shown that glycogenesis decreases and glycolysis increases during carcinogenesis, the accumulation of FDG in hepatocellular carcinoma varies because of varying degrees of activity of glucose-6-phosphatase (47,48). Therefore, it has been predicted that evaluation of liver tumors—especially hepatocellular carcinomas—with FDG PET would require dynamic imaging, blood sampling and kinetic analysis. Kinetic analysis is difficult to perform clinically and cannot be performed over the entire body, preventing staging. Studies using kinetic analysis have shown that the phosphorylation kinetic constant ( $k_3$ ) is elevated in malignant tumors, including hepatocellular carcinoma, compared with healthy liver. The dephosphorylation kinetic constant ( $k_4$ ) is low in metastatic lesions and in cholangiocarcinomas, but  $k_4$  was similar to  $k_3$  for the hepatocellular carcinomas that do not accumulate FDG (49–51). Our experience with more than 100 cases of liver lesions evaluated with FDG PET (52) is similar to that of other groups that have reported small series of patients (49–51): as much as 50%–70% of hepatocellular carcinoma and all other primary and metastatic tumors in the liver show accumulation of FDG compared with healthy liver and therefore can be imaged using the standard static imaging protocol. All benign tumors, including fibronodular hyperplasia, adenoma and regenerating nodules, had



**FIGURE 2.** Same patient as in Figure 1 at 1-y follow-up. FDG PET images (A, without attenuation correction; B, with attenuation correction) show two foci of uptake: one in lateral abdominal wall and one in liver. (C) Corresponding CT image shows corresponding lesions in lateral abdominal wall and in liver (arrows). However, lesions are subtle and were overlooked when CT was first interpreted without PET scan.

FDG uptake at the same level as healthy liver, except for rare abscesses with granulomatous inflammation. In some cases of hepatocellular carcinoma, because whole-body imaging is routinely performed, unsuspected metastases were identified, leading to a change in management. In other cases, FDG PET was the only imaging modality allowing visualization of the tumor and therapy monitoring. The value of FDG PET in monitoring therapy of hepatocellular carcinoma after transcatheter chemoembolization has also been shown (53,54). FDG PET was compared with lipiodol retention on CT in 30 patients with 32 lesions, and FDG PET was more accurate than CT in predicting the presence of residual viable tumor.

## MUSCULOSKELETAL NEOPLASMS

Soft-tissue sarcomas arise from mesenchymal structures anywhere in the body and represent 1% of all malignant tumors. They are known to invade surrounding structures and metastasize distantly, usually to the lungs. The therapeutic regimen is dictated by the grade of the tumor and the presence of metastases. A study by Griffith et al. (55) on 19 patients showed that FDG PET could be useful in differentiating benign from malignant soft-tissue masses. The authors reported some overlap between benign and malignant lesions by visual examination and lesion-to-background ratios. They recommended using SUV and correlation with anatomic images for optimal interpretation. Several studies have shown that the degree of FDG uptake appears to correlate with the grade of sarcoma (56–58). Because soft-tissue sarcomas are often heterogeneous, with large areas of necrosis and hemorrhage, FDG PET can guide the biopsy to a region with the highest grade tumor.

In some cases, FDG PET is useful in staging these tumors with whole-body imaging, detecting recurrence and monitoring therapy (55). Jones et al. (59) showed changes in FDG uptake during and after neoadjuvant therapy in soft-tissue and musculoskeletal sarcomas. The changes depended on the neoadjuvant therapy administered (chemotherapy or radiotherapy and hyperthermia), and the authors noticed persistent uptake with benign therapy-related fibrous tissue. Similar findings have been reported by another group of investigators who performed FDG PET to evaluate the response to hyperthermic isolated limb perfusion for locally advanced soft-tissue sarcomas (60).

In selected cases, FDG PET appears to be a useful adjunct to other imaging modalities, such as bone scintigraphy, in the evaluation of osseous metastases from prostate and breast cancer. Bone scintigraphy remains the best imaging modality for detecting bone metastases because of its high sensitivity. However, it does not differentiate benign from malignant lesions, because both cause bone remodeling; PET appears promising in this regard (61,62). A study of 20 patients with osseous lesions showed that using a 2.0 cutoff value for SUV, PET correctly identified 14 of 15 malignant lesions and 4 of 5 benign lesions (62). In our experience (52), FDG PET reveals bone metastases from various

primary tumors, including hepatocellular carcinoma, that were unsuspected clinically and were sometimes not seen on bone scans. Osteomyelitis and Paget's disease can have marked FDG uptake and cause false-positive findings (63,64).

