Usefulness of Dual Isotope ^{123}I -IMP and ^{201}Tl SPECT for the Diagnosis of Primary Central Nervous System Lymphoma and Glioblastoma

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Abstract

Introduction

Preoperative differential diagnosis between glioblastoma (GBM) and primary central nervous system lymphoma (PCNSL) is important because these tumors require different surgical strategies. This study investigated the usefulness of dual isotope, iodine-123-labeled N-isopropyl-p-iodoamphetamine (^{123}I -IMP) and thallium-201 chloride single photon emission computed tomography (^{201}Tl SPECT) for the differential diagnosis.

Methods

Twenty-five PCNSL patients and 27 GBM patients who underwent dual isotope, ^{123}I -IMP and ^{201}Tl SPECT are included. Tumor to normal (T/N) ratio was calculated from the ratio of maximum tracer counts in the contrast-enhanced lesion to the mean counts in the contralateral cerebral cortex. The mean and minimum apparent diffusion coefficient values (ADC_{mean} , and ADC_{min} , respectively) on magnetic resonance imaging were also analyzed.

Results

Tumor to normal (T/N) ratios of PCNSL were significantly higher than that of GBM for both isotopes and phases ($P < 0.001$). Both ADC values of PCNSL were significantly lower than those of GBM ($P < 0.001$). Delayed phase ^{123}I -IMP gave the most accurate findings for differentiation between PCNSL and GBM with the optimum cut-off value of 1.009, sensitivity 92.0%, specificity 88.9%, and area under the curve 0.945 (95% confidence interval, 0.883-1.000). Fifty of 52 patients (96.2%) showed retention index of ^{201}Tl SPECT 0.7 or higher, which indicates malignant brain tumors.

Conclusions

Delayed phase ^{123}I -IMP SPECT could differentiate between PCNSL and GBM with the highest accuracy. ^{201}Tl SPECT was useful for estimation of the malignancy and localization of the tumors. Dual isotope ^{123}I -IMP and ^{201}Tl SPECT was useful for the preoperative diagnosis of PCNSL and GBM.

Introduction

Glioblastoma (GBM) and primary central nervous system lymphoma (PCNSL) are the most common types of adult malignant brain tumor. Establishing the correct preoperative diagnosis is very important for the treatment strategy, as maximum safe resection is recommended for GBM, whereas biopsy is recommended for PCNSL [1,2].

Apparent diffusion coefficient (ADC) obtained from magnetic resonance (MR) imaging and 2-deoxy-2-[fluorine-18]fluoro-D-glucose (^{18}F]FDG) positron emission tomography (PET) are reported to be useful for

differentiation between PCNSL and high-grade glioma [3-8]. The ADC value of PCNSL is lower than that of high-grade glioma reflecting the higher cellular density [3-6]. Standardized uptake value (SUV) of [^{18}F]FDG PET of PCNSL is higher than those of high-grade glioma and metastatic brain tumor reflecting the more active glucose metabolism [7,8]. The accuracy of differentiation between these tumors based on ADC varies, but recent studies found sensitivity and specificity of around 70%, which are inadequate for definitive diagnosis [3,4]. [^{18}F]FDG PET also involves limitations such as the influence of blood glucose level [9], and accumulation into non-neoplastic lesions [10-12]. In addition, [^{18}F]FDG requires purification at a cyclotron center, so is unlikely to be available in all institutions [13].

Recently, single photon emission computed tomography (SPECT) has been evaluated for the diagnosis of brain tumor [14]. Accumulation and retention of thallium-201 chloride (^{201}Tl) SPECT within tumors are correlated with the malignant characteristics of the tumor [15-20], so ^{201}Tl SPECT is useful for differentiating between tumor recurrence and radiation necrosis [21-23]. Iodine-123-labeled N-isopropyl-p-iodoamphetamine (^{123}I -IMP) SPECT is specifically accumulated and retained in PCNSL, so is useful for the diagnosis of PCNSL [24-25]. Therefore, we hypothesized that combination of these tracers could differentiate between malignant tumor and non-neoplastic lesions, estimate the malignant characteristics, and effectively differentiate between PCNSL and GBM. This study investigated the usefulness of dual isotope ^{123}I -IMP and ^{201}Tl SPECT for the diagnosis of PCNSL and GBM.

