J of Nuclear Medicine Technology, first published online November 9, 2022 as doi:10.2967/jnmt.122.264729

A headrest made of "extruded polystyrene" reduces the influence of attenuation correction on the human brain single photon emission computed tomography images

Headrest of extruded polystyrene

Makoto Ohba1, Yasuaki Kokubo2, Koji Suzuki1, Masafumi Kanoto3, Yukihiko Sonoda2

1Department of Radiology, Yamagata University Hospital

2Department of Neurosurgery, Faculty of Medicine, Yamagata University

3Department of Radiology, Division of Diagnostic Radiology, Yamagata University Graduate School of Medical Science.

Yasuaki Kokubo

2-2-2 Iida-Nishi, Yamagata, 990-9585 Japan

Fax: +81-023-628-5351 E-mail: ykokubo@med.id.yamagata-u.ac.jp

Original Article

Abstract

Previous reports suggest that a headrest made of carbon significantly influences cerebral blood flow (CBF) in the anterior and posterior regions by image reconstruction and attenuation correction (AC). The present study aimed to develop a headrest that reduces the influence of the AC process on human brain single photon emission computed tomography.

Methods:

To validate the performance of a headrest made of extruded polystyrene (XPS), 10 healthy controls and 43 patients with cerebrovascular disease underwent 99mTc-ECD SPECT using a carbon headrest and an XPS headrest. We evaluated the anterior and middle/posterior ratio of the brain regions in the filtered back projection (FBP)-Chang AC, ordered subset expectation maximization method (OS-EM)-Chang AC, and OS-EM-CT-based AC (CTAC).

Results:

The anterior/posterior ratio with the carbon headrest was significantly higher than that with the XPS headrest in FBP-Chang AC and OSEM-Chang AC ($P<0.001$). There was no significant difference between the materials in OSEM-CTAC. The middle/posterior ratio did not differ to a statistically significant extent in any correction process.

Conclusion:

Brain SPECT image acquisition with a headrest made of XPS in processing by the FBP/OSEM Chang AC method enables the influence of the headrest to be reduced in brain SPECT image, especially in anterior and posterior brain regions.

Key words: SPECT (single photon emission computed tomography), headrest, image reconstruction, attenuation correction, XPS (extruded polystyrene)

Introduction

In brain single photon emission computed tomography (SPECT) image acquisition, various interactions (e.g., image reconstruction and attenuation correction [AC] and scatter correction [SC]) should be considered in the imaging process. The influence of these interactions results in decreased image contrast and errors that are compensated by AC and SC. There are two representative methods for AC in SPECT: Chang AC and computed tomography-based AC (CTAC). Chang AC is based on the assumption of uniform attenuation of gamma-rays by intracranial tissues. However, since there are complex structures in the cranium (e.g., air, soft tissues, the paranasal sinus, and various degrees of skull thickness, attenuation is difficult to accurately correct (1). On the other hand, the recent widespread use of SPECT/CT has led to correction using X-ray CT data, such as CTAC. The attenuation of intracranial tissue that is non-uniform from the attenuation coefficient distribution derived from X-ray CT data can also be corrected. Thus, CTAC is expected to become more accurate than Chang AC (2).

A headrest is indispensable for brain SPECT. At present, carbon and polyethylene are materials that are commonly used for the construction of standard headrests. Since the CT value of carbon is 300 HU, which affects the degree of gamma-ray attenuation, gamma-ray attenuation could affect image reconstruction processes, including AC and SC. Previous reports that compared SPECT images constructed using two types of AC methods have shown that the CTAC method is a more accurate AC method than the Chang method based on experimental data obtained with a phantom simulating the brain (3). Furthermore, in the case of the Chang method, the anterior region of the brain is visualized relatively high because uniform correction is performed without considering the attenuation of gamma rays in part of the headrest. Thus, CTAC could contribute to reducing the influence of the headrest in comparison to Chang AC. However, Chang AC is still used in the reconstruction process of SPECT because SPECT/CT is not widespread enough. Therefore, low-CT-value materials for the headrest are needed because of the rareness of SPECT/CT systems.

