INTRODUCTION

Colorectal cancer is one of the most common malignancies. Westernization of diet and an aging society are two reasons for the ongoing increase in the incidence of colorectal cancer. Approximately 80% of colorectal cancers are thought to arise from adenomas, and cancer-related mortality can be reduced by removal of adenomatous polyps. Colonoscopy is used to detect and remove adenomatous polyps.
2-18F-fluoro-2-deoxy-D-glucose positron emission tomography (FDG PET) measures the accumulation of 18F-FDG in cells with high rates of glycolysis. The clinical usefulness of FDG PET is widely accepted in the diagnosis and staging of various malignancies, such as lymphomas, melanomas, lung cancer, and colon cancer. The introduction of FDG PET/CT has paved the way for anatomic information regarding FDG uptake. Accordingly, PET/CT has been carried out, even for healthy check-ups, and some cases have been reported in which FDG colonic uptake revealed colonic adenomas or carcinomas.

This study was aimed at determining the usefulness of FDG PET/CT scans compared with colonoscopy in the evaluation of colonic neoplasms, such as adenomas and carcinomas.

**MATERIALS AND METHODS**

1. Subjects

A retrospective review was performed in consecutive patients who underwent PET/CT and colonoscopy within a 3 month interval between May 2007 and June 2008.

2. Colonoscopy

An experienced gastroenterologist performed all of the flexible endoscopic procedures. All abnormal colonic lesions were described and biopsied. The locations of the abnormal colonic lesions were classified into 5 segments, as follows; ascending, transverse, descending, and sigmoid colon, and rectum. The histopathologic findings were grouped as carcinomas, adenomas, hyperplastic polyps, and non-specific inflammation. The size of the polyp or mass was measured and compared with the width of a forceps.

3. FDG PET/CT scan

The patients fasted at least 4 hours prior to the intravenous injection of 370-666 MBq (10-18 mCi [0.14 mCi/kg]) of 18F-FDG. Blood glucose levels were checked in patients with diabetes and patients who did not know their blood glucose levels prior to the injection of 18F-FDG. A PET/CT scan was performed only when blood glucose levels did not exceed 150 mg/dL (8.3 mmol/L). Data acquisition was done using an integrated PET/CT system (Philips Gemini, DA Best, The Netherlands) 1 hour after the 18F-FDG injection. CT scanning was performed prior to the PET scan from the head to the pelvic floor with 120 kVp, 250 mA, and a 5.3 mm section thickness. Next, the PET scan was performed with a 5-min emission acquisition per imaging level and the images were reconstructed. PET image data was acquired by imaging reconstruction using a Row Action Maximum Likelihood Algorithm (RAMRA). The FDG PET/CT scan was reviewed by a nuclear medicine physician who had information about the patient’s clinical findings.

Abnormal colonic lesions noted on FDG PET/CT scans were described based on intensity, location, and patterns of FDG uptake. The intensity of FDG uptake was described by the standardized uptake value (SUVmax). The pattern of colonic FDG uptake was divided into the following 3 groups; focal, segmental, and diffuse.

4. Interpretation of FDG PET/CT image

Images of FDG uptake were classified into physiologic or pathologic based on the following definitions. When FDG uptake in the colon was diffuse without a focal increase in accumulation, and did not correspond with a delayed image, FDG uptake was interpreted as physiologic. In contrast, when FDG uptake in the colon was present as a clear focus without extension into the lumen and corresponded with a delayed image, it was interpreted as pathologic.

FDG uptake was considered true positive when it matched colonic lesions and false positive when there was no corresponding colonic lesion by colonoscopy. FDG uptake of FDG PET/CT was analyzed for sensitivity, specificity, and positive and negative predictive values. Comparison between true and false positive FDG uptake was analyzed by Student’s t-test. A P-value <0.05 was considered statistically significant.
RESULTS

1. Patient characteristics

One hundred two patients were enrolled; 42 patients were males and 60 patients were females. The age of the patients ranged from 28-89 years, and the mean age was 54.8 years. The mean interval between FDG PET/CT and colonoscopy was 17.4±19.0 days (range, 0-76 days). FDG PET/CT was performed for health check-ups in 10 subjects, for staging in 9 colon cancer patients, for follow-up of cured colon cancer in 19 patients, and for assessment of metastasis in 64 patients with malignancies. The malignancies other than colon cancer were as follows: gastric cancer, 9; lung cancer, 6; breast cancer, 3; ovarian cancer, 16; uterine cervix, 14; uterine cancer, 7; lymphoma, 3; cancers of unknown primary sites, 2; liver, 1; pancreas, 1; thyroid cancer, 1; and omental mass, 1. Forty-three patients had no abnormal findings on colonoscopy or FDG PET/CT.