Patients And Methods

This study included patients with histologically diagnosed PCNSL and GBM who underwent ^{123}I -IMP, ^{201}Tl SPECT, and ADC admitted to Gunma University Hospital from June 2010 to February 2020. The following patients were excluded; 2 patients positive for Epstein-Barr virus, and 4 patients with contrast-enhanced lesions smaller than 3 cm^3 [26]. No patients had acquired immune deficiency syndrome or long-term administration of immunosuppressant. Consequently, the study included 25 PCNSL patients and 27 GBM patients. [^{18}F]FDG-PET was performed in 29 patients. Clinical characteristics, pathological findings, and MIB-1 indexes were reviewed. The lesions with longest diameter were analyzed in patients with multiple lesions. The ethics committee of Gunma University Hospital approved this study.

MR Imaging

MR imaging was performed with a 1.5 T or 3.0 T imager. Diffusion-weighted image (DWI) was obtained using the following parameters: repetition time (TR), 4000-5000 msec; echo time (TE), 58-94 msec; flip angle, 90° (1.5T) or 180° (3T) with b-values of 1000 s/mm^2 . ADC was automatically generated. Slice thickness and interval were 5 mm and 0 mm, respectively. Signal intensities of the tumor on T1-weighted and T2-weighted images were categorized as low, iso, and high compared with the contralateral cerebral cortex. ADC analyses used a region of interest (ROI) manually set to cover the contrast-enhanced region of the tumors. Mean (ADC_{mean}) and minimum ADC values (ADC_{min}) were measured. Necrosis, cystic lesion, and hemorrhage were not included in the ROI [5].

^{123}I -IMP and ^{201}Tl SPECT

SPECT was performed using a dual-detector gamma camera (E-CAM, Canon Medical Systems, Otawara, Tochigi, Japan) equipped with low and medium energy collimators. ^{123}I -IMP and ^{201}Tl imaging were obtained at 30 min (early imaging) and 4 hours (delayed imaging) after intravenous injection of 111 MBq of ^{123}I -IMP and ^{201}Tl -chloride. Forty-five SPECT images were collected with a sampling time of 25s/view. The matrix size was 128×128. The collection windows were as follows. ^{23}I -IMP: 159keV±10%. ^{201}Tl : 70keV±20%. The tomography data were prefiltered through a Butterworth filter and reconstructed using Filtered Back Projection.

ROI was manually set to cover CE lesion of tumors in the axial slice. Tumor to normal ratio (T/N) of early and delayed images was calculated from the ratio of maximum tracer counts in the CE lesion to the mean counts of the contralateral cerebral cortex [25].

^{18}F FDG PET

^{18}F FDG PET/CT was performed as described previously [27]. Briefly, ^{18}F FDG was synthesized in the cyclotron facility of our institute. ^{18}F FDG was intravenously administered to the patients at a dose of 5.0 MBq/kg after fasting for at least 6 h. PET imaging was performed 60 min after administering ^{18}F FDG. Discovery STE (GE Healthcare, Waukesha, WI) or Biograph 16 (Siemens Medical Solutions, Knoxville, TN) scanners were used. Field of view was 700 mm and slice thickness was 3.27 mm. Three-dimensional data acquisition was performed for 2 minutes per bed position, followed by imaging reconstruction with the three-dimensional ordered-subset expectation maximization method. Segmented attenuation correction was based on 128×128 matrix images obtained by X-ray computed tomography (120 kV, 120-240 mA). The ROI was set to cover the contrast-enhanced region and the maximum standardized uptake value (SUV_{max}) in the ROI was measured.