In summary, FDG PET may be useful in the differentiation of malignant from benign skeletal lesions and may provide important diagnostic and prognostic information in patients with soft-tissue sarcomas.

## ENDOCRINE NEOPLASMS

Papillary thyroid carcinoma is imaged better with  $^{131}\text{I}$ , but FDG imaging is helpful for staging and detecting recurrence of anaplastic thyroid carcinoma, which usually is not  $^{131}\text{I}$  avid (65–70). FDG imaging is helpful in assessing the patient who is  $^{131}\text{I}$  negative but has an elevated thyroglobulin level (Fig. 3).

FDG PET is also an option for neuroendocrine tumors that fail to be imaged by other, more conventional, radiopharmaceuticals. For example, pheochromocytomas that are not shown with metaiodobenzylguanidine (MIBG) can be imaged successfully with FDG (71).

Neuroblastoma is the most common solid extracranial malignancy of childhood. As with pheochromocytoma, the conventional radiopharmaceuticals for imaging these neuroendocrine tumors are  $^{131}\text{I}$ -MIBG and  $^{111}\text{In}$ -octreotide. Shulkin et al. (72) compared FDG and MIBG imaging in 17 patients. FDG tumor uptake was present in 16 of these patients, both in the primary tumor and in the metastases. The uptake was more variable after therapy. The tumor of 1 patient was FDG avid but failed to accumulate MIBG. MIBG images were rated superior to FDG images in 13 patients. Detection of metastatic carcinoid may be significantly higher with  $^{111}\text{In}$ -octreotide than with FDG PET (73).

