ORIGINAL

A reduced physiological ^{18}F-fluorodeoxyglucose uptake in the brain and liver caused by malignant lymphoma being deprived of the tracer

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Abstract : *Purpose* : To investigate whether or not the physiological brain and liver FDG uptake are decreased in patients with highly accelerated glycolysis lesions. *Methods* : We retrospectively analyzed 51 patients with malignant lymphoma. We compared the FDG uptake in the brain and liver of the patients with that in a control group. In 24 patients with a complete response (CR) or partial response (PR) to treatment, we compared the brain and liver uptake before and after treatment. *Results* : The maximum standardized uptake value (SUVmax) and total glycolytic volume (TGV) of the brain as well as the SUVmax and mean standardized uptake value (SUVmean) of the liver in malignant lymphoma patients were 13.1 ± 2.3, 7386.3 ± 1918.4, 3.2 ± 0.5, and 2.3 ± 0.4, respectively ; in the control group, these values were 14.9 ± 2.4, 8566.2 ± 1659.5, 3.4 ± 0.4, and 2.5 ± 0.3, respectively. The SUVmax and TGV of the brain and the SUVmean of the liver in malignant lymphoma patients were significantly lower than the control group. The SUVmax and TGV of the brain after treatment were significantly higher than before treatment. Both the SUVmax and SUVmean of liver after treatment were higher than before treatment, but not significant. *Conclusion* : A decreased physiological brain and liver FDG uptake is caused by highly accelerated lesion glycolysis. J. Med. Invest. 68 : 181-185, February, 2021

Keywords **:** *brain, liver, malignant lymphoma*

INTRODUCTION

[^{18}F] fluoro-2-deoxyglucose (FDG) positron emission tomography/computed tomography (PET/CT) has been extensively utilized as a useful, non-invasive diagnostic imaging modality for evaluating a variety of neoplastic diseases (1-3). In the field of oncology, not only the visual assessment of the FDG uptake in tumor, the quantitative assessment of the FDG uptake in tumor lesions using the standardized uptake value (SUV) has generally been practiced (4, 5). Specifically, for malignant lymphoma, the liver and the blood pool of the mediastinum are used as a reference when assessing the tumor uptake (6-8).

However, the brain uptake is reportedly decreased in patients with large tumors with a high FDG uptake, such as malignant lymphoma and undifferentiated carcinoma (9-12). Furthermore, in the daily clinical course, the liver uptake may also seem to be decreased in patients with high-FDG-uptake tumors.

The purpose of the present study was to determine whether or not the brain and liver uptake in patients with high-FDG-uptake tumors is decreased compared to patients with no tumors showing an FDG uptake as a control. Considering the fact that the liver FDG uptake is frequently used for the reference region to evaluate tumor activity, it is meaningful to correctly comprehend the factors that affect the liver uptake.

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MATERIALS AND METHODS

Patients

We retrospectively analyzed 51 patients with malignant lymphoma. We compared the brain and liver uptake of these 51 patients with those of another 51 patients in the control group. Among 24 patients with a complete response (CR) or partial response (PR) to treatment, we compared the brain and liver uptake before and after treatment. In addition, the liver uptake in these 24 patients was compared before and after treatment specifically among those in whom the liver uptake before treatment were lower than the median of the control group.

This retrospective study was approved by the Ethics Committee of Tokushima University Hospital (approval number : 3210). The need for written informed consent from the patients was waived by the Ethics Committee of Tokushima University Hospital.

・Malignant lymphoma group

Fifty-one patients (male, n = 27 ; female, n = 24 ; mean age 64.6 years) in whom the uptake of FDG was detected in malignant lymphoma lesions with total lesion glycolysis (TLG) > 100 on PET/CT from April 2015 to January 2018 and in whom Hodgkin's or non-Hodgkin's lymphoma was histologically confirmed. All patients in the malignant lymphoma group underwent FDG PET/CT examination before any treatment for malignant lymphoma. None of them received treatment, such as chemotherapy, for at least 3 months before PET/CT examination. The patients had no history of cerebrovascular disorders, brain tumors, liver disorders, liver invasion, or liver tumors. We excluded cases of hepatic steatosis (less than 40 Hounsfield units on CT). Patients whose blood sugar was less than 140 mg/dl before FDG injection were included. Patients with diabetes mellitus were included if their blood glucose level is within this range.

