ORIGINAL COMMUNICATION

Amyloid PET in mild cognitive impairment and Alzheimer's disease with BF-227: comparison to FDG–PET

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Abstract We recently developed a novel PET tracer, ^{11}C-labeled 2-(2-[2-dimethylaminothiazol-5-yl]ethenyl)-6-(2-[fluoro]ethoxy)benzoxazole ([^{11}C]BF-227), and had success with in vivo detection of amyloid plaques in Alzheimer's disease (AD) brains (Kudo et al. in J Nucl Med 8:553–561, 2007). We applied this tracer to subjects with mild cognitive impairment (MCI) and AD in order to elucidate the status of amyloid plaque deposition in MCI and compared the diagnostic performance of BF-227-PET with that of FDG–PET in AD cases. We studied 12 aged normal (AN) subjects, 15 MCIs and 15 ADs with PET using [^{11}C]BF-227. PET images were obtained after administration of BF-227 and the regional standardized uptake value (SUV) and the ratio of regional to cerebellar SUV were calculated as an index of BF-227 binding. AD patients showed increased uptake of [^{11}C]BF-227 in the neocortical areas and striatum as well as decreased glucose metabolism in temporoparietal, posterior cingulate and medial temporal areas. MCI subjects showed a significant increase in BF-227 uptake in the neocortical areas similar to AD, and the most significant difference of BF-227 retention was observed in the parietal lobe if its retentions for MCI were compared to those for AD and AN. On the other hand, glucose hypometabolism in MCI was confined to cingulate and medial temporal cortices. Neocortical BF-227 uptake negatively correlated with glucose metabolism. Receiver operating characteristic (ROC) analysis indicated higher specificity and sensitivity with BF-227-PET than those with FDG–PET for differential diagnosis between AD and normal control. We conclude that [^{11}C]BF-227-PET has a possibility to be a useful technology for early detection of AD pathology and also even in the MCI stage.

Keywords Alzheimer's disease · Amyloid · Senile plaque · PET · MCI

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Introduction

Senile or amyloid plaque is a pathological hallmark of Alzheimer's disease (AD), and amyloid β peptide (Aβ), which is a main component of the senile plaque, is believed to play a key role in the pathogenesis of AD [8]. In recent years several laboratories, including ours, have succeeded in visualizing Aβ deposition in living patients' brains with

AD using PET probes [13, 14, 24]. Pittsburgh Compound-B (PIB), which is the most commonly used probe for $A\beta$ now, has been applied not only to AD but also to several other neurological disorders [15, 24].

Petersen from the Mayo clinic addressed the concept of mild cognitive impairment (MCI), which is an intermediate state between normal aging and AD [20, 21]. The criteria he stated for MCI are cognitive concern expressed by a physician, informant, participant or nurse; cognitive impairment in one or multiple domains (executive function, memory, language or visuospatial); normal functional activities; not demented.

Regional cerebral glucose metabolism (rCMRglu) has been studied by several investigators [9, 18, 19] using [^{18}F] 2-fluoro-deoxy-D-glucose (FDG) and PET in diseases causing dementia including AD. We used BF-227-PET as well as FDG–PET on the same subjects (AN, MCI, and AD) and carefully analyzed and compared the results with these two kinds of PET. Finally using these data we investigated and compared the specificity and sensitivity of BF-227 PET and FDG–PET in diagnosing AD.

Method

Twelve ANs, 15 subjects with MCI and 15 patients with AD were recruited in the present study. The demographic information of the subjects is shown in Table 1. The diagnosis for MCI and probable AD followed the MCI clinical criteria presented by "Petersen et al." [20] and "the National Institute of Neurological and Communicative Disorders and Stroke—Alzheimer's Disease and Related Disorders Association" [17], respectively. In 15 MCI subjects, 10 were amnestic multi-domain MCI and the other 5 subjects were amnestic single-domain MCI. Mini-mental state examination (MMSE) scores were significantly different between "AN and MCI", "AN and AD", and "MCI and AD". The study protocol was approved by the Committee on Clinical Investigation at Tohoku University School of Medicine and the Advisory Committee on Radioactive Substances at Tohoku University. After a complete description of the study to the patients and subjects, written informed consent was obtained.