We previously investigated the influence of headrests in brain SPECT using various SC and AC methods. We acquired a SPECT image with/without a carbon headrest to compare SPECT images. According to our results, the blood flow value in the anterior region of the brain is higher than that evaluated by methods other than the OSEM and CTAC image reconstruction methods (4). Thus, SPECT images are affected by the headrest unless both OSEM and CTAC are used to process the image. To solve this problem, we thought that it is necessary to use a headrest made of a material with a low CT value, almost equivalent to air, rather than carbon. Finally, we found a material, extruded polystyrene (XPS), which has a low CT value (practically equivalent to air) that can be used for the headrest. We developed a new headrest made of XPS. The purpose of this study is to verify the influence of the XPS headrest in comparison to a carbon headrest in healthy controls and patients with cerebrovascular disease.

Materials and Methods

This study was approved by the Ethical Review Committee of Yamagata University Faculty of Medicine for epidemiological research (Approval number: 2018-199). Written informed consent was obtained from patients and participants for their inclusion in this study and the publication of their data.

Subjects

<healthy controls>

We enrolled ten healthy controls (male, n=10; mean age, 50.20±7.97 years; range, 32-59 years) who had no organic lesions on magnetic resonance imaging (MRI) and stenosis/occlusion of the intracranial artery on magnetic resonance angiography (MRA). Although the healthy control group comprised of male volunteers only, it was coincidental and no selection bias was made. They were assessed by brain 99mTc-ethyl cysteinate dimer (ECD) SPECT with headrests made of carbon and XPS from July 2018 to April 2019.

<Patients with cerebrovascular disease>

We enrolled 43 patients (male, n=30; female, n=13; mean age, 59.46±16.46 years; range, 22-85 years). Seventeen patients had cervical internal carotid artery (ICA) stenosis, 16 had moyamoya disease and 4 had intracranial artery stenosis. They were assessed by brain 99mTc-ECD SPECT with carbon and XPS headrests from October 2018 to August 2020.

SPECT acquisition

Images were acquired by 99mTc- ECD SPECT/CT using a Symbia T2 (Siemens Healthineers, Erlangen, Germany) with a rotating, dual-detector gamma camera and low-energy high-resolution collimator (Siemens Healthineers), with 360° continuous rotation acquisition (2.5 min/rotation × 6 rotations). The acquisition conditions were as follows: magnification 1.45, 128 × 128 matrix (3.3 mm/pixel), main window, 141 ± 10.5 keV, and sub-window, 7%. Subjects were intravenously injected with 600 MBq of 99mTc-ECD while in the supine position with their eyes closed and their head placed on a headrest. SPECT acquisition with a headrest made of carbon was performed for 20 minutes, starting 5 minutes after injection, and CT imaging was also performed. Then, SPECT acquisition with a headrest made of XPS was performed for 20 minutes, starting 30 minutes after injection, and CT imaging was also performed.

Headrests

i) Carbon (Figure 1A)

The existing headrest was made of carbon. The shape of the headrest covers from the occipital region to the temporal region. The CT value of this carbon is 300 HU.

ii) XPS (figure1B)

Since XPS is easy to process, high strength, non-metal, low cost, and has a CT value as low as -980 HU, XPS was selected as a material for the new headrest.

The new headrest is a hybrid of XPS and stainless steel (SUS304). The shape has a structure without temporal parts to reduce the attenuation of gamma rays. To prevent unstable fixation of the patient head, we made a dent in the part that the back of the head touches. As a result of a strength test to verify whether the strength can withstand the SPECT examination in actual clinical practice, it was found to withstand a force of up to 200 N (kg·m/s2), and it was as durable as the carbon headrest, which could withstand a force of up to 180 N. Furthermore, if the occipital region is close to stainless steel, cerebral blood flow cannot be evaluated correctly due to metal artifacts. Therefore, the patient's neck was positioned at the joint between the XPS and the stainless steel so that it did not enter the cerebral blood flow evaluation site.

Image analysis

Images were reconstructed by filtered back projection (FBP) and the ordered subset expectation maximization method (OS-EM) with the combination of AC and SC. Chang AC, which is used in FBP and OS-EM, creates an attenuation coefficient distribution that does not consider the headrest, as correction only applies to intracranial tissue. The CTAC used in OS-EM creates an attenuation coefficient distribution of X-ray CT data and corrects both the intracranial tissue and headrest. SC in SPECT was performed with a multi-energy window.