The malignant lymphoma and control groups each included four cases of type 2 diabetes mellitus.

・Control group

Fifty-one age-, gender-, and body weight-matched patients who underwent FDG PET/CT from January 2018 to April 2018 were enrolled as the control group (12, 13). The control patients had already been treated for cancer and had no relapse for at least six months without treatment. They had no history of cerebrovascular disorders, brain tumors, liver disorders, liver invasion, or liver tumors. We excluded cases of hepatic steatosis (less than 40 Hounsfield units on CT). Patients whose blood sugar was less than 140 mg/dl before FDG injection were included.

Evaluating the FDG uptake of malignant lymphoma and in the brain and liver of the two groups

A physician specializing in nuclear medicine evaluated the FDG PET/CT images. The volume of the tumor with an SUV ≥ 2.5 was determined as the metabolic tumor volume (MTV) (ml) (14, 15). The TLG of patients with malignant lymphoma was calculated by establishing volumes of interest (VOI) for all abnormal uptakes of malignant lymphoma lesions on an image viewer (AW server 2.0 ; GE Healthcare). The maximum SUV (SUV_{max}) and total glycolytic volume (TGV) of the brain were calculated by setting the VOI in the whole brain of the two groups. The SUV_{max} and mean SUV (SUV_{mean}) of the liver were also calculated by setting the region of interest (ROI) in the liver of the two groups automatically using the function of AW server 2.0.

Statistical analyses

The parameters were expressed as the mean ± standard deviation. The homogeneity of variance was tested by the Levene's test. The normality of the distribution of the variables was tested by the Kolmogolov-Smirnov test. Student's *t*-test (normal distribution) or Welch's *t*-test (non-normal distribution) was applied to evaluate differences in the variables of the parameters. The relationships between the liver and brain uptake and the tumor lesion uptake level were quantified using Spearman's correlation analysis. The SPSS Statistics software program (version 24 ; IBM, Chicago, IL, USA) was used to perform the statistical analyses. A *p* value of less than 0.05 was considered statistically significant.

RESULTS

The details of the 51 cases of malignant lymphoma are as follows : 21 diffuse large B-cell lymphoma, 17 follicular lymphoma, 5 Hodgkin's lymphoma, 2 extra-nodal marginal zone lymphoma of mucosa-associated lymphoid tissue, 1 Burkitt lymphoma, 1 anaplastic large cell lymphoma, 1 T-cell lymphoma, and 3 malignant lymphoma of unknown classification. The TLG of the malignant lymphoma group was 2383.0 ± 3866.6 (range 112.8–21880.1). The therapeutic evaluation was as follows : 20 cases with CR, 4 cases with PR, and 1 case with progressive disease (PD) in 25 patients who underwent follow-up FDG PET/CT. The clinical characteristics of the study groups are shown in Table 1. None of the parameters of age, gender, body weight, blood glucose, and FDG dose in the two groups was statistically significant.

A comparison of the brain and liver uptake in the two study groups is shown in Table 2. The SUV_{max} and TGV of the brain and the SUV_{max} and SUV_{mean} of the liver in patients with malignant lymphoma were 13.1 ± 2.3, 7386.3 ± 1918.4, 3.2 ± 0.5, and 2.3 ± 0.4, respectively ; in the control group, these values were 14.9 ± 2.4, 8566.2 ± 1659.5, 3.4 ± 0.4, and 2.5 ± 0.3, respectively. The SUV_{max} and TGV of the brain and the SUV_{mean} of the liver of the malignant lymphoma patients were significantly lower than in the control group ($p = 0.0003$, 0.001, and 0.017, respectively). The SUV_{max} of the liver of the malignant lymphoma patients was lower than in the control group, but not to a significant degree ($p = 0.055$). There were no statistically significant correlations between TLG and liver SUV_{max} ($r = -0.060$, $p = 0.678$) and liver SUV_{mean} ($r = -0.191$, $p = 0.179$). There were no statistically significant correlations between the TLG and brain SUV_{max} ($r = -0.064$, $p = 0.654$) or brain TGV ($r = -0.114$, $p = 0.427$).