Statistical Analysis

All images were interpreted by 2 experienced nuclear physicians (A.T., and T.H.), and an experienced neurosurgeon (S.O.). The interpreting nuclear physicians were unaware of the patient's clinical history and data. All values are presented as median and interquartile range (IQR). Differences in medians of continuous measurements were tested by the Mann-Whitney U test. Fisher's exact and chi-square tests were used for categorical data comparisons as appropriate. Accuracy for diagnosis was analyzed with the receiver-operating-characteristic (ROC) curve. The optimum cut-off value was defined as the value that maximizes the sum of sensitivity and specificity. Statistical analysis was performed using free statistical software EZR [28]. A p values of less than 0.05 were considered significant.

Results

Clinical Characteristics

The clinical characteristics of PCNSL and GBM are shown in Table 1. All pathological diagnoses of PCNSL were diffuse large B cell lymphoma. The patients with PCNSL and GBM were aged 69 (IQR, 64.0-79.0) years and 72 (62.5-75.5) years, and were male in 11 cases (44.0%) and 15 (55.6%), respectively. Steroids were administered to 9 patients (36.0%) with PCNSL and 7 (25.9%) with GBM.

MR Imaging

MR imaging findings of PCNSL and GBM are shown in Table 2. The median maximum diameters of PCNSL and GBM were 38.0 (IQR, 30.0-50.0) mm and 44.0 (32.0-59.0) mm, multiple lesions occurred in 9 cases (36.0%) and 5 cases (18.5%).

The median ADC_{mean} values of PCNSL and GBM were 839 (IQR, 774-960) $\times 10^{-6}$ mm²/s and 1088 (933-1224.5) $\times 10^{-6}$ mm²/s, and median ADC_{min} values were 537 (478-607) $\times 10^{-6}$ mm²/s and 693 (616.5-750.5) $\times 10^{-6}$ mm²/s, respectively. Both ADC values of PCNSL were significantly lower than those of GBM ($p < 0.001$). ROC analysis of ADC_{mean} revealed sensitivity of 88.0% and specificity of 66.7%, with area under the curve (AUC) 0.838 (95% confidence interval [CI], 0.733-0.943) using the optimum cut-off value of 994×10^{-6} mm²/s. ROC analysis of ADC_{min} revealed sensitivity of 80.0% and specificity of 74.1%, with AUC 0.828 (95% CI, 0.715-0.941) using the optimum cut-off value of 615×10^{-6} mm²/s (Fig. 1).

¹²³I-HMP/²⁰¹Tl SPECT

Findings of ¹²³I-HMP and ²⁰¹Tl SPECT of PCNSL and GBM are shown in Table 3. The median T/N ratios of PCNSL and GBM were 1.18 (IQR, 0.85-1.29) and 0.77 (0.66-0.88) in the early phase ¹²³I-HMP, 1.32 (1.10-1.50) and 0.83 (0.73-0.93) in the delayed phase ¹²³I-HMP, 3.23 (2.85-3.85) and 2.46 (2.12-2.72) in the early phase ²⁰¹Tl, and 3.10 (2.60-3.71) and 2.34 (2.01-2.66) in the delayed phase ²⁰¹Tl, respectively. PCNSL showed significantly higher T/N ratio than GBM for both isotopes and phases ($p < 0.001$). Retention index (RI) of ¹²³I-HMP was 1.22 (IQR, 1.04-1.39) in PCNSL and 1.11 (0.96-1.19) in GBM, and RI of ²⁰¹Tl was 0.96 (0.87-1.14) in PCNSL and 0.93 (0.88-1.04) in GBM. Twenty-four of 25 PCNSL cases (96.0%) and 26 of 27 GBM cases (96.3%), in total 50/52 cases (96.2%), showed RI over 0.7 by ²⁰¹Tl SPECT.

