ANNALS OF SURGERY
Vol. 227, No. 3, 319–323

Utility of FDG-PET for Investigating Unexplained Plasma CEA Elevation in Patients With Colorectal Cancer

Fidelma L. Flanagan, MRCPI, FRCR,* Farrokh Dehdashti, MD,* Olagunju A. Ogunbiyi, FRCS,† Ira J. Kodner, MD,† Barry A. Siegel, MD*

From the Division of Nuclear Medicine, Edward Mallinckrodt Institute of Radiology, and the Division of Colon and Rectal Surgery, Department of Surgery, Washington University School of Medicine, St. Louis, Missouri†*

Objective
To assess the potential role of positron emission tomography (PET) with 2-[^{18}F]fluoro-2-deoxy-D-glucose (FDG) in patients with unexplained rising carcinoembryonic antigen (CEA) levels after the treatment of colorectal cancer.

Background
A rising CEA level after the resection of colorectal cancer is an early indicator of tumor recurrence. However, conventional imaging techniques have limited sensitivity for detecting recurrent disease in such patients. Especially after surgical intervention, FDG-PET is rapidly gaining an important role in establishing the extent of disease in the oncology patient.

Methods
Twenty-two patients with abnormal CEA levels and normal results of conventional methods of tumor detection were studied with FDG-PET. The PET results were compared with pathologic findings (n = 9) and long-term radiologic and clinical follow-up (n = 13).

Results
FDG-PET was abnormal in 17 of 22 patients. Tissue sampling was available in 7 of these 17 patients; all of these had recurrent disease. Definitive curative surgical intervention was performed in four patients. Subsequent dedicated imaging findings and clinical course confirmed the presence of extensive disease in 8 of the remaining 10 patients; the PET results in the other 2 patients were considered falsely positive. FDG-PET was negative in 5 of 22 patients. No disease was found by tissue sampling (n = 2) and clinical follow-up (n = 3). Overall, the positive-predictive value for PET was 89%, (15 of 17) and the negative-predictive value was 100% (5 of 5).

Conclusions
When conventional examinations are normal, FDG-PET is a valuable imaging tool in patients who have a rising CEA level after colorectal surgery.

Colorectal cancer is the second most common cancer in the United States. The recurrence rate after initial treatment is estimated at 30% to 40%, with most recurrences detected within 2 years of surgery.[1] Monitoring patients after curative resection of colorectal cancer is performed based on the assumption that early detection and early treatment of recurrence will improve the patients' survival rate.[2] Consequently, after the initial surgery, patients periodically undergo a number of clinical and radiologic examinations.[2] Serial determinations of the plasma carcinoembryonic antigen (CEA) concentration is the most frequently used method for the detection of asymptomatic recurrences.[3] The combination of an elevated plasma CEA concentration and an abnormal computed tomography (CT), sonography, or magnetic resonance imaging (MRI) examination can be used to direct an additional surgical procedure.

Often, however, a rising CEA level occurs in association with negative results of conventional imaging studies and clinical examination. Uncertainty regarding the presence of disease results in psychological distress to the patient and may lead the surgeon to resort to an exploratory second-look operation. Although, the likelihood of finding a recurrent tumor during a second-look surgery is quite high (nearly 90% in most series), the proportion of such patients suitable for curative resection is substantially less (12%–60%).[1] Accordingly, the availability of a more sensitive

Correspondence and reprints to: Dr. Farrokh Dehdashti, 510 South Kingshighway Boulevard, St. Louis, MO 63110.
Date accepted for publication August 19, 1997.

means for localizing tumor foci and for determining resectability would aid in the management of such patients.

Positron emission tomography (PET) is a functional imaging technique that relies on changes in physiologic or metabolic functions for the detection of disease. This contrasts with conventional imaging techniques (e.g., CT), which demonstrate morphological changes associated with disease. [^{18}F]fluoro-2-deoxy-D-glucose (FDG) is a glucose analog and its accumulation within cells is proportional to the rate of glucose transport and metabolism. The use of FDG-PET in oncology is based on the observation that neoplastic cells exhibit increased glucose utilization, and this imaging method has become an important tool in the clinical evaluation of patients with malignant tumors. Recent reports have documented the value of FDG-PET for detecting and staging many different tumors, especially lung, breast, and colon cancers.[4,5] In addition, PET has been shown to be particularly useful in distinguishing recurrent tumors from posttherapeutic changes.[6,7]

Several studies have reported a high sensitivity of FDG-PET in the detection of recurrent colorectal cancer.[4–6,8–12] However, these reports have focused mainly on the comparison of PET with CT. The role that FDG-PET might play in addressing the distinct clinical problem of a patient with postoperative elevation in plasma CEA concentration, but normal clinical and radiologic examinations, have not been assessed fully. Therefore, to evaluate the possible benefits of FDG-PET in this setting, we have reviewed retrospectively the records of 22 patients with previously resected cancer who had rising CEA levels and normal results of conventional imaging studies.