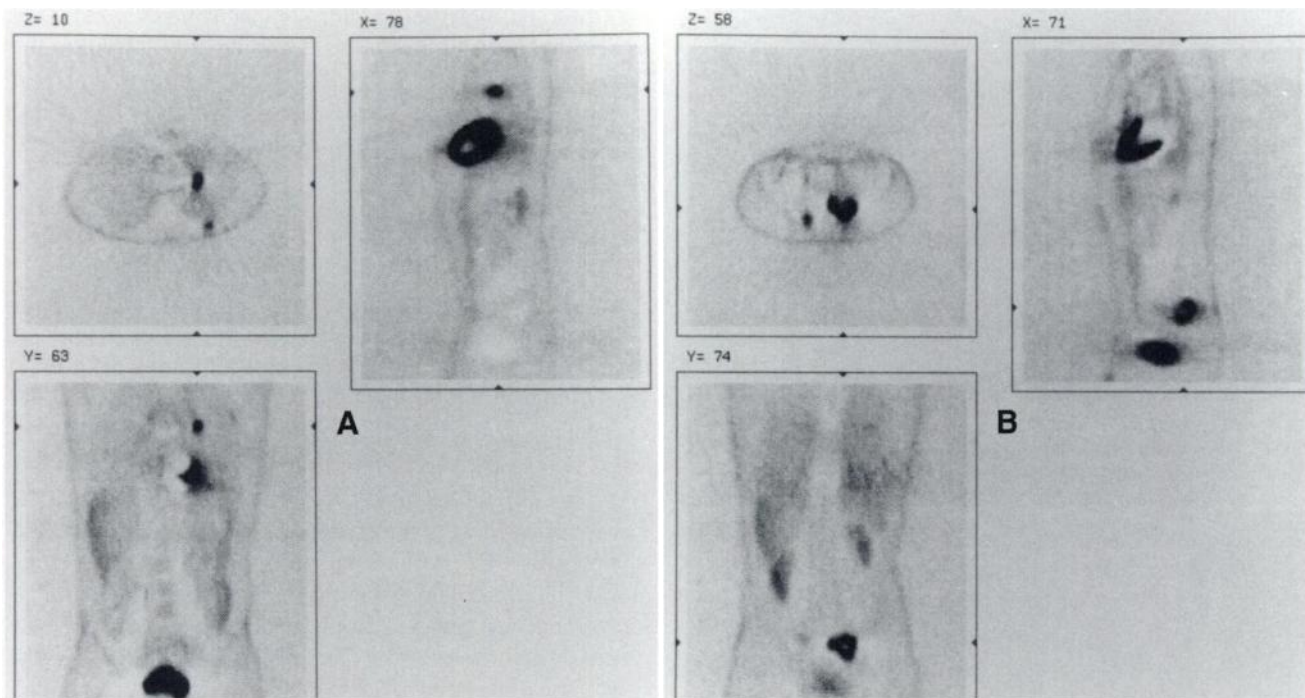
## INDETERMINATE ADRENAL MASSES

Incidentally discovered adrenal masses in patients with no history of malignancy are rarely metastatic. An adrenal mass detected in a patient with cancer has a 27%–36% probability of being malignant (74). Therefore, it is important to be able to accurately differentiate benign from malignant adrenal lesions in patients with a history of malignancy. CT cannot differentiate adrenal metastases from benign nonhyperfunctioning adenomas, but MRI with T2-weighted imaging is promising (75). In a study with a limited number of patients, FDG PET was 100% accurate in identifying 14 malignant and 10 benign adrenal lesions (76). In a group of 33 patients in whom CT revealed bronchogenic carcinoma and adrenal masses, the sensitivity and specificity of FDG PET were 100% and 33%, respectively, in predicting malignancy (77). These data predict that FDG PET could be used to avoid biopsy in this population (Fig. 4).

## GENITOURINARY NEOPLASMS

FDG is excreted by the kidneys, and the high concentration of FDG in the urine obscures visualization of structures





**FIGURE 3.** A 56-y-old man with history of resected thyroid carcinoma. He presented with elevated thyroglobulin but negative  $^{131}\text{I}$  whole-body scan findings. (A and B) FDG PET images without attenuation correction show foci of uptake in left lung, in posterior rib at same level and two in pelvic site, indicating metastases.

adjacent to the renal collecting system and the bladder. With good hydration, administration of diuretics and placement of a urinary catheter, visualization of perineal and paravesicular lesions can be improved. The reported experience of FDG PET with genitourinary neoplasms is limited to studies with few patients.

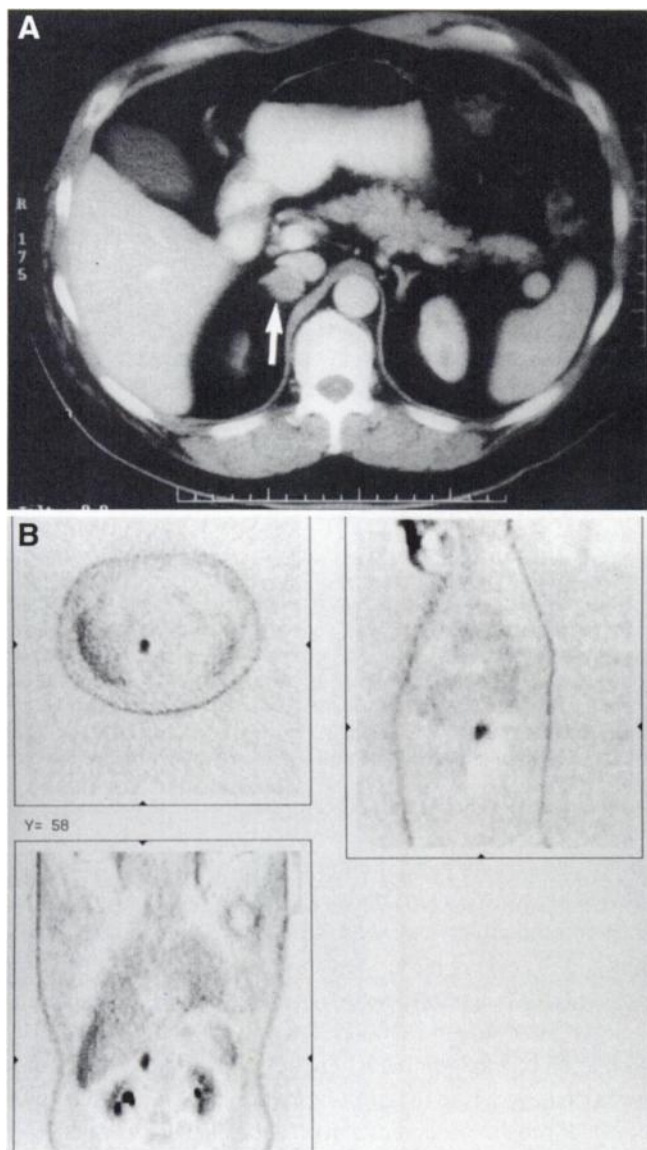
An excellent review of the applications of PET in urologic oncology was written by Hoh et al. (78). FDG accumulates in most renal cell (78,79) and bladder carcinomas (80). In a study of 29 patients (81), PET sensitivity was 77% in detecting the primary tumor. There were six false-negative malignant tumors and three false-positive benign tumors (angiomyolipoma, pericytoma and pheochromocytoma). High-grade tumors appear to have higher FDG uptake (which correlates with higher Glu-1 intensity by peroxidase staining) than do low-grade tumors (82). FDG PET seems promising to stage and monitor therapy of renal cell carcinoma with high uptake (83), but further clinical and outcome studies need to be performed.