99mTc-ECD SPECT was analyzed using a three-dimensional stereotaxic ROI template (3D-SRT) (PDRadiopharma Inc., Tokyo, Japan) to verify the influence of the headrest materials. The ROIs were grouped into 12 segments (A: callosomarginal, B: precentral, C: central, D: parietal, E: angular, F: temporal, G: posterior, H: pericallosal I: lenticular nucleus J: thalamus K: hippocampus, and L: cerebellar) in each hemisphere (5). We evaluated the anterior region (A+B)/the posterior region (G) count ratios and the middle region (D+F)/the posterior region (G) to investigate the influence in the anterior and middle areas of the brain defined by 3D-SRT (Figure 2). We divided the images into the following three groups based on the methods of image reconstruction and AC: FBP-Chang AC, OSEM-Chang AC, OSEM-CTAC. The results in the four groups were compared between carbon and XPS to clarify the influence of the materials.

All statistical analyses were performed using the SPSS software program (Ver. 26; SPSS Inc., Chicago, IL, USA). Differences in the A+B/G and D+F/G ratios among the different image reconstruction and correction methods with/without a headrest were analyzed using a paired t-test. P values of <0.01 were considered to indicate statistical significance.

Results

Healthy controls

Table 1 shows the comparison of the average A+B/G ratio and D+/G ratio for each group using the carbon and XPS headrests. In FBP-Chang AC and OSEM-Change AC, there were significant differences in the A+B/G ratio between the carbon and XPS headrests ($p<0.001$). On the other hand, in OSEM-CTAC, there were no significant differences in the A+B/G ratio between the carbon and XPS headrests. There were no significant differences in the D+F/G ratio between the carbon and XPS headrests in any of the groups.

Figure 3 shows representative images. For the anterior brain region (A+B), images constructed using FBP-Chang AC and OSEM-Chang AC with a carbon headrest were higher than those with an XPS headrest. On the other hand, images constructed using OSEM-CTAC with a carbon headrest did not differ from images constructed using the same methods with an XPS headrest.

Table 2 compares the average A+B/G ratio and D+F/G ratio for each group between the between carbon and XPS headrests. In FBP-Chang AC and OSEM-Change AC, significant differences in the A+B/G ratio were observed between the carbon and XPS headrests ($p<0.001$). On the other hand, in OSEM-CTAC, the A+B/G ratio did not differ between the carbon and XPS headrests. The D+F/G ratio did not differ to a statistically significant extent between the carbon and XPS headrests in any of the groups.

Figure 4 shows representative images. A 45-year-old male suffering from atherothrombotic infarction due to left middle cerebral artery (MCA) stenosis underwent MRI, 3D-CT angiography (CTA), and 99mTc-ECD SPECT. MRI-FLAIR (fluid-attenuated inversion-recovery) showed high-intensity lesions due to cerebral infarction on the left frontal and temporal lobes, including an insular cortex. 3D-CTA showed severe stenosis of the left MCA. For the anterior brain region (A+B), images constructed using FBP-Chang AC and OSEM-Chang AC with a carbon headrest were higher than those obtained using an XPS headrest. On the other hand, images using OSEM-CTAC with a carbon headrest did not differ from those obtained using an XPS headrest. The ischemic side/non-ischemic side ratio of the number of counts of ROI "B" that includes middle cerebral artery territory was 0.97 for carbon and 0.95 for XPS when viewed with FBP-Chang AC.

Discussion

<XPS as a headrest material>

Previous studies reported that the headrest affected SPECT images when the Chang method was used for AC (2,3). The cause of this effect is considered to be the influence of the carbon from which the headrest is constructed on image reconstruction processes, especially AC. Since carbon has a high CT value of 300 HU, a carbon headrest can cause the attenuation of gamma rays generated from the brain parenchyma in the region in contact with the headrest (e.g., the occipital region in Chang AC). Thus, the posterior region

(G) is relatively low, and the anterior region (A+B) is considered to have a high cerebral blood flow distribution. Our previous report (4) showed that with FBP-Chang AC, OSEM-Chang AC, significant differences were observed in the A+B/G ratio between images obtained with and without a headrest. As a result, the anterior region (A+B) was considered to appear to have a higher cerebral blood flow than the posterior region (G) except for when the OSEM-CTAC method was used. Therefore, we need to create a headrest made of materials with low CT values and a low degree of gamma-ray attenuation. Among such materials, the CT value of extruded polystyrene (XPS) is -980 HU, which is extremely low. Since XPS is composed of innumerable bubbles, it is considered that the attenuation of gamma rays is small and that the CT value is low. Furthermore, the structure of XPS differs from that of expanded polystyrene (EPS) beads, which is a well-known polystyrene material with a structure of continuous large bubbles. In XPS, the bubbles are not continuous and are partitioned by a thin film of polystyrene resin. Since it also plays a support role, it has high strength and is suitable for headrest construction. Additionally, since it is made in a completely sealed state, it suppresses water attenuation and heat conduction, so the material itself is unlikely to change and is considered to have high durability. Thus, we finally selected XPS as a headrest material.