Results of ROC analysis of ¹²³I-HMP and ²⁰¹Tl SPECT are shown in Fig. 1. Early phase ¹²³I-HMP SPECT had sensitivity of 73.0% and specificity of 88.9%, with AUC 0.809 (95% CI, 0.684-0.934) using the optimum cut-off value of 0.986. Delayed phase ¹²³I-HMP SPECT had sensitivity of 92.0% and specificity of 88.9%, with AUC 0.945 (95% CI, 0.883-1.000) using the optimum cut-off value of 1.009. Early phase ²⁰¹Tl SPECT had sensitivity of 80.0% and specificity of 81.5%, with AUC 0.849 (95% CI, 0.740-0.958) using the optimum cut-off value of 2826. Delayed phase ²⁰¹Tl SPECT had sensitivity of 56.0% and specificity of 100%, with AUC 0.841 (95% CI, 0.735-0.948) using the optimum cut-off value of 3.084. Delayed phase ¹²³I-HMP SPECT gave the most accurate findings for the differential diagnosis between PCNSL and GBM.

[¹⁸F]FDG PET

Twenty-nine patients, 16 with PCNSL and 13 with GBM, underwent [¹⁸F]FDG PET in addition to ¹²³I-IMP, ²⁰¹Tl SPECT, and ADC. Steroids were administered to 11 patients (7/16 [43.8%] with PCNSL, 4/13 [30.8%] with GBM) before SPECT, and 13 patients (12/16 [75.0%] with PCNSL, 1/13 [7.7%] with GBM) before [¹⁸F]FDG PET. The median SUV_{max} of [¹⁸F]FDG PET was significantly higher for PCNSL than GBM (PCNSL 17.9 [IQR, 13.5-25.7], GBM 9.2 [6.9-11.3], $p < 0.001$). Results of ROC analysis of ¹²³I-IMP delay, ²⁰¹Tl SPECT delay, ADC_{mean}, and [¹⁸F]FDG PET are shown in Fig. 2. SUV_{max} of [¹⁸F]FDG PET had sensitivity of 75.0% and specificity of 92.3%, with AUC 0.909 (95% CI, 0.806-1.00) using the optimum cut-off value of 13.987. Delayed phase ¹²³I-IMP SPECT had sensitivity of 93.8% and specificity of 92.3%, with AUC 0.942 (95% CI, 0.845-1.00) using the optimum cut-off value of 1.094. Delayed phase ²⁰¹Tl SPECT had sensitivity of 56.2% and specificity of 100.0%, with AUC 0.812 (95% CI, 0.656-0.969) using the optimum cut-off value of 3.156. ADC_{mean} had sensitivity of 69.2% and specificity of 93.8%, with AUC 0.868 (95% CI, 0.737-0.998) using the optimum cut-off value of $969 \times 10^{-6} \text{ mm}^2/\text{s}$. Delayed phase ¹²³I-IMP SPECT showed the highest AUC for differentiation between PCNSL and GBM. Representative cases of PCNSL and GBM are shown in Figs. 3 and 4.

Discussion

The present study found that delayed phase ¹²³I-IMP SPECT was the most useful imaging examination for differentiation between PCNSL and GBM, compared with early phase ¹²³I-IMP SPECT, early and delayed phase ²⁰¹Tl SPECT, and ADC_{mean} and ADC_{min} on MR imaging. ²⁰¹Tl SPECT was less useful for differentiation compared with ¹²³I-IMP SPECT. However, high RI was helpful to estimate the extent of the malignant tumor. T/N ratio of ²⁰¹Tl SPECT was higher than that of ¹²³I-IMP SPECT, which was helpful to establish the tumor localization.

The imaging characteristics of PCNSL are homogeneous enhancement, and multiple lesions in 34-58% of cases [29-31]. However, ring-like enhancement occurs in 25% of PCNSL, and multiple lesions occur in 10-20% of GBM [32], so preoperative discrimination between PCNSL and GBM are still controversy on preoperative conventional MR imaging.