A comparison of the brain and liver uptake before and after treatment in 24 CR and PR cases is shown in Table 3. The SUV_{max} and TGV of the brain and the SUV_{max} and SUV_{mean} of the liver in patients with malignant lymphoma were 13.2 ± 1.8, 7545.1 ± 1727.8, 3.2 ± 0.4, 2.3 ± 0.3, respectively, before treatment and 14.6 ± 2.3, 8459.6 ± 1834.6, 3.3 ± 0.3, 2.4 ± 0.3, respectively, after treatment. The SUV_{max} and TGV of the brain of 24 malignant lymphoma patients after treatment with CR and PR were significantly higher than before treatment ($p = 0.015$ and 0.027, respectively). Both the SUV_{max} and SUV_{mean} of liver of 24 patients after treatment were higher than before treatment, but not to a significant degree ($p = 0.446$ and 0.237, respectively). In the 24 cases, an evaluation limited to cases in which the liver uptake (SUV_{max}, SUV_{mean}) before treatment was lower than the median of the control group (SUV_{max} : n = 13, SUV_{mean} : n = 16) showed that the liver SUV_{max} after treatment in 13 cases was higher than that before treatment, but not to a significant degree

Table 1. The clinical characteristics of the study groups

	Malignant lymphoma ($n = 51$)	Control group ($n = 51$)	*p* value
Age (years)	64.6 ± 13.6	64.4 ± 12.6	$p = 0.952$
Gender			$p = 1.000$
Female	24	24	
Male	27	27	
Weight (kg)	58.5 ± 9.2	58.1 ± 12.0	$p = 0.861$
Blood glucose (mg/dl)	102.9 ± 14.5	103.8 ± 10.4	$p = 0.707$
FDG (MBq)	179.1 ± 31.1	181.4 ± 39.4	$p = 0.743$

Data were represented as mean ± standard deviation. A *p* value less than 0.05 was considered statistically significant.
FDG, fluorodeoxyglucose

Table 2. A comparison of the brain and liver uptake of the study groups

Parameter	Malignant lymphoma group ($n = 51$)	Control group ($n = 51$)	*p* value
Brain			
SUV_{max}	13.1 ± 2.3	14.9 ± 2.4	$p = 0.0003$
TGV	7386.3 ± 1918.4	8566.2 ± 1659.5	$p = 0.001$
Liver			
SUV_{max}	3.2 ± 0.5	3.4 ± 0.4	$p = 0.055$
SUV_{mean}	2.3 ± 0.4	2.5 ± 0.3	$p = 0.017$

Data are presented as the mean ± standard deviation. A *p* value less than 0.05 was considered statistically significant.
SUV_{max}, maximum standardized uptake value ; SUV_{mean}, mean standardized uptake value ; TGV, total glycolytic volume

($p = 0.051$), and the liver SUV_{mean} after treatment in 16 cases was significantly higher than that before treatment ($p = 0.005$) (Table 4).

Fig. 1 shows PET/CT images of a case showing a decreased brain and liver uptake with a high FDG uptake in malignant lymphoma lesions. Fig. 2 shows PET/CT images of a control case. Fig. 3A shows the FDG PET/CT images of a case which showed a reduced brain and liver uptake with a high uptake to the tumor lesions of diffuse large B-cell lymphoma. Thereafter, this case showed an increased brain and liver uptake with a decreasing uptake of the tumor after chemotherapy (Fig. 3B).