MATERIALS AND METHODS

From June 1993 to June 1996, 128 patients with a history of colorectal carcinoma underwent FDG-PET at our institution. Twenty-two patients (age range 26–84, 17 men and 5 women) had a plasma CEA concentration greater than 5.0 ng/mL (mean 25 ng/mL) and had normal results of imaging studies, endoscopy, and physical examinations. All 22 patients had normal CEA plasma levels after the surgical resections of their primary tumors, but subsequently had developed a serial rise in their CEA plasma levels on routine follow-up examinations.

Before PET, all of the patients with a history of rectal or rectosigmoid carcinoma underwent CT of the chest, abdomen, and pelvis, while patients with a prior history of colon cancer had CT of the abdomen and the pelvis. The CT examinations were performed no more than 4 weeks before the PET on a fourth-generation CT unit (Siemens Somatom + or Somatom +S). Images of the chest and upper abdomen were obtained from the neck to below the level of the liver using 10-mm contiguous slices. Oral contrast (400–500 mL) was administered before scanning. The CT examinations were interpreted in a routine clinical fashion.

Positron emission tomography was performed with a commercially available scanner (ECAT Exact; CTI PET Systems, Knoxville, TN) that allowed for simultaneous collection of 47 transverse slices over a total span of 16.2 cm. The reconstructed spatial resolution under the clinical imaging conditions was approximately 10 mm (full width at half maximum). The patients fasted for at least 4 hours before the injection of FDG and, to ensure the fasting state, the blood glucose concentration was determined before FDG administration. All images were performed with the patient in the supine position. Approximately 40 minutes after intravenous administration of 10 to 15 mCi (370–555 MBq) FDG, a series of 3 to 5 overlapping, 47-slice emission images (each of 10–15 minute duration) were performed. A 2-minute transmission scan was performed with a rotating ^{68}Ge/^{68}Ga rod source immediately after each emission scan. Attenuation correction of the emission scan was performed with the segmentation method.[13] To ensure adequate clearance of bladder activity, a Foley catheter was inserted in the urinary bladder at the beginning of the PET study. To minimize renal pelvicalyceal activity, which might obscure structures in the upper abdomen, approximately 1500 mL of normal saline solution was infused slowly throughout the patient and, unless contraindicated, 20 mg furosemide was administered intravenously 20 minutes after the injection of FDG.

Image processing and reconstruction were performed on a SUN (SUN Microsystems, Inc. Mountain View, CA) computer workstation. Images were displayed in three orthogonal projections and as whole-body maximum-pixel-intensity reprojection images for visual interpretation. All PET images were evaluated qualitatively in a routine clinical fashion, including correlation with CT images; reported abnormalities represented the consensus of at least two nuclear medicine physicians. The results of the PET study were used in planning patient management at the discretion of the referring surgeon.

The medical records, both inpatient and outpatient, were reviewed. The PET results were correlated with histologic findings and long-term radiologic and clinical follow-up periods (shortest follow-up period after PET was 6 months).

Lesions that were seen by PET, but that were not biopsied, were considered to be true-positive findings if the disease became obvious (in the same location as identified by PET) on a follow-up imaging study directed by PET and within 6 months (median 11 months) of the PET examination. Abnormal foci seen on PET that were not verified on follow-up of this duration were considered false-positive findings. When no abnormality was seen on PET, and when further intervention was not performed, this was considered to be a true-negative result, if by other imaging modalities or by clinical follow-up, no disease was identified within 6 months of the PET examination.