Table 1 Demographic details of the subjects in this study

	N	Gender	Age	MMSE
AN	12	M/F = 7/5	66.3 ± 3.3	29.9 ± 0.3
MCI	15	M/F = 8/7	78.3 ± 3.8	25.5 ± 2.5
AD	15	M/F = 5/10	72.5 ± 6.9	19.5 ± 3.7

AN aged normal, *MCI* mild cognitive impairment, *AD* Alzheimer's disease. MMSE scores are significantly different between "AN and MCI", "AN and AD", and "MCI and AD"

The PET procedure for BF-227 was described precisely before [14]. BF-227 and its *N*-desmethylated derivative (a precursor of [^{11}C]BF-227) were custom-synthesized by Tanabe R&D Service Co. [^{11}C]BF-227 was synthesized from the precursor by *N*-methylation in dimethyl sulfoxide using [^{11}C]methyl triflate. The [^{11}C]BF-227 PET study was performed using a PET SET-2400 W scanner (Shimadzu Inc., Japan). After intravenous injection of 211–366 mBq of [^{11}C]BF-227, dynamic PET images were obtained for 60 min with each subject's eyes closed. Standardized uptake value (SUV) images of [^{11}C]BF-227 were obtained by normalizing tissue radioactivity concentration by injected dose and body weight. The FDG–PET procedure was described previously [19]. Subjects were scanned in a quiet and dimly-lit room with their eyes closed after at least 4 h of food restriction. Following a 68 Ga/Ga transmission scan of 7 min duration, an emission scan, which lasted 60 min after intravenous injection of FDG, was performed. The emission data were corrected for tissue attenuation using the transmission data. Regions of interest (ROIs) were placed on individual axial magnetic resonance (MR) images in the cerebellar hemisphere, striatum, frontal, lateral temporal, medial temporal, parietal, occipital, anterior and posterior cingulate cortices. The ROI information was then copied onto dynamic PET SUV images, and regional SUVs were sampled using Dr. View/LINUX software (AJS inc., Japan). Because there were neither senile plaques nor glucose hypometabolism in the cerebellum of AD, ratios of regional SUV to cerebellar SUV (SUVR) were calculated as an index of [^{11}C]BF-227 retention and CMRglu. Neocortical SUVR was calculated by averaging SUVRs in the frontal, lateral temporal, parietal and posterior cingulate cortices.

For statistical comparison in the three groups, we applied one-way analysis of variance (ANOVA) followed by the Bonferroni-Dunn post hoc test. The performance of diagnostic indices to discriminate among groups was assessed using the ROC analysis. Areas under ROC curves (AUC) were calculated and compared using GraphPad Prism Software (GraphPad Software Inc., San Diego, CA). Statistical significance was defined as $p < 0.05$.

Results

BF-227 retention in MCI

First, we analyzed PET images with [^{11}C]BF-227 among the three groups (AN, MCI, and AD), and representative brain PET images are shown in Fig. 1. As indicated in the figure, some MCI subjects showed strong retention of [^{11}C]BF-227, but other MCI subjects did not. Most AD cases, however, indicated strong accumulation of [^{11}C]BF-227 especially in

Fig. 1 Representative axial brain PET images with BF-227. Both the AD cases showed high SUVR compared to the aged normal subjects, although the MCI cases showed heterogeneity, that is, one MCI case (MMSE = 25) showed a comparative SUVR level to AN but another case showed SUVR as high as the AD level
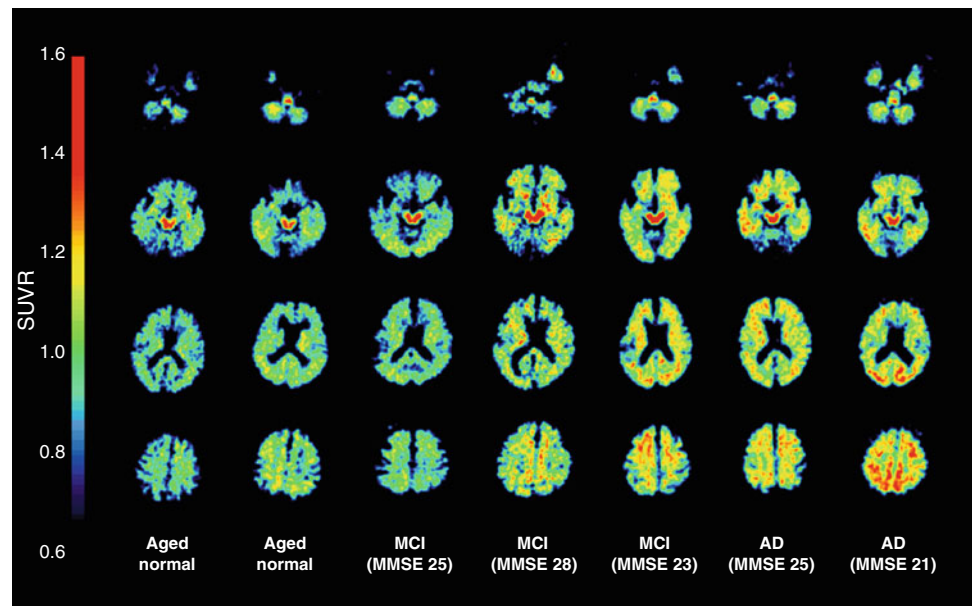
frontal, temporal and parietal cortices. If the retention pattern of [^{11}C]BF-227 is compared to that of PIB, the accumulation of [^{11}C]BF-227 in the frontal lobe looks much weaker than that of PIB [3].