Table 3. The brain and liver uptake before and after treatment in 24 CR and PR cases

Parameter	Pre-treatment	Post-treatment	*p* value
Brain			
SUV_{max}	13.2 ± 1.8	14.6 ± 2.3	$p = 0.015$
TGV	7545.1 ± 1727.8	8459.6 ± 1834.6	$p = 0.027$
Liver			
SUV_{max}	3.2 ± 0.4	3.3 ± 0.3	$p = 0.446$
SUV_{mean}	2.3 ± 0.3	2.4 ± 0.3	$p = 0.237$

Data are presented as the mean ± standard deviation. A *p* value less than 0.05 was considered statistically significant.
CR, complete response ; PR, partial response ; SUV_{max}, maximum standardized uptake value ; SUV_{mean}, mean standardized uptake value ; TGV, total glycolytic volume

Table 4. The CR/PR cases in which liver uptake pre-treatment is less than median of control group

Parameter	Pre-treatment	Post-treatment	*p* value
Liver			
SUV_{max} (n = 13)	2.9 ± 0.3	3.2 ± 0.3	$p = 0.051$
SUV_{mean}(n = 16)	2.2 ± 0.3	2.4 ± 0.2	$p = 0.005$

Data are presented as the mean ± standard deviation. A *p* value less than 0.05 was considered statistically significant.
CR, complete response ; PR, partial response ; SUV_{max}, maximum standardized uptake value ; SUV_{mean}, mean standardized uptake value

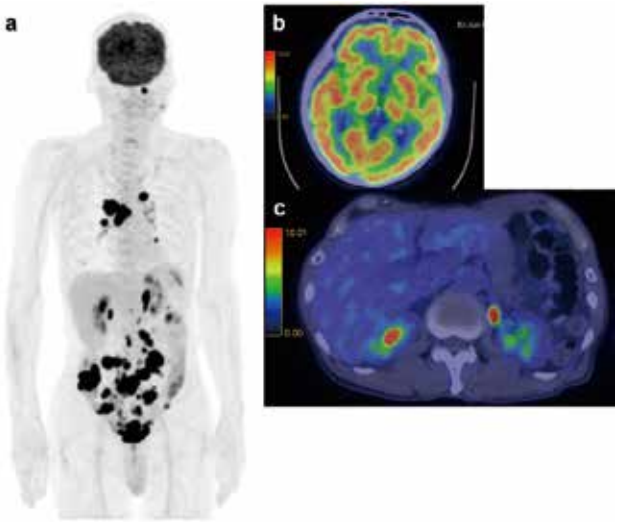

Fig 1. FDG PET/CT images of representative case showing brain and liver uptake decrease with high tumor uptake. The tumor was diffuse large B-cell lymphoma (DLBCL). Maximum intensity projection of FDG PET (a), PET/CT fusion image of brain (b), PET/CT fusion image of liver (c) of a 70-year-old male. Each parameter follows ; SUVmax of 2.9, SUVmean of 2.2 in liver, SUVmax of 11.4, TGV of 6958.0 in brain, SUVmax of 31.3, TLG of 3450.4, MTV of 329.6 in DLBCL lesions.