Table 1. SUMMARY OF CLINICAL, IMAGING, AND HISTOPATHOLOGIC DATA OF PATIENTS (n = 22)

Patient	Age (yr)	Primary Tumor Location/Duke Stage	CEA (ng/mL)	Recurrent Disease (PET)	Follow-up			Therapy
					Pathology	Radiology	Clinical	
1	68	Colon/B	40	Hepatic metastases	NA	–	DF (48 mo)	None
2	29	Rectum/C1	33	Extensive metastases (pelvis, spleen)	NA	+	PD (12 mo)	Chemotherapy
3	70	Rectosigmoid/B	26	Splenic metastasis	+ resection	–	DF (24 mo)	Resection
4	66	Colon/C1	10	–	NA	–	DF (24 mo)	None
5	84	Colon/B	11	–	NA	–	DF (11 mo)	None
6	65	Colon/B	38	Hepatic metastasis	+ resection	–	DF (18 mo)	Resection
7	60	Rectal/B	16	Pelvic recurrence Peritoneal metastases	NA	+	PD (10 mo)	Chemotherapy
8	70	Colon/B	11	–	– biopsy	–	DF (9 mo)	None
9	69	Rectal/C	18	Hepatic metastases	NA	+	PD (6 mo)	Chemotherapy
10	59	Colon/C	34	Hepatic metastases	NA	+	PD (11 mo)	Chemotherapy
11	59	Rectal/D	17	Pulmonary metastases	+ biopsy	+	PD (10 mo)	Chemotherapy
12	26	Rectal/B	45	–	NA	–	DF (13 mo)	None
13	62	Rectal/C2	43	Adrenal and para-aortic nodal metastases	NA	+	PD (8 mo)	Chemotherapy
14	67	Colon/B	19	Hepatic metastasis	+ resection	–	DF (24 mo)	Resection
15	45	Colon/B	32	Peritoneal metastases	+ biopsy	+	PD (13 mo)	Chemotherapy
16	69	Rectosigmoid/D	28	Hepatic and pulmonary metastases	NA	+	PD (9 mo)	Chemotherapy
17	56	Colon/C2	24	Peritoneal metastases	NA	+	PD (7 mo)	Chemotherapy
18	49	Rectal/C	15	Presacral recurrence Mediastinal nodal metastases	NA	+	PD (7 mo)	Chemotherapy
19	75	Rectal/C	11	Pelvic metastases	NA	–	DF (9 mo)	None
20	53	Appendix/B	11	–	– biopsy	–	DF (13 mo)	None
21	70	Rectal/C2	39	Pancreatic metastasis, pelvic and inguinal nodal metastases	+ biopsy	+	PD (14 mo)	Chemotherapy
22	71	Rectal/C	39	Pelvic metastasis	+ resection	+	DF (24 mo)	Resection and chemotherapy

NA = not available; – = no disease; + = presence of disease; DF = disease free; PD = progression of disease.

RESULTS

The clinical and pathologic features of our 22 patients are outlined in Table 1. At the time of PET, the CEA concentrations in these patients ranged from 10 to 45 ng/mL.

Abnormal foci of increased FDG accumulation were seen in 17 of the 22 patients (77%), with one lesion identified in each of 4 patients, and more than one lesion identified in the remaining 13 of these 17 patients. These foci of increased FDG accumulation were identified in several locations; spleen (2 patients), liver (6 patients), pelvis (6 patients), chest (3 patients), abdominal and pelvic nodes (2 patients), and the peritoneum (4 patients).

Results of tissue sampling were available in 7 of these 17 patients, all of whom had recurrent disease. Definitive curative surgical intervention was performed in four patients because the recurrent tumor was confined to a single resectable location; all of these patients had normal CEA concentrations after surgical resection of the recurrent disease. In the remaining three patients, only a single abnormality was biopsied. However, because of the distribution and extent of the abnormal foci in each of these patients, chemotherapy was administered without further surgical intervention.

Tissue sampling was not performed in the other 10 patients with abnormal PET studies. Subsequent dedicated imaging findings and clinical course confirmed the presence of extensive disease in eight of these patients (Table 1). These patients received chemotherapy because their recurrent disease was not considered amenable to curative resection (Table 1).

Overall, the positive predictive value for PET was 89% (15 of 17). False-positive results were obtained in two patients. In one of the patients (patient 19), 2 focal areas of increased FDG accumulation in the pelvis were interpreted as suspicious for

local recurrence. Subsequent CT showed that these foci represented asymmetric activity in the bowel and in a bladder diverticulum, respectively. In addition, a cystogram and a pelvic examination under general anesthesia did not disclose disease in these areas. This patient is alive and disease free 9 months after the PET study, and her CEA levels has returned to normal. The PET study of the second patient (patient 1) was of suboptimal quality because of the patient's large size, but showed focally increased activity in the dome of the liver that was considered suspicious for metastasis. Extensive further radiologic and clinical evaluation of this patient failed to confirm this abnormality. This patient is alive and well 4 years later. However his plasma CEA levels continue to fluctuate from 45 to 90 ng/mL.