Figure 2 shows the mean neocortical and regional SUVRs of [^{11}C]BF-227 for the three groups. Both the mean neocortical SUVRs for MCI and AD are significantly higher than that for AN. As we previously reported [1], significantly higher SUVRs were observed in most cerebral regions in AD compared to AN except for the medial temporal lobe. MCI subjects indicated a significantly increased SUVR in frontal, lateral temporal, parietal, occipital cortices as well as anterior cingulate gyrus compared to AN, and the most prominent increase was observed in the lateral temporal cortex. A significantly lower SUVR in MCI was observed in the parietal cortex compared to AD. In the other neocortical regions, MCI subjects showed a tendency towards milder retention of BF-227 than that in AD. In the relationship between BF retentions and MMSE scores in all the subjects together (NC, MCI, and AD), no strong correlations were observed (data not shown).

Cerebral glucose metabolism in AN, MCI and AD

Next, we analyzed CMRglu in the same subjects using FDG–PET in order to compare to the findings with [^{11}C]BF-227, which is considered to indicate amyloid plaque depositions. As a result, a significant reduction of neocortical SUVR was observed in both MCI and AD patients compared to AN in FDG–PET (Table 1; Fig. 3). Regional SUVR in FDG–PET was significantly decreased in the cingulate gyrus and medial temporal cortex of MCI

subjects and in the lateral temporal, parietal, posterior cingulate and medial temporal cortices of AD patients, compared to AN. Table 2.

Neocortical SUVR of FDG–PET for each subject was plotted against neocortical SUVR of BF-227-PET (Fig. 4a). SUVR of BF-227 negatively correlated to SUVR of FDG in analyzing the subjects from three groups all together ($r = -0.337$, $p = 0.029$). A significant correlation of regional SUVR in BF-227-PET and FDG–PET was also observed in the temporal and parietal cortices (data not shown). However, no significant correlation was observed when the analysis was confined to the subjects in each group.

Furthermore, in order to compare sensitivity and specificity to differentiate AD from AN, ROC analysis was performed for the lateral temporal SUVR of BF-227 and posterior cingulate SUVR of FDG (Fig. 4b). The AUC for BF-227 (0.994) is much higher than that for FDG (0.839), indicating that BF-227 is more sensitive as well as more specific than FDG in diagnosing AD.

Discussion

Our group recently developed a novel PET tracer, BF-227, and has reported that this compound is able to selectively detect dense amyloid deposits including senile plaques primarily in the posterior association area of AD patients. In the present study we applied this tracer to MCI cases and concluded that the mean value for the MCI cases with BF-227 was intermittent between AN and AD. Also we clarified that BF-227-PET is a useful technology to distinguish early AD patients from AN compared to FDG–PET.