2. Pathologic diagnosis and features of colonic lesions

Colonoscopy revealed 81 abnormal colonic lesions in 47 patients. The pathologic findings were as follows: malignant lesions, 13 (12 adenocarcinomas and 1 lymphoma); adenomas, 26; hyperplastic polyps, 11; and benign inflammatory lesions, 31. Malignant lesions were located in the rectum (n=6), sigmoid colon (n=4), and ascending, transverse, and descending colon (n=1 each). The mean size of the malignant tumors, as measured by endoscopy, was 29±17 mm (range, 4-50 mm). Adenomas were located in the transverse (n=8), sigmoid (n=6), descending (n=5), and ascending colon (n=4), and rectum (n=3). The mean size of the adenomas was 8±3 mm (range, 3-12 mm; Table 1).

3. Clinical features of increased FDG uptake

FDG PET/CT showed FDG uptake in 42 colonic lesions in 29 of 102 patients. The uptake was interpreted as pathologic and physiologic colonic uptake in 24 and 18 lesions, respectively.

In the lesions with pathologic FDG colonic uptake, the mean intensity of SUV max was 8.3±5.9 (range, 2.3-25). The patterns of uptake revealed focal uptake in 23 lesions, segmental uptake in 1 lesion, and no lesions with diffuse uptake. Lesions with pathologic FDG colonic uptake were located in the rectum (n=12), and sigmoid (n=6), ascending (n=3), transverse (n=2), and descending colon (n=1).

In lesions with physiologic FDG colonic uptake, the mean intensity of SUV max was 6.8±2.0 (range, 3.7-11.2). The pattern of uptake revealed focal uptake in 11 lesions, segmental uptake in 3 lesions, and diffuse uptake in 4 lesions. Physiologic FDG colonic uptake was located in the ascending, transverse, and sigmoid colon, and rectum (n=4 lesions each), and the descending colon (n=2 lesions) (Table 2).

Table 1. Pathologic Diagnoses and Features of Colonic Lesions

|                      | Malignant tumor | Adenoma | Hyperplastic polyp |
|----------------------|-----------------|---------|-------------------|
| Number of lesions    | 13†             | 26      | 11                |
| Size (mm), mean±SD*  | 29±17           | 8±3     | 6±2               |
| Location             |                 |         |                   |
| Ascending colon      | 1               | 4       | 3                 |
| Transverse colon     | 1               | 8       | 1                 |
| Descending colon     | 1               | 5       | 1                 |
| Sigmoid colon        | 4               | 6       | 2                 |
| Rectum               | 6               | 3       | 4                 |

†SD, standard deviation.
13, 12 carcinomas and 1 lymphoma.

Table 2. Clinical Features of Increased FDG Uptake Lesions

|                      | Pathologic uptake | Physiologic uptake |
|----------------------|-------------------|--------------------|
| Number of lesions    | 24                | 18                 |
| SUV max, mean±SD*    | 8.3±5.9           | 6.8±2.0            |
| Pattern              |                   |                    |
| Focal                | 23                | 11                 |
| Segmental            | 1                 | 3                  |
| Diffuse              | 0                 | 4                  |
| Location             |                   |                    |
| Ascending colon      | 3                 | 4                  |
| Transverse colon     | 2                 | 4                  |
| Descending colon     | 1                 | 2                  |
| Sigmoid colon        | 6                 | 4                  |
| Rectum               | 12                | 4                  |

SUV max, standardized uptake value.
†SD, standard deviation.
4. Diagnostic value of FDG PET/CT for the detection of colonic neoplasms

Among 13 malignant tumors proven by colonoscopic biopsy, FDG PET/CT revealed FDG uptake in 11 malignant lesions, physiologic colonic uptake in 1 lesion, and no FDG uptake in 1 lesion (Table 3). The sensitivity, specificity, positive and negative predictive values, and diagnostic accuracy of FDG PET/CT scans for the diagnosis of colonic malignancy by pathologic FDG uptake were 84.6% (11/13), 90.4% (122/135), 45.8% (11/24), 98.4% (122/124), and 89.9% (133/148), respectively (Table 4).