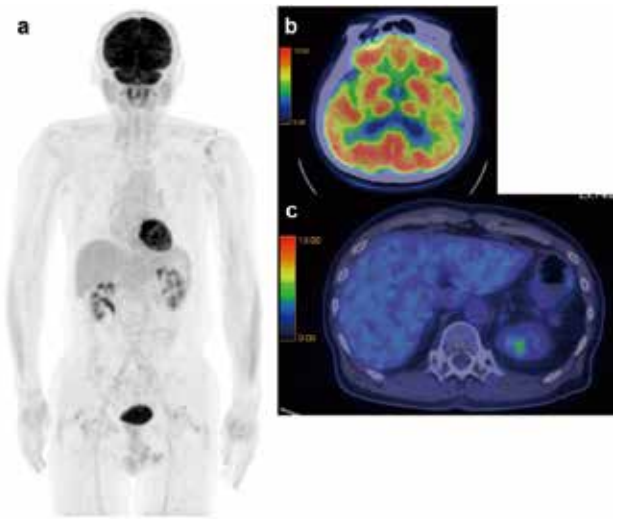

Fig 2. FDG PET/CT images of representative case of control group. Maximum intensity projection of FDG PET (a), PET/CT fusion image of brain (b), PET/CT fusion image of liver (c) of a 60-year-old male. Each parameter follows ; SUVmax of 3.4, SUVmean of 2.6 in liver, SUVmax of 14.0, TGV of 8058.0 in brain.

DISCUSSION

The uptake of FDG in the brain of patients with malignant lymphoma was significantly lower than that in the control group. However, no significant correlation was found between the brain uptake and TLG of lymphoma in this study. A previous report described a statistically significant negative correlation between TLG of lymphoma and the brain FDG uptake in patients with non-Hodgkin's lymphoma (12). Previous papers have also validated the phenomenon of a decreased brain FDG uptake due to a substantial tumor uptake (12, 16), implying that there is competition between the tumor and brain to capture FDG (12).

Several factors that may decrease the brain uptake have been reported. The extent of the brain uptake depends on the blood glucose level. Previous authors have reported a significant impact of glycemia on the FDG uptake in the brain cortex, as patients with higher blood glucose levels presented progressively lower cortical SUVs (17-20). Exercise also reduces the brain FDG uptake (21, 22). Lactate is a substrate other than glucose that is reportedly utilized by the brain during high-intensity exercise in order to compensate for the increased energy requirement to maintain neuronal activity ; this activity may reduce the brain uptake. For this reason, patients with hyperglycemia (blood glucose levels above 140 mg/dl) were excluded from our study. We also urged all patients to avoid intense exercise before the PET/CT examination.

In the present study, we showed that the brain uptake after treatment in CR and PR cases was significantly higher than that before treatment. This result suggests that the distribution