<Comparison between carbon and XPS for the acquisition of 99mTc-ECD SPECT images>

For the anterior brain region (A+B), images obtained using FBP-Chang AC and OSEM-Chang AC with a carbon headrest were higher than those with XPS in healthy volunteers and patients with cerebrovascular disease. This is because the gamma rays generated from the brain parenchyma around the headrest, especially in the occipital region, are absorbed by the carbon headrest due to the gamma ray attenuation. Thus, the cerebral blood flow distribution is low in the occipital region and relatively high in the anterior region (3).

According to our results, the use of an XPS headrest reduces the difference between the anterior and posterior regions of the brain. Thus, AC by using XPS is less likely to affect image acquisition, even when using the Chang method. In OSEM-CTAC, there was no significant difference between carbon and XPS. This is because correction is made based on both the intracranial tissue and headrest from the X-ray CT data, considering the non-uniformity of the brain in the CTAC method (6). Therefore, OSEM-CTAC can be considered a reference standard. The A+B/G ratio by Chang AC using XPS and OSEM-CTAC was similar. The skull has different degrees of thickness depending on the site. Since the occipital bone is thicker than the frontal bone, it is considered that the attenuation of gamma rays is significant in the occipital region. Thus, the Chang method, which assumes that the head is a uniform absorber, is considered to be more significantly affected by the carbon headrest (7).

Regarding the clinical meaning of the difference between carbon and XPS, a representative case demonstrated in figure 4 suggested the possibility of underestimating decreased blood flow in ischemic lesions.

On the other hand, Regarding the ratio D + F (middle brain region) / G (posterior brain region) ratio, no significant difference was observed between carbon and XPS in any combination of image reconstruction and AC methods. Regions D, F, and G were all regions that were covered by the carbon headrest. Thus, it is considered that the region was affected by the headrest, the same as the posterior region.

A limitation of the present study is that the structure of the XPS headrest does not cover the side part of the head in order to minimize the interaction (e.g., attenuation and scattering of gamma rays emitted from brain tissue) in comparison to the carbon headrest. Consequently, fixation during examination may have been a little unstable. Thus, further improvement is needed. When performing AC using the Chang method, the XPS headrest is considered to have less effect on images than the conventional carbon headrest. Therefore, in the future, XPS may be considered as a headrest material for SPECT image acquisition.

Conclusions

We developed a new headrest for brain SPECT that was constructed from XPS instead of carbon. XPS has a low CT value of -980 HU, with excellent versatility, workability, and strength. There were significant differences in the A+B (anterior region)/G (posterior region) ratios in FBP-Chang AC, OS-EM-Chang AC between the carbon and XPS headrests in healthy controls and patients with cerebrovascular disease. On the other hand, the A+B/G ratios in OSEM-CTAC were not affected by the headrest material. There was no significant difference in the D+F (middle brain region) /G ratio in FBP-Chang AC, OS-EM-Chang AC. Thus, a headrest made of XPS reduces the influence of attenuation correction on brain SPECT image especially in anterior and posterior brain regions when processing by the FBP/OSEM Chang AC method.

Declarations, ethics approval, and consent to participate:

This study was approved by the Ethical Review Committee of Yamagata University Faculty of Medicine for epidemiological research (Approval number: 2018-199). Written informed consent was obtained from the patients and participants for inclusion in this study and for the publication of their data.

Conflicts of interest: The authors declare no conflicts of interest in association with the present study.

Sources of funding: None

KEY POINTS:

Question: This study aims to develop a headrest that reduces the influence of the attenuation correction (AC) process on the human brain SPECT.

Pertinent Findings: This study is a prospective comparative study. A headrest made of “extruded polystyrene (XPS)” reduces the influence of attenuation correction on brain SPECT image, especially in anterior and posterior brain regions, when processing by the FBP/OSEM Chang AC method in healthy volunteers and cerebrovascular patients.

Implications for Patient Care: This headrest made of XPS could allow us to acquire more precise human brain SPECT images.

References

1.Farid K, Habert MO, Martineau A, Vigneron NC, Sibon I. CT nonuniform attenuation and TEW scatter corrections in brain Tc-99m ECD SPECT. Clin Nucl Med. 2011;36:665-8.