With respect to the 26 adenomas in FDG PET/CT, there were no lesions with pathologic uptake, 1 lesion with physiologic uptake, and no uptake in 25 lesions.

| Pathology by colonoscopy | FDG uptakes of PET/CT | Pathologic uptake (n=24) | Physiologic uptake (n=18) | No uptake (n=106) |
|--------------------------|-----------------------|--------------------------|---------------------------|------------------|
| Malignant tumor (n=13)   | 11                    | 1                        | 1                         |
| Adenoma (n=26)           | 0                     | 12                       | 5                         |
| Hyperplastic polyp (n=11) | 0                     | 2                       | 3                         |
| Non-specific inflammation (n=31) | 3       | 2                      | 26                        |
| No mucosal lesion (n=67)  | 10                    | 14                       | 43                        |

FDG, 2-18F-fluoro-2-deoxy-D-glucose; PET, positron emission tomography.

| Table 4. Diagnostic Accuracy of FDG PET/CT for the Detection of Colonic Neoplasm |
|---------------------------------|-----------------|-----------------|----------------------|
| Lesion (%) | Malignant tumor (n=13) | Adenoma (n=26) | Adenoma & malignant tumor (n=39) |
| Sensitivity (%) | 84.6 | 90.4 | 88.1 |
| Specificity (%) | 72.3 | 45.8 | 45.8 |
| Positive predictive value (%) | 98.4 | 79.0 | 77.8 |
| Negative predictive value (%) | 89.9 | 66.2 | 72.3 |

FDG, 2-18F-fluoro-2-deoxy-D-glucose; PET, positron emission tomography.

The sensitivity, specificity, positive and negative predictive values, and diagnostic accuracy of FDG PET/CT in the detection of colonic adenomas as well as malignant tumors by pathologic FDG uptake, were 28.2% (11/39), 88.1% (96/109), 45.8% (11/24), 77.8% (76/124), and 72.3% (107/148), respectively (Table 4).

There was no FDG uptake in all 11 hyperplastic polyps. However, among 31 non-specific inflammatory lesions, there were 3 lesions with pathologic FDG colonic uptake and 2 lesions with physiologic colonic uptake (Table 3).

Among 42 lesions with FDG colonic uptake on FDG PET/CT scans, 13 (31.0%) were pathologic and true positives. The mean intensity of FDG uptake (SUV_{max}) was 9.4±6.0 in the lesions with pathologic uptake and 6.9±3.9 in the lesions with physiologic uptake; however, these values were not statistically different (P=0.129).

The mean size of colonoscopic lesions was larger in lesions with true-positive uptake than lesions with false-positive uptake (31.3±15.5 mm vs. 8±6.4 mm, P=0.003) (Table 5). The pattern of FDG uptake was focal in all true-positive lesions, but false-positive focal uptake in 22 lesions, segmental uptake in 4 lesions, and diffuse uptake in 4 lesions. However, the pattern of uptake between the two groups was not statistically different (P=0.129).

The location of true-positive FDG uptake was the...
rectum (n=6 lesions), sigmoid colon (n=4 lesions), and ascending and transverse colon (n=1 lesion each). In contrast, FDG uptake of false-positive lesions was located in the rectum (n=10 lesions), sigmoid colon (n=6 lesions), descending colon (n=3 lesions), transverse colon (n=5 lesions), and ascending colon (n=6 lesions). This distribution of FDG colonic uptake was not statistically different between the true- and false-positive groups (P=0.599).

**DISCUSSION**

We compared FDG colonic uptake on FDG PET/CT with colonoscopic findings. FDG PET/CT had a sensitivity of 84.6% and a specificity of 90.4% for colonic malignancies, and a sensitivity of 28.2% and a specificity of 88.1% for adenomas and malignancies of the colon. Two of 13 colon cancer patients had no pathologic uptake on FDG PET/CT. Both patients had luminal obstruction of the colon due to advanced colon cancer in the ascending or sigmoid colon. A self-expandable metal stent was inserted in the patient with the sigmoid colon obstruction. Both patients had faint focal uptake (SUVmax, 4.53 and 2.84) in the obstructed lesions. The uptake was interpreted as physiologic in one patient and the uptake was considered normal in the other patient. Mucosal and submucosal edema can induce vascular and lymphatic obstruction to the lesion, and ultimately induce false-negative FDG uptake due to over-estimation of the image of FDG uptake than the combined CT scan.