Fig. 2 Box plots of SUVR values with BF-227 PET for AN, MCI and AD. Each *dot* indicates the mean SUVR from "the mean neocortex" and "the eight regions", that is, frontal, temporal, parietal, occipital, anterior cingulate, posterior cingulated, striatum and medial temporal cortex. *Box* indicates interquartile range. *Vertical bars* indicate minimum–maximum range
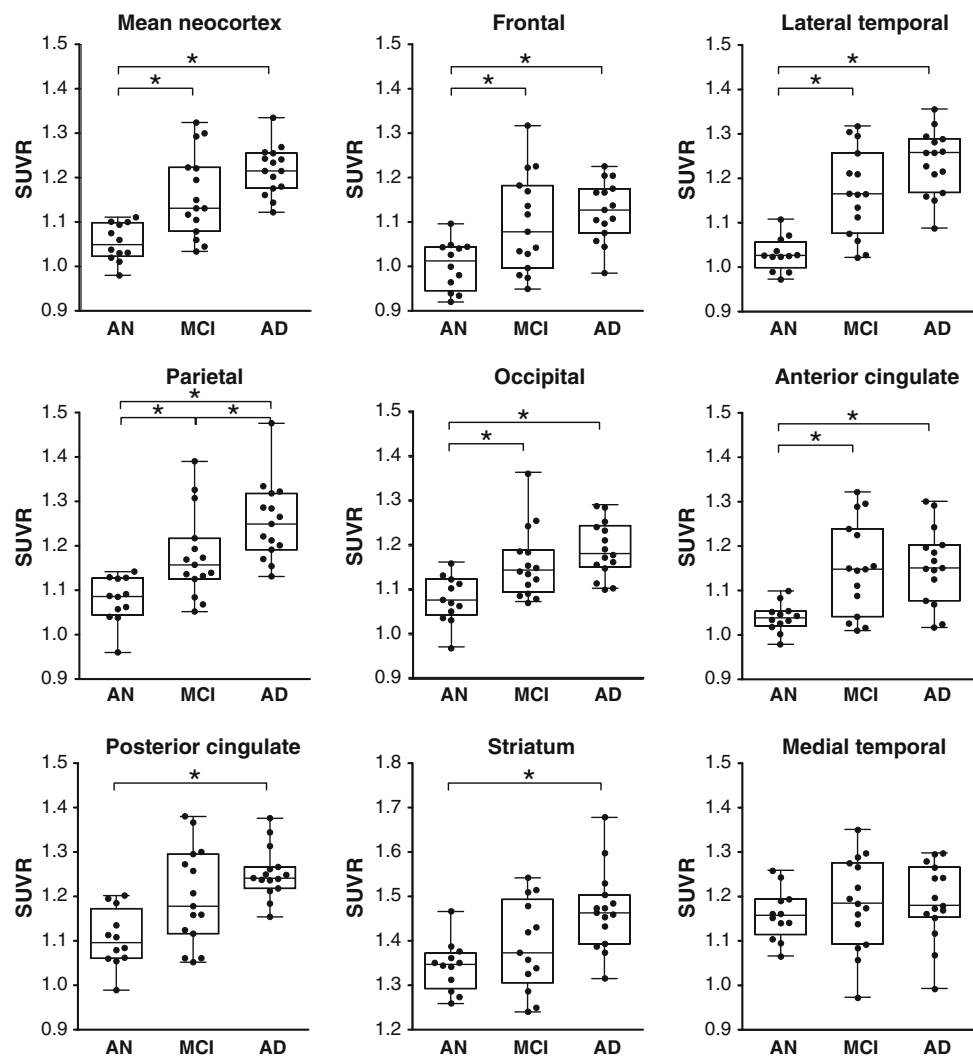
MCI is now classified into 4 subtypes, that is, amnestic single-domain MCI, amnestic multi-domain MCI, non-amnestic single-domain MCI and non-amnestic multi-domain MCI. The important thing is that MCI (especially amnestic MCI) is regarded as a prodromal state of AD, in other words, a high percentage of MCI subjects are considered to convert to AD. It has been reported that 10–20% of MCI cases are going to convert to AD although only 1–2% of normal elderly convert to AD [21]. The present study concludes that MCI has high levels of [11C]BF-227 retention indicating that senile plaque deposition already advances severely in the stage of MCI before dementia symptoms become obvious. Previous amyloid PET studies using 18F-labeled 2-(1,1-dicyano-propen-2-yl)-6-(2-fluoroethyl)-methylamino-naphthalene (FDDNP) or PIB also indicated significant tracer retention in MCI and AD. Small et al. [24] presented that FDDNP can detect a high signal in MCI by binding not only for amyloid plaques but also tau neurofibrillary tangles, and

the retention level for MCI is between AN and AD. On the other hand, several groups reported that about a half of the MCI subjects showed PIB uptake in the AD range, and other MCI subjects indicated retention levels lower than the AD range [12]. A group from Sweden concluded that MCI subjects who converted to AD later showed significantly higher PIB retention compared to non-converting MCI subjects and NC [6]. The present study also revealed higher retention of BF-227 in 60–70% of MCI subjects and in almost all the AD patients. Therefore, the amyloid PET technique is considered to be a highly useful and strong method for early detection of AD patients in the MCI stage. These pieces of information are indispensable in applying new treatment technologies against dementia into the prodromal stage of Alzheimer's disease. In other words, because it is considered that aggregation and deposition of Aβ starts much earlier before patients indicate symptoms of dementia, it is undoubtedly important to detect Aβ deposition as early as