2.Gillen R, Firbank MJ, Lloyd J, O'Brien JT. CT-based attenuation and scatter correction compared with uniform attenuation correction in brain perfusion SPECT imaging for dementia. Phys Med Biol. 2015;60:6775-87.

3.Ishii K, Hanaoka K, Okada M, Kumano S, Komeya Y, Tsuchiya N, et al. Impact of CT attenuation correction by SPECT/CT in brain perfusion images. Ann Nucl Med. 2012;26:241-7.

4.Ohba M, Kokubo Y, Suzuki K, Kanoto M, Sonoda Y. Influence of a headrest on the process of image reconstruction and attenuation correction on human brain single-photon emission computed tomography. J Nucl Med Technol. 2020;49:54-57

5.Takeuchi R, Yonekura Y, Matsuda H, Konishi J. Usefulness of a three-dimen sional stereotaxic ROI template on anatomically standardised 99mTc-ECD SPECT. Eur J Nucl Med Mol Imaging. 2002;29:331–341.

6.Patton JA, Turkington TG. SPECT/CT physical principles and attenuation correction. J Nucl Med Technol. 2008;36:1-10.

7.Hayashi M, Deguchi J, Utsunomiya K, Yamada M, Komori T, Takeuchi M et al. Comparison of methods of attenuation and scatter correction in brain perfusion SPECT. J Nucl Med Technol. 2005;33:224-9.

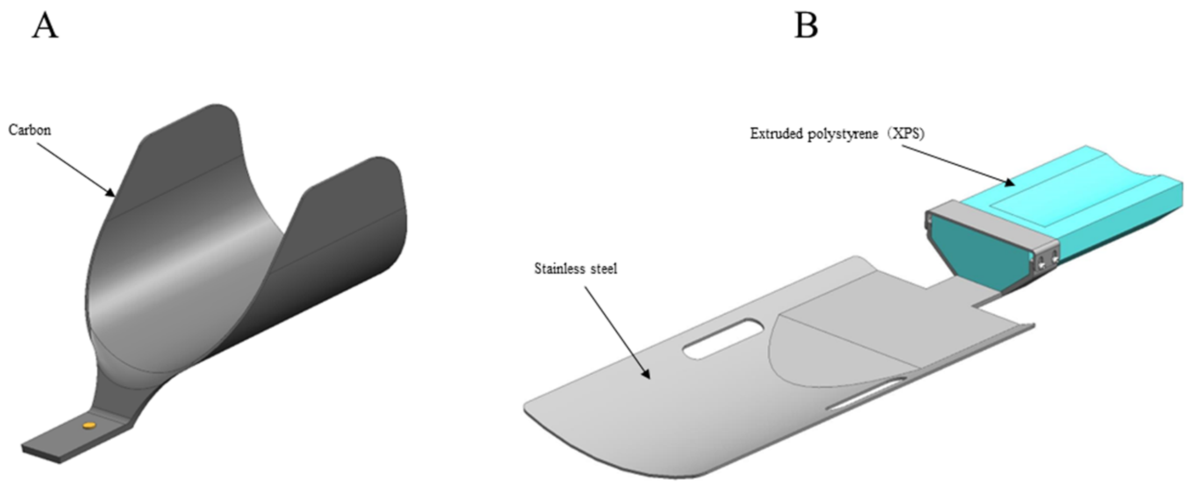

Figure 1A. Carbon headrest

The CT value is 300 HU. The headrest covers the temporal to occipital regions of the head.

Figure 1B. XPS headrest

The CT value is -980 HU. The headrest is a hybrid type constructed from XPS and stainless steel. It covers the occipital region of the head, which is in contact with the XPS.