ADC value on MR imaging is reported to be useful for the diagnosis of brain tumor. ADC value of PCNSL is lower than that of GBM reflecting the higher cellular density [3-6]. The best sensitivity and specificity for differentiation between PCNSL and GBM are 85% and 90%, respectively [5]. However, recent studies showed sensitivity and specificity are about 70% [3,4], indicating that ADC is not sufficiently accurate to diagnose these tumors. Our study also found that ADC value was valuable, but relatively less effective to differentiate these tumors.

PCNSL is reported to uptake more FDG than GBM [13]. The cut-off value and the accuracy vary, but the diagnostic accuracy of [¹⁸F]FDG PET was sensitivity 100% and specificity 71.4%, and sensitivity 84.2%

and specificity 84.1% with the cut-off value 12 [7,8]. [^{18}F]FDG PET is also useful for the staging of lymphoma due to its ability to evaluate systemic lesions [33]. However, [^{18}F]FDG PET is affected by blood glucose level, steroid administration, and previous radiation therapy [9]. [^{18}F]FDG must be produced in a cyclotron, so may not be available in all institutions [13].

Our study revealed that ^{123}I -IMP SPECT can differentiate between PCNSL and GBM with higher accuracy than ADC and is comparable to [^{18}F]FDG PET. IMP is a lipophilic tracer, so is permeable to the blood-brain barrier and correlates with cerebral blood flow [34]. IMP shows high first-pass uptake by brain tissues with nonspecific amine binding sites and reveals slow washout [26]. Transient accumulation in the early phase is considered to reflect blood flow, blood pooling, and pH in the tissue [25, 35, 36, 39]. Some brain tumors with high early IMP uptake, including meningiomas, metastatic brain tumors, lymphoma, and gliomas in the early phase have been reported [36]. Dynamic SPECT scan studies have revealed that these accumulations resulted from intravascular retention of ^{123}I -IMP [36].

On the other hand, the mechanisms of ^{123}I -IMP accumulation on delayed phase remain to be elucidated. Delayed SPECT images may reflect the distribution of hydrophilic metabolites of IMP resulting from further oxidation of the aliphatic side chain [26]. In addition to PCNSL, delayed PCNSL, delayed IMP accumulation had been reported in cellular blue nevus, and cartinoid [36,37]. These tumors express abundant amine-binding receptor to produce melanin or mono amine. ^{123}I -IMP may be retained over delayed phase by binding to amine-binding receptor [25,36,37]. IMP accumulates in malignant lymphoma specifically in delayed phase, so is expected to be useful to diagnose PCNSL [24-26]. In our results, delayed phase ^{123}I -IMP SPECT showed the highest AUC for differentiation between PCNSL and GBM among several imaging results. Delayed phase ^{123}I -IMP accumulation on SPECT could be an important preoperative marker for predicting PCNSL, as other brain tumors with delayed IMP retention are less frequent.

^{201}Tl is the most commonly used tracer to evaluate tumors. Uptake of ^{201}Tl is considered to reflect proliferation of tumor and blood flow, so uptake and retention are correlated with the malignant characteristics of the tumors [15-20, 40, 44 41]. Therefore, ^{201}Tl SPECT is reported to be useful to estimate the malignancy of tumors and differentiate between tumor recurrence and radiation necrosis [21-23]. The present study revealed that ^{201}Tl SPECT was inferior to ^{123}I -IMP SPECT for differentiation between PCNSL and GBM, as 50/52 cases (96.2%) showed RI over 0.7, which is considered to indicate malignant tumor [19], and was useful to estimate the malignancy of tumors. ^{201}Tl SPECT is also superior to ^{123}I -IMP SPECT for estimating the localization of the tumor due to its higher T/N ratio.