FDG-PET was negative for recurrent disease in 5 of the 22 patients. These patients are all alive and disease free, with follow-up intervals ranging from 9 to 24 months. In two of these patients, biopsy at the anastomotic site was negative for tumor recurrence. In the remaining three patients, clinical follow-up and radiologic examinations failed to document disease progression. The plasma CEA levels decreased to normal in four of these patients and has remained stable but elevated in one patient. The negative predictive value for PET was thus 100%.

DISCUSSION

In recent years, FDG-PET has emerged as an extremely useful technique in oncologic practice.[4,5] Because PET detects regional metabolic abnormalities, rather than morphological abnormalities, it appears to be particularly helpful for assessing patients suspected to have tumor recurrence and in patients whom posttherapeutic alterations in anatomy make it difficult to interpret conventional imaging studies. Moreover, it appears that PET is more sensitive than conventional cross-sectional imaging methods for detecting recurrent disease and distant metastases. For example, the reported sensitivity and specificity of CT for detection of liver metastases has been as low as 42% and 50%.[14] CT portography is highly sensitive (80%–90%), but has a considerable rate of false-positive findings.[14] Recent series have shown that FDG-PET has an overall sensitivity of 93% to 100% and a specificity of 78% to 100% in the detection of recurrent disease in patients treated for colorectal cancer.[4–6,8–10,12,15] In one report, PET altered clinical management in 40% of the patients with recurrent disease.[8]

The use of CEA monitoring in the follow-up evaluation of patients with treated colorectal cancer is based on the general, well-documented principles that elevated CEA concentrations will revert to normal after curative resection, but will persist if the residual tumor is left behind. In addition, an increase in CEA concentration on serial measurements after curative surgery is indicative of tumor recurrence.[16] The ready availability of this test and its relatively low cost, and the lack of better markers for predicting tumor recurrence, contribute to its acceptance in clinical practice.[16–18] However, there are no published randomized, prospective studies that clearly document the benefits of CEA monitoring, and the impact of this practice on survival has been questioned.[1,16,19–22] Despite this, CEA monitoring is widely used in the follow-up evaluation of patients with colorectal cancer; it is estimated that nearly 500,000 patients in the United States are undergoing such monitoring.[17]

The potential role of FDG-PET in detecting recurrence in asymptomatic patients with elevated plasma CEA concentrations and negative conventional imaging has been addressed in a limited fashion as a component of other studies of the role of PET in recurrent colorectal cancer. Scott et al.[11] studied 16 patients with suspected recurrent colorectal cancer; 10 of their patients had elevated CEA levels and normal or equivocal CT findings, and PET correctly identified recurrent tumors in 8 of these patients. Similarly, in a study by Schiepers et al.,[9] of 76 patients evaluated for recurrent colorectal cancer, 4 had unexplained elevated CEA concentrations. PET correctly identified pelvic recurrence in one patient, was falsely negative in one patient, and gave true-negative results in the remaining two patients. In the series reported by Beets et al.,[8] PET correctly detected occult pelvic recurrence in two of three patients with negative conventional imaging studies and elevated CEA concentrations.

We have shown that FDG-PET is a considerable clinical utility in the evaluation of patients whose only abnormality is an unexplained elevation of plasma CEA concentrations after curative colorectal surgery. FDG-PET correctly identified one or more foci of cancer in all 15 patients in whom recurrent disease was subsequently confirmed and was normal in 5 of 7 patients who had no evidence for recurrent disease on follow-up evaluation. Of even greater importance is the impact of PET on the management of these patients. All 22 of our patients were potential candidates for blinded second-look exploratory laparotomy. Guided by the results of FDG-PET, curative surgery was attempted in only 4 of 15 patients (27%) with disease, and it appears to have been successful in all of the patients. Surgery was not performed in 11 patients because FDG-PET correctly indicated that the curative tumor resection could not be accomplished. Although there were two instances of false-positive PET findings, they did not lead to mismanagement of these patients; in both patients the findings were equivocal and the referring physicians opted for additional radiologic and follow-up studies.