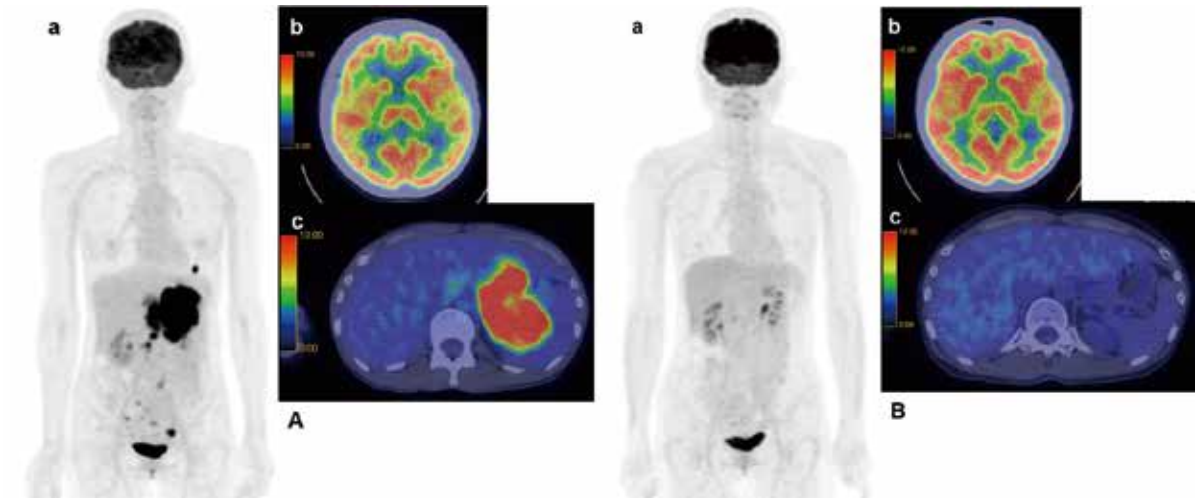

Fig 3. The increase and recovery of brain and liver uptake with decreasing tumor uptake after chemotherapy. FDG PET/CT images of the case in which had showed decreased brain and liver uptake with high uptake in the lesions of tumor of DLBCL (A), which showed the uptake of brain and liver increase and recovery with decreasing uptake of tumor after chemotherapy (B). Maximum intensity projection of FDG PET (a), PET/CT fusion image of brain (b), PET/CT fusion image of liver (c) of a 40-year-old female. A : Each parameter follows ; SUVmax of 2.9, SUVmean of 2.2 in liver, SUVmax of 12.3, TGV of 6896.1 in brain. B : Each parameter follows; SUVmax of 3.0, SUVmean of 2.4 in liver, SUVmax of 14.7, TGV of 8054.2 in brain.

to the brain increased after treatment because the uptake in the tumor was reduced, supporting the notion that there is competition between the tumor and brain in capturing FDG.

The FDG uptake (SUV_{mean}) of the liver in patients with malignant lymphoma was also significantly lower than that in control patients. However, while the SUV_{max} of the liver in patients with malignant lymphoma was lower than that in control patients as well, no significant differences were seen. A previous paper validated the phenomenon of a decreased liver FDG uptake due to a substantial tumor uptake (16). The decrease in the liver FDG uptake in the presence of tumors with a large amount of FDG accumulated is suspected to be due to competition between the tumor and the liver, as reported for the decreased brain uptake in the presence of tumors with a large amount of FDG accumulated. Since some of the FDG that should intrinsically accumulate in the liver is taken up by the tumor instead, the liver's allocation is consequently decreased.

Several factors that may influence the liver uptake have been reported so far. Abele *et al*. reported no association between the liver attenuation and the FDG uptake measured in terms of the SUV_{mean} (23). However, Keramida *et al*. reported that the liver FDG uptake was increased in cases of hepatic steatosis (CT density of liver <40 HU) (24). The authors suggested that this likely results from the uptake in inflammatory cells being superimposed on the hepatocyte uptake. Liu *et al*. also reported that a mild and moderate degree of fatty liver had a positive effect on the liver FDG uptake, whereas a severe degree of fatty liver negatively affected the FDG uptake (25). In the present study, we excluded patients with hepatic steatosis.

Keramida *et al*. additionally reported that the fasting hepatic FDG uptake was higher in men than in women (26). However, Lin reported that there was no statistically significant relationship between gender and the SUV_{max} or SUV_{mean} of the liver (27). Since the uptake of the liver may be affected by gender, the ratio between men and women was set to be the same for both groups in the present study. Lin *et al*. further reported that age had a significant and positive impact on both the SUV_{max} and SUV_{mean} of the liver on FDG PET (27). Viglianti *et al*. reported that increased blood glucose levels had a mild effect on the liver SUV (19). Since the uptake of the liver may be affected by age and blood glucose levels, the average age and blood glucose levels were set to be roughly the same in both groups in the present study.

In the present study, we showed that the liver uptake after treatment in CR and PR cases was higher than that before treatment, although there was no significant difference. In cases in which the liver uptake was low before treatment, the value (SUV_{mean}) after treatment in CR and PR was significantly higher than that before treatment. This result suggests that, similar to the distribution to the brain, the distribution to the liver was increased due to a decreased tumor uptake.

The present study has some limitations. First, there was selection bias due to the retrospective nature of the study. Second, this study may have included hidden liver lesions within the ROI. Patients with locally identifiable abnormalities in the liver were excluded from the analysis but may also have had liver hemangiomas, small liver cysts, vascular abnormalities, undetectable hepatocellular carcinoma or liver metastasis with a low FDG uptake and so on. Finally, it was reported that the body mass index (BMI) affects the liver FDG uptake (25) ; however, as this was a retrospective study, it was not possible to compute the BMI because the height data were unavailable. As such, there may have been a significant difference in the BMI between the two groups, although there was no significant difference in the body weight between the two groups.