Fig. 3 Box plots of SUVR values with FDG–PET for AN, MCI and AD. Each *dot* indicates the mean SUVR from the mean neocortex and eight cerebral regions, that is, frontal, temporal, parietal, occipital, anterior cingulate, posterior cingulated, striatum and medial temporal cortex. *Boxes* indicate interquartile range. *Vertical bars* indicate minimum–maximum range
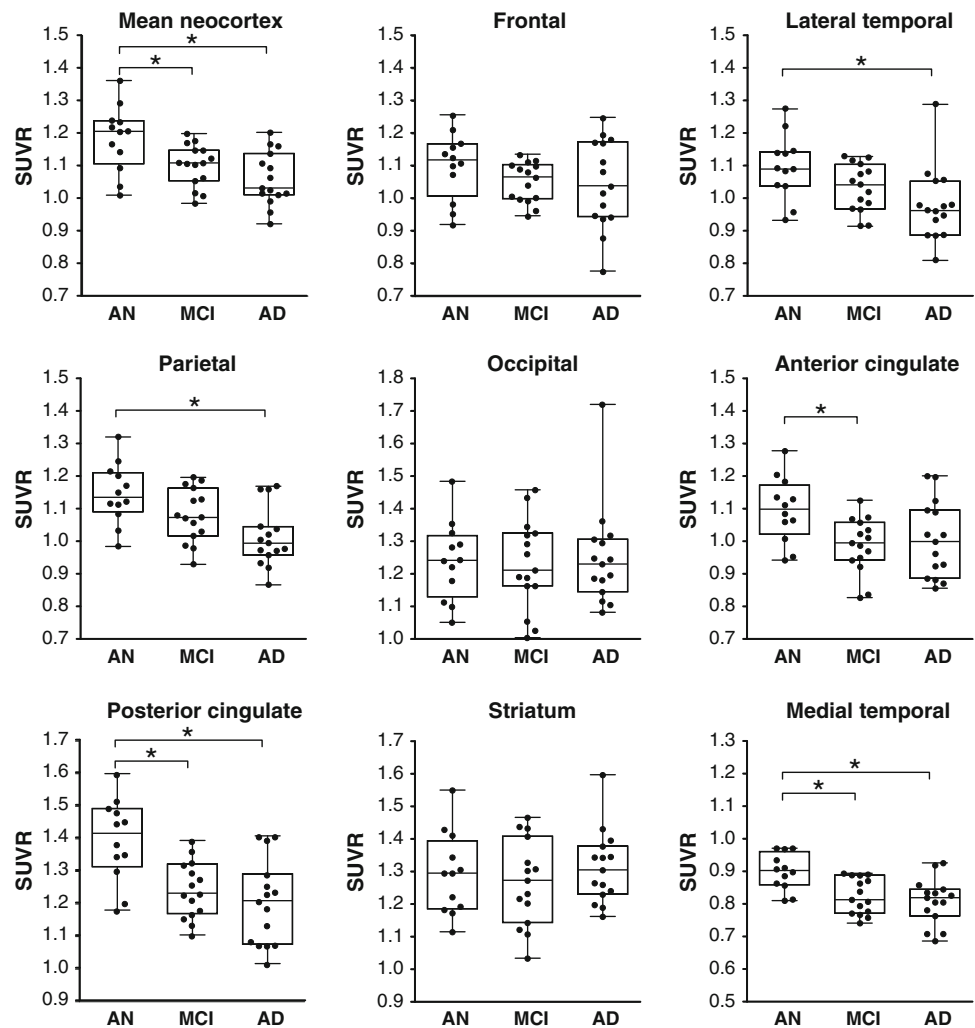

Table 2 Comparison of SUVR values of BF-227-PET and FDG–PET

		Mean neo cortex	Frontal	Lateral temporal	Parietal	Occipital	Anterior cingulate	Posterior cingulate	Striatum	Medial temporal
BF-227	AN	1.05 ± 0.04	1.00 ± 0.06	1.03 ± 0.04	1.08 ± 0.05	1.08 ± 0.05	1.04 ± 0.03	1.11 ± 0.07	1.34 ± 0.06	1.16 ± 0.06
	MCI	$1.16 \pm 0.10*$	$1.10 \pm 0.11*$	$1.17 \pm 0.10*$	$1.18 \pm 0.10*$	$1.16 \pm 0.08*$	$1.15 \pm 0.11*$	1.20 ± 0.11	1.41 ± 0.11	1.18 ± 0.10
	AD	$1.22 \pm 0.06*$	$1.13 \pm 0.07*$	$1.24 \pm 0.07*$	$1.25 \pm 0.09*†$	$1.19 \pm 0.06*$	$1.16 \pm 0.09*$	$1.25 \pm 0.06*$	$1.47 \pm 0.09*$	1.19 ± 0.09
FDG	AN	1.18 ± 0.10	1.10 ± 0.11	1.10 ± 0.10	1.15 ± 0.09	1.24 ± 0.12	1.10 ± 0.10	1.39 ± 0.13	1.29 ± 0.13	0.90 ± 0.06
	MCI	$1.10 \pm 0.06*$	1.05 ± 0.06	1.03 ± 0.07	1.08 ± 0.08	1.23 ± 0.14	$0.99 \pm 0.08*$	$1.24 \pm 0.09*$	1.27 ± 0.13	$0.82 \pm 0.06*$
	AD	$1.06 \pm 0.08*$	1.05 ± 0.14	$0.98 \pm 0.11*$	$1.01 \pm 0.09*$	1.25 ± 0.15	1.00 ± 0.12	$1.20 \pm 0.13*$	1.31 ± 0.11	$0.81 \pm 0.07*$