For prostate carcinoma, both the primary tumor and pelvic lymph nodes are difficult to image because of the proximity of the bladder. In addition, the uptake appears relatively low in prostate carcinoma (SUV 2.5–3.5) and may reflect low metabolism in a slow-growing tumor (84–87). Patients who had higher SUVs (>5.0) had rapid disease progression and did not respond well to hormone deprivation or radiation therapy. Relatively high uptake in benign prostatic hyperplasia increases the difficulty of differentiating benign from malignant prostatic lesions with PET. For skeletal metastases from prostate carcinoma, FDG PET is

not as sensitive as bone scintigraphy. A study of 34 patients showed that the sensitivity of PET was only 65% but the positive predictive value was 98%, an advantage over bone scintigraphy, which is very sensitive but poorly specific (86). Yeh et al. (88) reported a sensitivity of only 20% in detecting skeletal metastases. FDG PET may have a role in the evaluation of indeterminate bone lesions on bone scans and may also have a role in detecting recurrence in patients with elevated prostate-specific antigen levels and normal CT findings (78).

The role of FDG PET in patients with testicular cancer is still under investigation. Preliminary studies suggest that FDG PET may be useful for initial staging after orchiectomy by detecting metastases not seen by conventional imaging (78). After chemotherapy, PET may be able to differentiate viable tumor from scar tissue but not scar tissue from mature teratoma (89–91). As for other tumors, PET may also be indicated to localize recurrence in patients with a rising blood level of tumor markers.

For ovarian carcinoma, preliminary studies are more encouraging. In two studies totaling 60 patients evaluated for recurrent ovarian carcinoma, the sensitivity of PET was superior to that of CT in detecting recurrent disease, ranging from 83% to 93% for PET and 67% to 87% for CT. The specificity was 80% for PET and 50% for CT (92–95). In these studies and in our own experience (unpublished data), PET identified occult foci that were not seen on CT (Fig. 5). False-negative findings have been reported for carcinosarcoma.



**FIGURE 4.** A 52-y-old man with history of melanoma resected from left arm 6 mo previously. (A) He presented with 1-cm nodule in right adrenal gland on CT (arrow). (B) FDG PET images without attenuation correction show FDG uptake corresponding to right adrenal gland, indicating metastasis. Patient underwent right adrenalectomy, and lesion was proven malignant by histology.

#### ESOPHAGEAL AND GASTRIC CARCINOMAS

Approximately one third of patients with esophageal and gastric carcinomas undergoing surgery are found to have occult metastases. The limited published experience with esophageal and gastric carcinomas suggests that FDG PET is highly sensitive in detecting primary tumors and metastases to the liver and distant sites (96–100). The sensitivity of both PET and CT appears limited in detecting local lymph node involvement, probably because of the proximity of the primary tumor, and in assessing peritoneal spread. Because patients present with distant metastases at the time of recurrence more often than at the time of initial diagnosis,

PET may be most helpful for staging patients when they present with recurrence. For example, in the study by Flanagan et al. (96), PET detected the primary esophageal tumor in all 36 patients and distant metastases in 5 patients. CT failed to detect all distant metastases. The extent of nodal disease was revealed in 76% of the 29 patients who underwent surgery by PET and in only 45% by CT. In the study by Block et al. (97), PET detected 53 of 58 primary tumors and distant metastases in 17 patients, compared with 5 patients with CT. Of the 21 patients with lymph node involvement found at surgery, 52% of this involvement was detected with PET and 28% with CT. Luketich et al. (98) reported their experience with 35 patients, in whom the sensitivity, specificity and accuracy of PET were 88%, 93% and 91%, respectively, for distant metastases, and 45%, 100% and 48%, respectively, for locoregional nodal metastases. For gastric carcinomas, the sensitivity, specificity and accuracy of PET in detecting the primary tumor, locoregional metastases and distant metastases appear to be in the same range as that for esophageal carcinomas (100). In patients who underwent PET before and after chemotherapy, FDG uptake appeared to decrease in patients who responded to treatment but not in nonresponders (99).