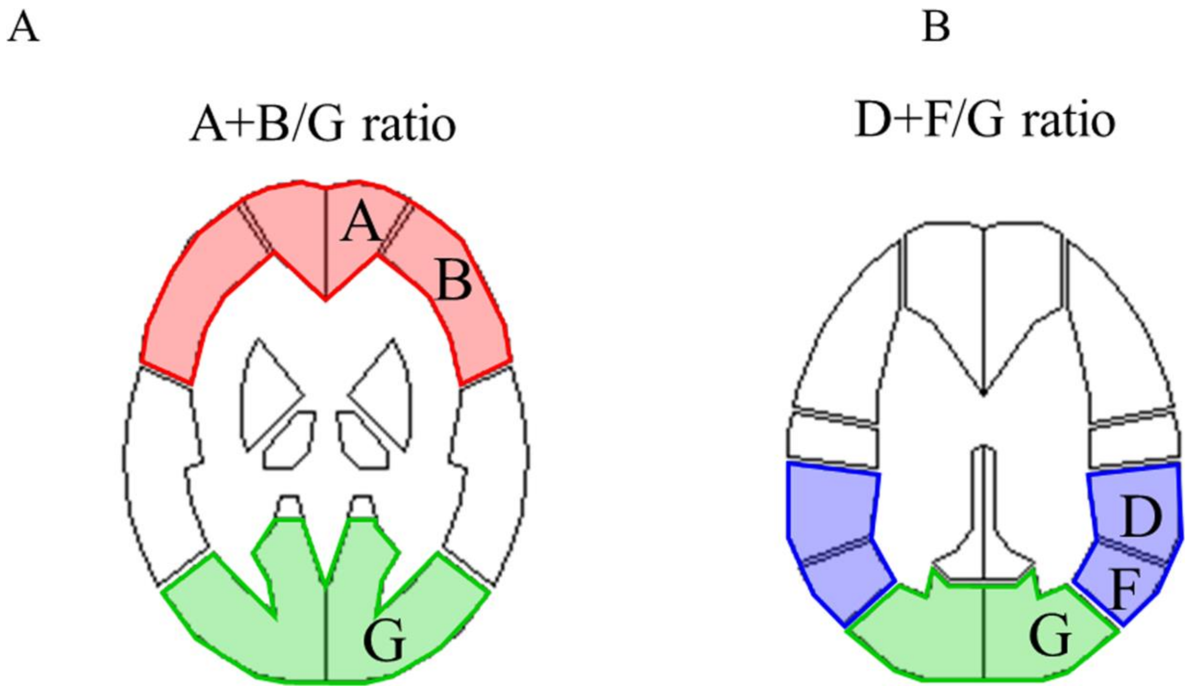

Figure 2A, B. Three-dimensional stereotaxic ROI template (3D-SRT)

Region “A”, which is the territory of the callosomarginal segment and region “B”, which is the territory of the precentral segment, is defined as the anterior brain region. Region “G”, which is the territory of the posterior segment, is defined as the posterior brain region. The ratio of the anterior region to the posterior region is defined as the A+B/G ratio.

Region “D”, which is the territory of the parietal segment and region “F”, which is the territory of the temporal segment, is defined as the middle brain region. The ratio of the middle region to the posterior region is defined as the D+F/G ratio.