SPECT can simultaneously image two isotopes with different energy windows [42,43]. Since the mechanisms of uptake into tumors are different depending on the isotopes, simultaneous injection of dual isotopes is expected to improve diagnostic accuracy and efficiency. Drug resistance of brain tumors could be estimated by technetium-99m methoxy-2-isobutylisonitrile SPECT in addition to ^{201}Tl SPECT [42]. The lipophilic tracer technetium-99m hexamethylpropyleneamine oxime could estimate tumor

invasion and differentiate between tumor recurrence and radiation necrosis even in tumor with low uptake of ^{201}TI [43,44]. The present study revealed that ^{201}TI SPECT is useful for diagnosis of malignant tumor, and ^{123}I -IMP SPECT is useful for differentiation between PCNSL and GBM. In the clinical setting, ^{123}I -IMP and ^{201}TI SPECT can differentiate between malignant tumors and non-neoplastic lesion, between malignant tumors and benign tumors, and between PCNSL and GBM at the same time. Dual isotope ^{123}I -IMP and ^{201}TI SPECT are useful and efficient for the preoperative diagnosis of PCNSL and GBM.

Conclusions

Delayed phase ^{123}I -IMP SPECT can more accurately differentiate between PCNSL and GBM compared with ^{201}TI SPECT and ADC. ^{201}TI SPECT is useful to estimate the malignant characteristics and localization of the tumors. Dual isotope ^{123}I -IMP and ^{201}TI SPECT are useful and efficient imaging methods for preoperative diagnosis of PCNSL and GBM.

Declarations

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Ethical approval

This study was conducted under the institutional review board approval. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

The institutional review boards approved an opt-out method of informed consent.

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Tables

Table 1. Clinical characteristics of patients with PCNSL and GBM

	PCNSL (N = 25)	GBM (N = 27)	p value
Age, median (IQR), years	69 (64.0-79.0)	72 (62.5-75.5)	0.59
Male, number (%)	11 (44.0)	15 (55.6)	0.58
Steroid use before SPECT, number (%)	9 (36.0)	7 (25.9)	0.55
MIB-1 index, median (IQR), %	80 (73.0-80.0)	32 (27.4-41.5)	<0.001*

IQR = interquartile range, * p < 0.01

Table 2. MR imaging characteristics of patients with PCNSL and GBM

MR imaging findings	PCNSL (N = 25)	GBM (N = 27)	p value
Maximal diameter, median (IQR), mm	38.0 (30.0-50.0)	44.0 (32.0-59.0)	0.48
Multiple lesions, number (%)	9 (36.0)	5 (18.5)	0.22
T1 weighted signal intensity, number (%)			0.78
low	13 (52.0)	12 (44.4)	
iso-high	12 (48.0)	15 (55.6)	
T2 weighted signal intensity, number (%)			0.24
low-iso	5 (20.0)	2 (7.4)	
High	20 (80.0)	25 (92.6)	
Contrast enhancement, number (%)			
Homogeneous	22 (88.0)	1 (3.7)	<0.001*
Heterogeneous	3 (12.0)	8 (29.6)	0.18
Ring like	0 (0.0)	18 (66.7)	<0.001*
ADC _{mean} , median (IQR), $\times 10^{-6}$ mm ² /s	839 (774-960)	1088 (933-1224.5)	<0.001*
ADC _{min} , median (IQR), $\times 10^{-6}$ mm ² /s	537 (478-607)	693 (616.5-750.5)	<0.001*