However, despite these limitations, our present findings suggest that the decrease in the physiological uptake of the brain might be caused by a high uptake in malignant lymphoma lesions. Our study also suggested that a decrease in the physiological uptake in the liver may also be caused by a high uptake in malignant lymphoma lesions. Furthermore, the present study is the first report to confirm that the uptake in the brain and liver, which had been reduced due to a high uptake in the malignant lymphoma lesions, was recovered by the uptake of the tumor decreasing after treatment. The FDG uptake is graded in relation to the reference regions of the normal mediastinum and liver. The Deauville criteria and the Deauville five-point scale, in which the normal mediastinum and liver are used for the reference regions, are used to evaluate the activity of malignant

lymphoma (6-8). Identifying factors that affect the uptake of the normal liver therefore seems to be crucial.

CONCLUSIONS

In malignant lymphoma patients with a high FDG uptake in the tumors, the uptake in the liver and brain is decreased. Furthermore, the uptake in these organs tends to recover with the decreased uptake in the tumor after treatment. Highly accelerated lesion glycolysis in malignant lymphoma seems to induce a decreased physiological brain and liver FDG uptake. Some of the FDG that should accumulate in the brain and liver is taken up by the tumor, resulting in a decreased allocation to the brain and liver.

CONFLICT OF INTERESTS

The authors have no conflict of interest to declare.