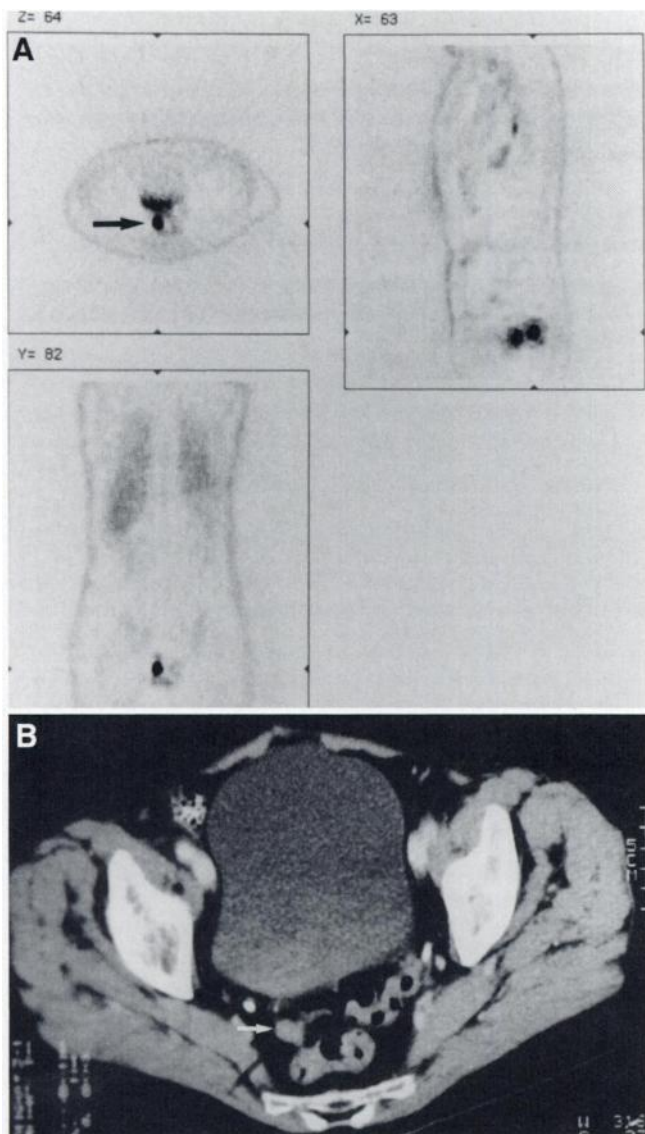
#### CONCLUSION

Several clinical indications for FDG PET in oncology are now well established and have been approved by the Health Care Financing Administration, which regulates Medicare reimbursement. These indications include evaluation of pulmonary nodules, initial staging of non-small cell lung carcinoma, preoperative staging of recurrent colorectal carcinoma in patients with elevated carcinoembryonic antigen levels, staging of recurrent melanoma and staging of Hodgkin's disease and non-Hodgkin's lymphoma.

Other applications for FDG PET in patients with various body tumors are rapidly growing and becoming accepted in the field of oncology. FDG PET does not replace other imaging modalities such as CT but appears to be very helpful in specific situations in which CT has known limitations, such as differentiation of benign from malignant and indeterminate lesions on CT, differentiation of post-treatment changes from recurrent tumor, differentiation of benign from malignant lymph nodes, detection of unsuspected distant metastases and monitoring of therapy.

Current FDG PET applications for breast carcinoma include detection in patients with nonpalpable lesions and equivocal mammography findings due to dense breast tissue, mastoplasia, prior biopsy or fibrocystic disease; staging of high-risk carcinoma; and monitoring of therapy. For pancreatic carcinoma, FDG PET is used for detection in patients with equivocal findings on conventional imaging, staging of recurrent disease and monitoring of therapy. For hepatocellular carcinoma, the technique is used to stage tumors and assess their uptake at the time of initial diagnosis. Therapy of tumors with uptake can then be monitored with FDG PET. Another current application is detection of recurrence of





**FIGURE 5.** A 60-y-old woman with history of total hysterectomy and bilateral oophorectomy for ovarian carcinoma. She presented with elevated blood level of tumor markers but normal CT findings. (A) FDG PET images show focus of uptake posterior to bladder (arrow). Anterior uptake is residual uptake in bladder that can occur even when emission scanning is performed with irrigation Foley catheter, as in this patient. (B) Retrospective review of CT scan shows corresponding nodule (arrow) that could not be differentiated from unopacified bowel without PET scan. Metastasis was confirmed at surgery.

anaplastic thyroid carcinoma when tumor marker is elevated and conventional  $^{131}\text{I}$  scintigraphy shows normal findings. Finally, FDG PET is used to evaluate indeterminate adrenal lesions and to detect and stage recurrent gastroesophageal carcinoma.

The addition of FDG PET in the evaluation of oncology patients in well-defined algorithms including a combination of imaging studies appears to be cost effective by accurately identifying patients who will benefit from invasive procedures and by avoiding unnecessary and costly invasive procedures.

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