ADC = apparent diffusion coefficient, IQR = interquartile range, * p < 0.01

Table 3. Results of ¹²³I-MP/²⁰¹Tl SPECT

	PCNSL (N = 25)	GBM (N = 27)	p value
T/N ratio, median (IQR)			
^{123}I -IMP early	1.18 (0.85-1.29)	0.77 (0.66-0.88)	<0.001*
^{123}I -IMP delayed	1.32 (1.10-1.50)	0.83 (0.73-0.93)	<0.001*
-	-	-	-
^{201}Tl early	3.23 (2.85-3.85)	2.46 (2.12-2.72)	<0.001*
^{201}Tl delayed	3.10 (2.60-3.71)	2.34 (2.01-2.66)	<0.001*
RI, median (IQR)			
^{123}I -IMP	1.22 (1.04-1.39)	1.11 (0.96-1.19)	0.09
^{201}Tl	0.96 (0.87-1.14)	0.93 (0.88-1.04)	0.72

T/N = Tumor to normal ratio, RI = Retention index, * p < 0.01

Figures

Figure 1

Figure 1

Figure 1

ROC analysis of T/N ratio of 123I-IMP/201TI SPECT and ADC_{mean}/ADC_{min} for differentiation between PCNSL and GBM. Optimum cut-off value, sensitivity, specificity, and AUC of the tracers, phases, and ADC are as follows. 123I-IMP SPECT early phase: cut-off value 0.986, sensitivity 73.0%, specificity 88.9%, AUC 0.809 (95% CI, 0.684-0.934). 123I-IMP SPECT delayed phase: cut-off value 1.009, sensitivity 92.0%, specificity 88.9%, AUC 0.945 (95% CI, 0.883-1.000). 201TI SPECT early phase: cut-off value 2826,

sensitivity 80.0%, specificity 81.5%, AUC 0.849 (95% CI, 0.740-0.958). 201TI SPECT delayed phase: cut-off value 3.084, sensitivity 56.0%, specificity 100%, AUC 0.841 (95% CI, 0.735-0.948). ADCmean: cut-off value 994×10^{-6} mm²/s, sensitivity 88.0%, specificity 66.7%, AUC 0.838 (95% CI, 0.733-0.943). ADCmin: cut-off value 615×10^{-6} mm²/s, sensitivity 80.0%, specificity 74.1%, AUC 0.828 (95% CI, 0.715-0.941).

Figure 2

Figure 2

ROC analysis of [18F]FDG PET, ADCmean, and delayed phase 123I-IMP/201TI SPECT for differentiation between PCNSL and GBM. Optimum cut-off value, sensitivity, specificity, and AUC of SUVmax, tracers, and ADC are as follows. [18F]FDG PET: cut-off value 13.987, sensitivity 75.0%, specificity 92.3%, AUC 0.909 (95% CI, 0.806-1.00). 123I-IMP SPECT delayed phase: cut-off value 1.094, sensitivity 93.8%, specificity 92.3%, AUC 0.942 (95% CI, 0.845-1.00). 201TI SPECT delayed phase: cut-off value 3.156, sensitivity 56.2%, specificity 100.0%, AUC 0.812 (95% CI, 0.656-0.969). ADCmean: cut-off value 969×10^{-6} mm²/s, sensitivity 69.2%, specificity 93.8%, AUC 0.868 (95% CI, 0.737-0.998).

Figure 3

Representative case of PCNSL in a 53-year-old female. E: Contrast-enhanced T1-weighted image showing homogeneous contrast-enhanced lesion in the left temporal lobe. T/N ratios of tracers and phases are as follows. A: 1.73 (123I-IMP SPECT early phase). B: 1.49 (123I-IMP SPECT delayed phase). C: 3.09 (201TI SPECT early phase). D: 4.21 (201TI SPECT delayed phase).

Figure 4

Representative case of GBM in a 72-year-old male. E: Contrast-enhanced T1-weighted image showing heterogeneous contrast-enhanced lesion in the left temporo-occipital lobe. T/N ratios of tracers and phases are as follows. A: 0.68 (123I-IMP SPECT early phase). B: 0.83 (123I-IMP SPECT delayed phase). C: 2.46 (201Tl SPECT early phase). D: 2.11 (201Tl SPECT delayed phase).