An alternative, more widely available approach for detecting occult foci of colorectal cancer, is radioimmunoscintigraphy (RIS), which uses one of several different radiolabeled monoclonal antibodies directed against colorectal carcinomas. Various reports on RIS have indicated a wide range of sensitivities (18%–90%) and specificities (76%–97%) for the detection of recurrent disease in patients treated for colorectal cancer.[23–27] The results obtained are dependent upon size and location of the lesion and the type of monoclonal antibody and the radionuclide label employed. The best results are usually in the detection of extrahepatic disease. The use of RIS in patients with unexplained elevations of plasma CEA concentrations

have been studied and a wide range of sensitivities (57%–85%) and specificities (67%–100%) for lesion detection also have been reported.[28–31] Haseman et al.[31] who studied the largest number of such patients (140 patients), reported an overall sensitivity of 79% and specificity of 84%. The relatively high frequency of false-negative results thus limits value of RIS in this clinical setting. Limited direct comparisons of RIS and FDG-PET,[15,32,33] including one study where the monoclonal antibody was labeled with Cu-64 and imaged by PET,[33] also suggest that FDG-PET is more sensitive for the detection of recurrent colorectal cancer. However, larger controlled studies of these two methods for tumor detection are needed.

Our results suggest that FDG-PET is an effective means for evaluating patients with unexplained elevations in plasma CEA concentrations after treatment of colorectal cancer. A negative FDG-PET study indicates that recurrent tumor is unlikely in this clinical setting. FDG-PET further appears to have a high sensitivity for detecting resectable tumor foci and for showing when the recurrent disease will not be resectable. FDG-PET is thus likely to reduce the number of unnecessary operations performed in this patient population.

Acknowledgments

The authors thank Andrea Sykes for her assistance in the preparation of this manuscript and greatly appreciate the clinical assistance of Diana D. Trask, CNMT