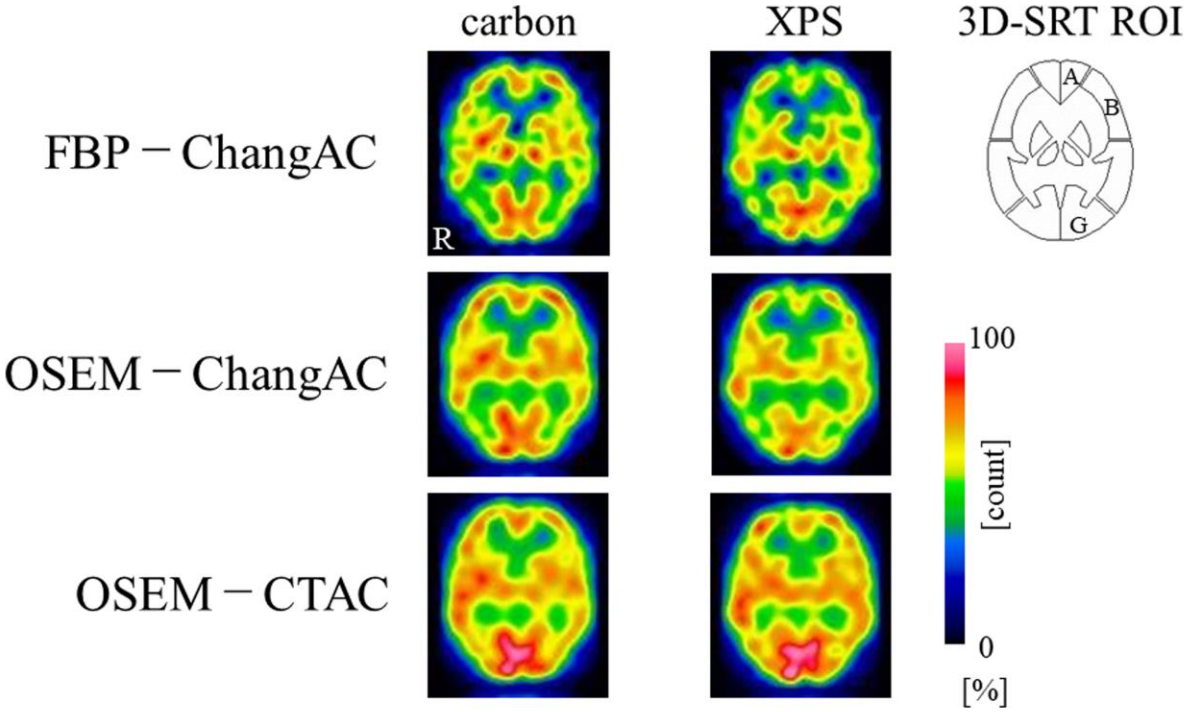

Figure 3. Comparison of 99mTc-ECD SPECT images obtained using carbon and XPS headrests in healthy controls

it is considered that AC

Images constructed with FBP-ChangAC and OSEM-ChangAC using a carbon headrest show higher CBF in the anterior part of the brain in comparison to images constructed with the same methods using an XPS headrest. In images constructed with OSEM-CTAC, the anterior and posterior parts of the brain did not differ between the images obtained using carbon and XPS headrests.

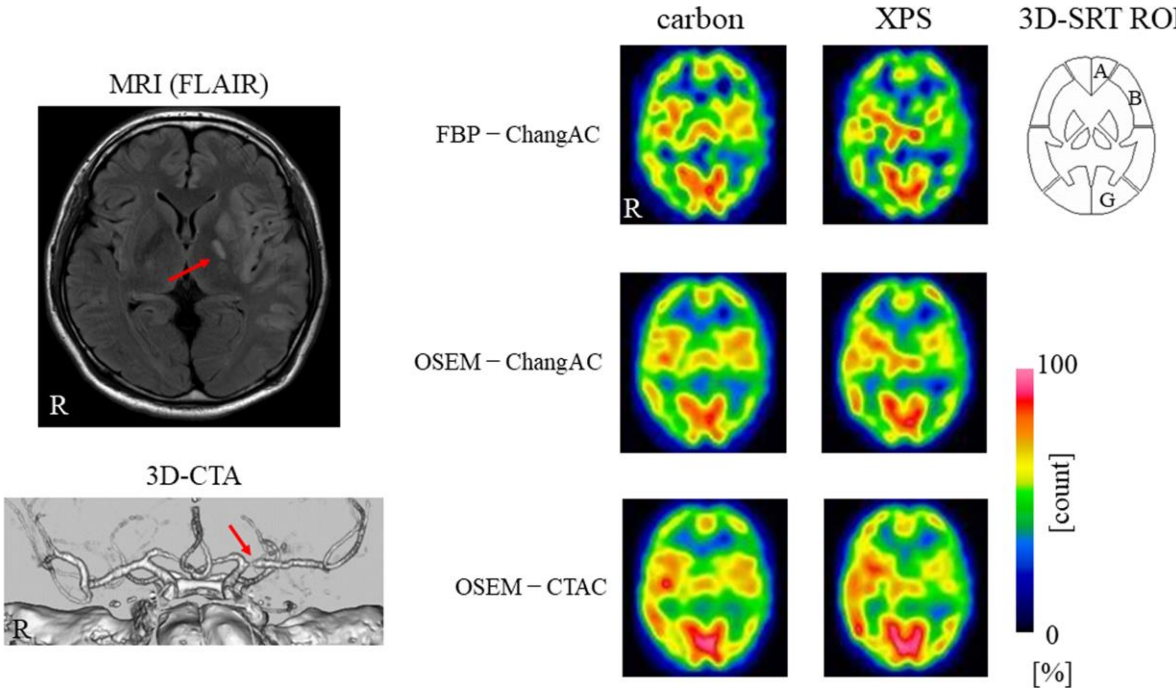

Figure 4. Comparison of 99mTc-ECD SPECT images obtained using carbon and XPS headrests in patients with cerebrovascular disease

MRI-FLAIR (fluid-attenuated inversion-recovery) images showed high-intensity lesions due to cerebral infarction in the left frontal and temporal lobes, including an insular cortex. 3D-CTA showed severe stenosis of the left MCA. For the anterior brain region (A+B), images constructed using FBP-Chang AC and OSEM-Chang AC with a carbon headrest showed higher CBF in comparison to images constructed using the same methods with an XPS headrest. Images constructed using OSEM-CTAC with a carbon headrest showed no difference from images constructed using the same methods with an XPS headrest.