Twenty-seven lesions with incidental colonic FDG uptake on FDG PET in 3,000 patients without a known history of colorectal carcinoma were shown to be dysplastic adenomas or hyperplastic polyps (n=7) and malignancies (n=6). Of 39 patients, including those patients with a history of colorectal malignancy in another study, non-physiologic FDG uptake on FDG PET had a sensitivity of 74% and a specificity of 84% for large adenomatous polyps and carcinomas. FDG PET failed to detect small polyps of diameter 3-10 mm in 4 out of 11 patients.

FDG PET/CT can not only detect colorectal carcinomas, but also colorectal adenomas. The sensitivity of detection for colonic adenomas on FDG PET scans is known to correlate with the size of the adenoma. The positivity rate for colonic adenomas <9 mm in size on FDG PET scans was 0%, but 90% for colonic adenomas >13 mm in size. Twenty-six adenomas were detected by colonoscopy in the current study. Sixteen adenomas were <9 mm in size, 9 adenomas were 10 mm in size, and 1 adenoma was 12 mm in size, but only 1 lesion presented as a faint physiologic FDG uptake in a lesion <9 mm in size.

The histopathologic results of colonic polyps could include types other than adenomas and carcinomas. Hyperplastic polyps ranged from 3-38 mm in size and were not detected with FDG PET/CT. Histopathologic findings were described as carcinomas, adenomas, and hyperplastic polyps in this study. There was no FDG uptake in the hyperplastic polyps.

Colonic FDG uptake frequently shows up on FDG PET/CT scans, and is usually physiologic uptake. The causes of physiologic uptake were not identified, but presumed to be correlated with peristaltic muscular activity of the bowel, existence of lymphoid tissue, and presence of FDG-secreting cells. Most physiologic FDG colonic uptake is known to present a diffuse or segmental pattern, and in some cases, correlate with infected or inflammatory bowel disease. In the current study, the pattern of true-positive FDG uptake was focal in all lesions, and of the pattern of false-positive update was focal in 22 lesions, segmental in 4 lesions, and diffuse in 4 lesions. Even though this study did not demonstrate a difference in the pattern of uptake of FDG between the true- and false-positive groups due to the small number of cases, pathologic uptake was prone to focal uptake.

The presumption that the use of an oral CT contrast agent can distinguish pathologic from physiologic uptake and increase the sensitivity of FDG PET/CT scans has been reported to be medically insignificant. However, a negative oral contrast agent, such as mannitol, has been used to avoid contrast-induced artifacts.

In conclusion, FDG colonic uptake on FDG PET/CT is a useful diagnostic method to detect colorectal carcinoma, but inadequate for pre-cancerous lesions and adenomas. The intensity, pattern, and location of FDG colonic uptake did not differ between malignant and benign lesions, but a high SUVmax and focal-uptake
pattern might be prone to pathologic uptake, and luminal obstructive colon cancer might induce a false-negative uptake on FDG PET/CT. Therefore, FDG colonic uptake on FDG PET/CT needs further evaluation, such as colonoscopy.

요 약

목적: 대장 종양과 선종의 진단에 FDG PET/CT의 진단적 유용성을 후향적 방법으로 알아보고자 하였다. 대상 및 방법: FDG PET/CT와 대장내시경을 2007년 5월부터 2008년 6월 사이에 3개월 이내의 간격으로 함께 시행한 환자 102명 (남자 42명, 여자 60명, 연령 28-89세) 전부 선택하였다. FDG PET/CT에서 보이는 음영은 핵의학 전문의가 판독하였고 비정상적인 음영이라 판단된 것은 조직학적으로 확인하였다. 결과: 102명의 환자 중에서 43명은 FDG PET/CT와 대장내시경에 병적인 소견이 없었고 59명에서 105개의 결장 병소를 확인하였다. PET/CT에서 병적으로 판단한 24개의 병소 중에서 11곳이 조직학적으로 악성임이 확인되었다. 생리적 음영의 위양성이라 생각했던 18곳의 FDG 음영 중에서 결장암 1개, 선종 1개, 비후성 용종 12개가 발견되었다. 대장암에 대한 PET/CT의 예민도는 84.6%, 특이도 90.4%, 양성 예측도 45.8%, 음성 예측도 98.4%였으나, 대장암과 선종은 포함한 종양에 대한 예민도, 특이도, 양성 및 음성 예측도는 각각 28.2%, 88.1%, 45.8%, 77.8%로 악성도가 낮았다. 결론: FDG PET/CT는 대장암 진단하는 유용한 방법이지만, 선종을 발견하는 악성도는 낮기 때문에 선별검사로는 대장 내시경검사가 필요하다.

색인어: 양전자 방출 전산화 단층촬영; 대장내시경; 대장 종양

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