References

1. Cohen AM, Minsky BD, Schilsky RL. Colon cancer. In: DeVita VT Jr, Hellman S, Rosenberg SA (eds). Cancer. Principles and practice of oncology, 4th edition. Philadelphia: Lippincott;1993:929–977.
2. Kelly CJ, Daly JM. Colorectal cancer. Principles of postoperative follow-up. Cancer 1992;70:1397–1408.
3. Vernava AM III, Longo WE, Virgo KS, Coplin MA, Wade TP, Johnson FE. Current follow-up strategies after resection of colon cancer. Results of a survey of the American Society of Colon and Rectal Surgeons. Dis Colon Rectum 1994;37:573–583.
4. Strauss LG, Conti PS. The applications of PET in clinical oncology. J Nucl Med 1991;32:623–648.
5. Conti PS, Lilien DL, Hawley K, Keppler J, Grafton ST, Bading JR. PET and [^{18}F]-FDG in oncology: a clinical update. Nucl Med Biol 1996;23:717–735.
6. Strauss LG, Clorius JH, Schlag P, et al. Recurrence of colorectal tumors: PET evaluation. Radiology 1989;170:329–332.
7. Patz EF Jr, Lowe VJ, Hoffman JM, Paine SS, Harris LK, Goodman PC. Persistent or recurrent bronchogenic carcinoma: detection with PET and 2-[F-18]-2-deoxy-D-glucose. Radiology 1994;191:379–382.
8. Beets G, Penninckx F, Schiepers C, et al. Clinical value of whole-body positron emission tomography with [^{18}F]fluorodeoxyglucose in recurrent colorectal cancer. Br J Surg 1994;81:1666–1670.
9. Schiepers C, Penninckx F, De Vadder N, et al. Contribution of PET in the diagnosis of recurrent colorectal cancer: comparison with conventional imaging. Eur J Surg Oncol 1995;21:517–522.
10. Haberkorn U, Strauss LG, Dimitrakopoulou A, et al. PET studies of fluorodeoxyglucose metabolism in patients with recurrent colorectal tumors receiving radiotherapy. J Nucl Med 1991;32:1485–1490.
11. Scott AM, Berlangieri SU, Zalcberg J, et al. Detection of recurrent colorectal cancer with F-18-FDG positron emission tomography (PET). J Nucl Med 1995;36:107P (abstract).
12. Ito K, Kato T, Tadokoro M, et al. Recurrent rectal cancer and scar: differentiation with PET and MR imaging. Radiology 1992;182:549–552.
13. Xu M, Luk WK, Cutler PD, Digby WM. Local threshold for segmented attenuation correction of PET imaging of the thorax. IEEE Trans Nucl Sci 1994;41:1532–1537.
14. Vitola JV, Delbeke D, Sandler MP, et al. Positron emission tomography to stage suspected metastatic colorectal carcinoma to the liver. Am J Surg 1996;171:21–26.
15. Schlag P, Lehner B, Strauss LG, Georgi P, Herfarth C. Scar or recurrent rectal cancer. Positron emission tomography is more helpful for diagnosis than immunoscintigraphy. Arch Surg 1989;124:197–200.
16. Wang JY, Tang R, Chiang JM. Value of carcinoembryonic antigen in the management of colorectal cancer. Dis Colon Rectum 1994;37:272–277.
17. Northover J. The use of prognostic markers in surgery for colorectal cancer. Eur J Cancer 1995;31A:1207–1209.
18. Slentz K, Senagore A, Hibbert J, Mazier WP, Talbott TM. Can preoperative and postoperative CEA predict survival after colon cancer resection? Am Surgeon 1994;60:528–532.
19. Moertel CG, Fleming TR, Macdonald JS, Haller DG, Laurie JA, Tangen C. An evaluation of the carcinoembryonic antigen (CEA) test for monitoring patients with resected colon cancer. JAMA 1993;270:943–947.
20. Northover JMA, Slack WW. A randomized, controlled trial of CEA-prompted second-look surgery in recurrent colorectal cancer; a preliminary report. Dis Colon Rectum 1984;27:576 (abstract).
21. Ohlsson B, Breland U, Ekberg H, Graffner H, Tranberg K-G. Follow-up after curative surgery for colorectal carcinoma. Randomized comparison with no follow-up. Dis Colon Rectum 1995;38:619–626.
22. Hida J, Yasutomi M, Shindoh K, et al. Second-look operation for recurrent colorectal cancer based on carcinoembryonic antigen and imaging techniques. Dis Colon Rectum 1996;39:74–79.
23. Goldenberg DM, Larson SM. Radioimmunodetection in cancer identification. J Nucl Med 1992;33:803–814.
24. Abdel-Nabi H, Doerr RJ. Clinical applications of indium-111-labeled monoclonal antibody imaging in colorectal cancer patients. Semin Nucl Med 1993;23:99–113.
25. Nabi HA. Radiolabeled antibodies in clinical nuclear medicine: a technology coming of age. In: Freeman LM (ed.), Nuclear Medicine Annual 1993. New York: Raven Press; 1993:1–27.
26. Neal CE, Meis LC. Correlative imaging with monoclonal antibodies in colorectal, ovarian, and prostate cancer. Semin Nucl Med 1994;24:272–285.
27. Rutgers EJT. Radio-immunotargeting in colorectal carcinoma. Eur J Cancer 1995;31A:1243–1247.
28. Patt YZ, Podoloff DA, Curley S, et al. Monoclonal antibody imaging in patients with colorectal cancer and increasing levels of serum carcinoembryonic antigen. Experience with ZCE-025 and IMMU-4 monoclonal antibodies and proposed directions for clinical trials. Cancer 1993;71:4293–4297.
29. Maguire RT, Pascucci VL, Maroli AN, Gulf JV. Immunoscintigraphy in patients with colorectal, ovarian, and prostate cancer. Results with site-specific immunoconjugates. Cancer 1993;72:3453–3462.
30. Patt YZ, Podoloff DA, Curley S, et al. Technetium 99m-labeled IMMU-4, a monoclonal antibody against carcinoembryonic antigen, for imaging of occult recurrent colorectal cancer in patients with rising serum carcinoembryonic antigen levels. J Clin Oncol 1994;12:489–495.
31. Haseman MK, Brown DW, Keeling CA, Reed NL. Radioimmunodetection of occult carcinoembryonic antigen-producing cancer. J Nucl Med 1992;33:1750–1757.
32. Bohdiewicz PJ, Scott GC, Juni JE, et al. Indium-111 OncoScint CR/OV and F-18 FDG in colorectal and ovarian carcinoma recurrences. Early observations. Clin Nucl Med 1995;20:230–236.
33. Philpott GW, Schwarz SW, Anderson CJ, et al. RadioimmunoPET: detection of colorectal carcinoma with positron-emitting copper-64-labeled monoclonal antibody. J Nucl Med 1995;36:1818–1824.