Mean SUVR value for each brain region was obtained from AN, MCI and AD. * $p < 0.05$, versus AN, † $p < 0.05$ versus MCI

possible in order to begin medication to prevent or treat cognitive decline before the manifestations of dementia become clear.

In most PIB positive MCI and AD cases presented by several different laboratories, the frontal cortex showed high PIB retention, although the frontal cortex is not a region where amyloid plaques are predominantly rich in

the early stage of AD or MCI according to the autopsy studies [1, 10]. Our newly developed tracer, BF-227, showed relatively high retention in temporal and parietal lobes for MCI and AD compared to the results with PIB. Since it is well known that the functional activity of the parietal lobe decreases in the early stage of AD [16], it is reasonable that the distribution of high BF-227-PET
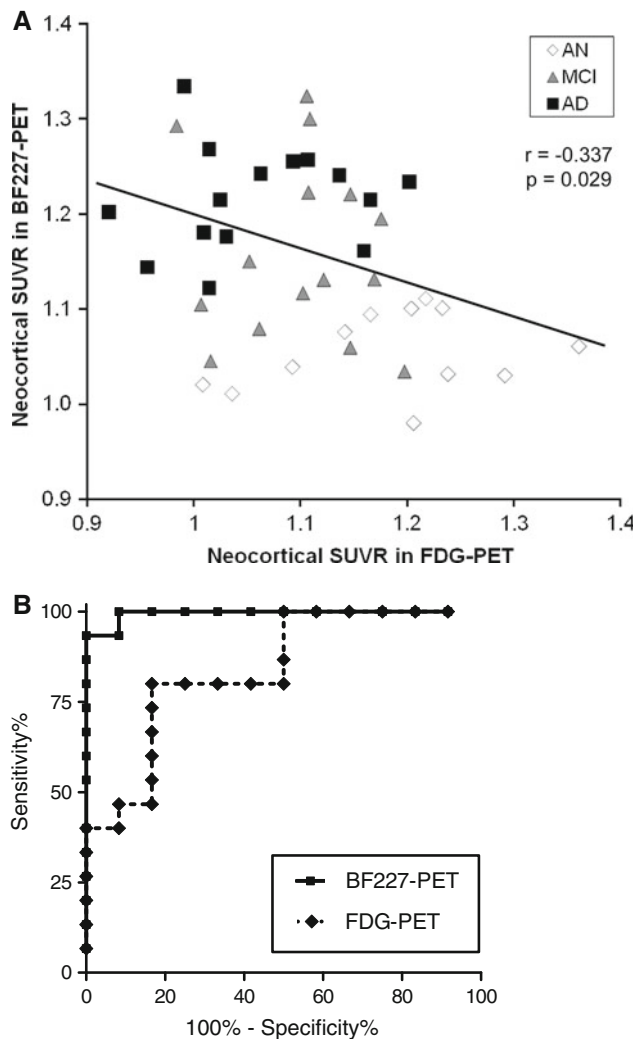
Fig. 4 a Relationship between neocortical SUVRs in FDG–PET and BF-227-PET. Neocortical SUVR of FDG–PET for each subject was plotted against neocortical SUVR of BF-227-PET. White, gray and black dots indicate AN, MCI and AD, respectively. b Receiver operating characteristic (ROC) curves of BF-227 and FDG–PET. BF-227-PET SUVR in the lateral temporal cortex and FDG–PET SUVR in the posterior cingulate cortex for differentiation between AD and AN

retention is closely related to the area indicating functional deterioration in the early stage of AD or MCI.