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REFERENCES

1. Strauss LG, Conti PS : The applications of PET in clinical oncology. J Nucl Med 32 : 623-648, 1991
2. Hawkins RA, Hoh CK : PET FDG studies in oncology. Nucl Med Biol 21 : 739-747, 1994
3. Hoh CK, Hawkins RA, Glaspy JA, Dahlbom M, Tse NY, Hoffman EJ, Schiepers C, Choi Y, Rege S, Nitzsche E, Maddahi J, Phelps ME : Cancer detection with whole-body PET using 2-[18F]fluoro-2-deoxy-D-glucose. J Comput Assist Tomogr 17 : 582-589, 1993
4. Wahl RL, Jacene H, Kasamon Y, Lodge MA : From RECIST to PERCIST : Evolving Considerations for PET response criteria in solid tumors. J Nucl Med 50 : 122-150, 2009
5. Zasadny KR, Wahl RL : Standardized uptake values of normal tissues at PET with 2-[fluorine-18]-fluoro-2-deoxy-D-glucose : variations with body weight and a method for correction. Radiology 189 : 847-850, 1993
6. Meignan M, Gallamini A, Meignan M, Gallamini A, Haioun C : Report on the First International Workshop on Interim-PET-Scan in Lymphoma. Leuk Lymphoma 50 : 1257-1260, 2009
7. Barrington SF, Kluge R : FDG PET for therapy monitoring in Hodgkin and non-Hodgkin lymphomas. Eur J Nucl Med Mol Imaging 44 : 97-110, 2017
8. Zijlstra JM, Burggraaff CN, Kersten MJ, Barrington SF ; EHA Scientific Working Group on Lymphoma : FDG-PET as a biomarker for early response in diffuse large B-cell lymphoma as well as in Hodgkin lymphoma? Ready for implementation in clinical practice? Haematologica 101 : 1279-1283, 2016
9. Basu S, Nair N : Unusually elevated liver radioactivity on F-18 FDG PET in Hodgkin's disease : hepatic 'superscan'. Clin Nucl Med 29 : 626-628, 2004
10. Paone G, Itti E, Haioun C, Gaulard P, Dupuis J, Lin C, Meignan M : Bone marrow involvement in diffuse large B-cell lymphoma : correlation between FDG-PET uptake and type of cellular infiltrate. Eur J Nucl Med Mol Imaging 36 : 745-750, 2009
11. Su HY, Liu RS, Liao SQ, Wang SJ : F-18 FDG PET superscan. Clin Nucl Med 31 : 28-29, 2006
12. Hanaoka K, Hosono M, Shimono T, Usami K, Komeya Y, Tsuchiya N, Yamazoe Y, Ishii K, Tatsumi Y, Sumita M : Decreased brain FDG uptake in patients with extensive non-Hodgkin's lymphoma lesions. Ann Nucl Med 24 : 707-711, 2010
13. Kode V, Karsch H, Osman MM, Muzaffar R : Impact of Renal Failure on F18-FDG PET/CT Scans. Front Oncol 7 : 155, 2017
14. Mikhaeel NG, Smith D, Dunn JT, Phillips M, Møller H, Fields PA, Wrench D, Barrington SF : Combination of baseline metabolic tumour volume and early response on PET/CT improves progression-free survival prediction in DLBCL. Eur J Nucl Med Mol Imaging 43 : 1209-1219, 2016
15. Satoh Y, Onishi H, Nambu A, Araki T : Volume-based parameters measured by using FDG PET/CT in patients with stage I NSCLC treated with stereotactic body radiation therapy : prognostic value. Radiology 270 : 275-281, 2014
16. Viglianti BL, Wale DJ, Wong KK, Johnson TD, Ky C, Frey KA, Gross MD : Effects of Tumor Burden on Reference Tissue Standardized Uptake for PET Imaging : Modification of PERCIST Criteria. Radiology 287 : 993-1002, 2018
17. Sprinz C, Zanon M, Altmayer S, Watte G, Irion K, Marchiori E, Hochhegger B : Effects of blood glucose level on 18F fluorodeoxyglucose (18F-FDG) uptake for PET/CT in normal organs : an analysis on 5623 patients. Sci Rep 8 : 2126, 2018
18. Büsing KA, Schönberg SO, Brade J, Wasser K : Impact of blood glucose, diabetes, insulin, and obesity on standardized uptake values in tumors and healthy organs on 18F-FDG PET/CT. Nucl Med Biol 40 : 206-213, 2013
19. Viglianti BL, Wong KK, Wimer SM, Parameswaran A, Nan B, Ky C, Townsend DM, Rubello D, Frey KA, Gross MD : Effect of hyperglycemia on brain and liver 18F-FDG standardized uptake value (FDG SUV) measured by quantitative positron emission tomography (PET) imaging. Biomed Pharmacother 88 : 1038-1045, 2017
20. Claeys J, Mertens K, D'Asseler Y, Goethals I : Normoglycemic plasma glucose levels affect F-18 FDG uptake in the brain. Ann Nucl Med 24 : 501-505, 2010
21. Kemppainen J, Aalto S, Fujimoto T, Kalliokoski KK, Långsjö J, Oikonen V, Rinne J, Nuutila P, Knuuti J : High intensity exercise decreases global brain glucose uptake in humans. J Physiol 568 : 323-332, 2005
22. Dalsgaard MK : Fuelling cerebral activity in exercising man. J Cereb Blood Flow Metab 26 : 731-750, 2006
23. Abele JT, Fung CI : Effect of hepatic steatosis on liver FDG uptake measured in mean standard uptake values. Radiology 254 : 917-924, 2010
24. Keramida G, Potts J, Bush J, Verma S, Dizdarevic S, Peters AM : Accumulation of (18)F-FDG in the liver in hepatic steatosis. AJR Am J Roentgenol 203 : 643-648, 2014
25. Liu G, Li Y, Hu P, Cheng D, Shi H : The combined effects of serum lipids, BMI, and fatty liver on 18F-FDG uptake in the liver in a large population from China : an 18F-FDG-PET/CT study. Nucl Med Commun 36 : 709-716, 2015
26. Keramida G, Peters AM : Fasting hepatic glucose uptake is higher in men than women. Physiol Rep 5 : e13174, 2017
27. Lin CY, Ding HJ, Lin CC, Chen CC, Sun SS, Kao CH : Impact of age on FDG uptake in the liver on PET scan. Clin Imaging 34 : 348-350, 2010