Low rCMRglu in AD especially in the posterior cingulate, precuneus, temporoparietal and frontal cortices was reported. FDG–PET has also been used in investigations for MCI, and low rCMRglu in the temporo-parietal and medial frontal cortices and hippocampus was reported as the most prominent predictor of subsequent cognitive decline [2–5]. Our results indicate, however, that amyloid retention detected by BF-227 is more sensitive and specific than FDG–PET for AD diagnosis. Therefore it is reasonable that amyloid PET is more sensitive than FDG–PET for detecting MCI, which is regarded as a prodromal state of

dementia or early AD. According to previous autopsy studies with MCI, amyloid plaques were found predominantly in the temporal lobe structure and most amnestic MCI cases showed Braak stage II or III [11, 22]. Furthermore both neurofibrillary tangles and senile plaques were found in nondemented aging and "preclinical" AD, and profound neuronal loss was observed in layer II of the entorhinal cortex [7, 23]. Our results with BF-227 PET for MCI presented here agree with postmortem studies because BF-227 also showed high retention predominantly in the temporal lobe and the retention was intermittent between NC and AD. There are some discrepancies, however, between the results with our BF-227-PET and with autopsy, that is, some cerebral white matter, thalamus and pons showed high retention of BF-227 in MCI, although these regions are usually not rich in senile plaques in the autopsy studies. Although it is considered that the deposition of BF-227 in these regions comes from its non-specific retention by high lipophilicity, it is supposed that more precise studies are needed using more subjects for both PET and autopsy.

We now have to carefully consider the heterogeneity of BF-227 retention in MCI, which was also observed in FDDNP or PIB studies, that is, some subjects show rich retention but others do not. Although it was reported that MCI subjects showing high retention of PIB had a high tendency to convert to AD as we mentioned above [6], the number of subjects they examined was relatively small. Therefore, further careful studies are needed to clarify if the accumulation of amyloid PET probes correlates with the severity of cognitive impairment and a conversion rate to dementia.

Our results using BF-227 for MCI are "continuous" rather than "off/on", "negative/positive" or "dichotomous" signals compared to those with PIB. We speculate that because BF-227 can depict a small difference of amyloid deposition more finely than PIB, the results with BF-227 in MCI are more continuous than those with PIB. Therefore, BF-227 could reveal a degree of senile plaque deposition more precisely and accurately than PIB as far as in cases with MCI.

We would like to conclude that our newly developed amyloid PET tracer, BF-227, can detect amyloid aggregation and deposition in MCI cases and the PET signal intensity for MCI was intermittent between NC and AD. Results obtained with BF-227 PET are significantly more sensitive and specific than FDG–PET in diagnosing AD. As far as the retention pattern in the frontal and parietal cortices, BF-227 more accurately reflects senile plaque deposition observed in the autopsy studies than PIB does. Therefore, BF-227 PET should be an invaluable tool for diagnosis of AD in the early stage. Finally, we recently developed a novel probe, which has similar structure to BF-

227, labeled with F-18, and applied it to living humans. We have finished more than 20 cases so far and obtained similar results to BF-227.

References

1. Bennett DA, Cochran EJ, Saper CB, Leverenz JB, Gilley DW, Wilson RS (1993) Pathological changes in frontal cortex from biopsy to autopsy in Alzheimer's disease. Neurobiol Aging 14:589–596

2. Chételat G, Desgranges B, de la Sayette V, Viader F, Eustache F, Baron JC (2003) Mild cognitive impairment: Can FDG-PET predict who is to rapidly convert to Alzheimer's disease? Neurology 60:1374–1377

3. Chételat G, Eustache F, Viader F, De La Sayette V, Pélerin A, Mézenge F, Hannequin D, Dupuy B, Baron JC, Desgranges B (2005) FDG–PET measurement is more accurate than neuropsychological assessments to predict global cognitive deterioration in patients with mild cognitive impairment. Neurocase 11:14–25

4. de Leon MJ, Convit A, Wolf OT, Tarshish CY, DeSanti S, Rusinek H, Tsui W, Kandil E, Scherer AJ, Roche A, Imossi A, Thorn E, Bobinski M, Caraos C, Lesbre P, Schlyer D, Poirier J, Reisberg B (2001) Fowler et al. Prediction of cognitive decline in normal elderly subjects with 2-[(18)F]fluoro-2-deoxy-D-glucose/positron-emission tomography (FDG/PET). Proc Natl Acad Sci USA 98:10966–10971

5. Drzezga A, Lautenschlager N, Siebner H, Riemenschneider M, Willoch F, Minoshima S, Schwaiger M, Kurz A (2003) Cerebral metabolic changes accompanying conversion of mild cognitive impairment into Alzheimer's disease: a PET follow-up study. Eur J Nucl Med Mol Imaging 30:1104–1113

6. Forsberg A, Engler H, Almkvist O, Blomqvist G, Hagman G, Wall A, Ringheim A, Långström B, Nordberg A (2008) A PET imaging of amyloid deposition in patients with mild cognitive impairment. Neurobiol Aging 29:1456–1465

7. Gómez-Isla T, Price JL, McKeel DW Jr, Morris JC, Growdon JH, Hyman BT (1996) Profound loss of layer II entorhinal cortex neurons occurs in very mild Alzheimer's disease. J Neurosci 16:4491–4500

8. Hardy J, Selkoe DJ (2002) The amyloid hypothesis of Alzheimer's disease: progress and problems on the road to therapeutics. Science 297:353–356

9. Herholz K, Carter SF, Jones M (2007) PET studies in dementia. Br J Radiol 80:S160–S167

10. Iwatsubo T, Odaka A, Suzuki N, Mizusawa H, Nukina N, Ihara Y (1994) Visualization of A beta 42(43) and A beta 40 in senile plaques with end-specific A beta monoclonals: evidence that an initially deposited species is A beta 42(43). Neuron 13:45–53

11. Jicha GA, Parisi JE, Dickson DW, Johnson K, Cha R, Ivnik RJ, Tangalos EG, Boeve BF, Knopman DS, Braak H, Petersen RC (2006) Neuropathologic outcome of mild cognitive impairment following progression to clinical dementia. Arch Neurol 63:674–681

12. Kemppainen NM, Aalto S, Wilson IA, Någren K, Helin S, Brück A, Oikonen V, Kailajärvi M, Scheinin M, Viitanen M, Parkkola R, Rinne JO (2007) PET amyloid ligand [11C]PIB uptake is increased in mild cognitive impairment. Neurology 68:1603–1606

13. Klunk WE, Engler H, Nordberg A, Wang Y, Blomqvist G, Holt DP, Bergström M, Savitcheva I, Huang GF, Estrada S, Ausén B, Debnath ML, Barletta J, Price JC, Sandell J, Lopresti BJ, Wall A, Koivisto P, Antoni G, Mathis CA, Långström B (2004) Imaging brain amyloid in Alzheimer's disease with Pittsburgh Compound-B. Ann Neurol 55:306–319

14. Kudo Y, Okamura N, Furumoto S, Tashiro M, Furukawa K, Maruyama M, Itoh M, Iwata R, Yanai K, Arai H (2007) 2-(2-[2-Dimethylaminothiazol-5-yl]ethenyl)-6-(2-[fluoro]ethoxy)benzoxazole: a novel PET agent for in vivo detection of dense amyloid plaques in Alzheimer's disease patients. J Nucl Med 8:553–561

15. Mathis CA, Klunk WE, Price JC, DeKosky ST (2005) Imaging technology for neurodegenerative diseases: progress toward detection of specific pathologies. Arch Neurol 62:196–200

16. Matsuda H (2007) Role of neuroimaging in Alzheimer's disease, with emphasis on brain perfusion SPECT. J Nucl Med 48:1289–1300

17. McKhann G, Drachman D, Folstein M, Katzman R, Price D, Stadlan EM (1984) Clinical diagnosis of Alzheimer's disease: report of the NINCDS-ADRDA Work Group under the auspices of Department of Health and Human Services Task Force on Alzheimer's Disease. Neurology 34:939–944

18. Minoshima S, Giordani B, Berent S, Frey KA, Foster NL, Kuhl DE (1997) Metabolic reduction in the posterior cingulate cortex in very early Alzheimer's disease. Ann Neurol 42:85–94

19. Okamura N, Arai H, Higuchi M, Tashiro M, Matsui T, Hu XS, Takeda A, Itoh M, Sasaki H (2001) [18F]FDG–PET study in dementia with Lewy bodies and Alzheimer's disease. Prog Neuropsychopharmacol Biol Psychiatry 25:447–456

20. Petersen RC, Smith GE, Waring SC, Ivnik RJ, Tangalos EG, Kokmen E (1999) Mild cognitive impairment: clinical characterization and outcome. Arch Neurol 56:303–308

21. Petersen RC (2004) Mild cognitive impairment as a diagnostic entity. J Intern Med 256:183–194

22. Petersen RC, Parisi JE, Dickson DW, Johnson K, Cha R, Ivnik RJ, Tangalos EG, Boeve BF, Knopman DS, Braak H, Petersen RC (2006) Neuropathologic features of amnestic mild cognitive impairment. Arch Neurol 63:665–672

23. Price JL, Morris JC (1999) Tangles and plaques in nondemented aging and "preclinical" Alzheimer's disease. Ann Neurol 45:358–368

24. Small GW, Kepe V, Ercoli LM, Siddarth P, Bookheimer SY, Miller KJ, Lavretsky H, Burggren AC, Cole GM, Vinters HV, Thompson PM, Huang SC, Satyamurthy N, Phelps ME, Barrio JR (2006) PET of brain amyloid and tau in mild cognitive impairment. N Engl J Med 355:2652–2663