Graphical Abstract

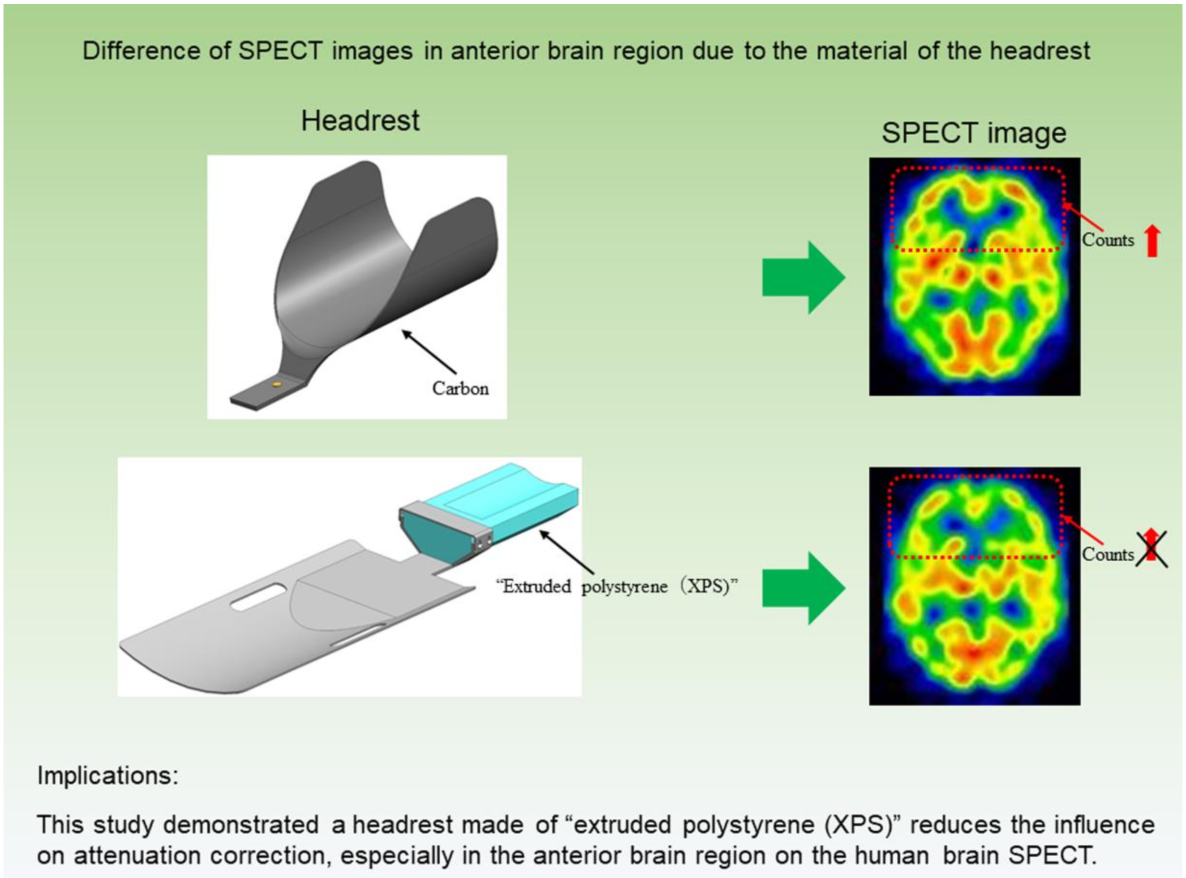

Table1 Comparison of A+B/G and D+F/G ratio between the carbon and XPS headrests in healthy controls

Healthy controls	A+B/G ratio			D+F/G ratio		
(n=10)	Carbon	XPS	P value	Carbon	XPS	P value
FBP-ChangAC	0.97±0.02	0.93±0.02	* P < 0.001	0.89±0.02	0.89±0.02	0.173
OSEM-ChangAC	0.98±0.04	0.94±0.02	* P < 0.001	0.90±0.02	0.90±0.02	0.423
OSEM-CTAC	0.91±0.02	0.91±0.02	0.322	0.88±0.01	0.88±0.01	0.037

*P<0.01

Table 2: Comparison of the A+B/G and D+F/G ratio between the carbon and XPS geadrests in patients with cerebrovascular disease

Patients with cerebrovascular disease	A+B/G ratio			D+F/G ratio		
(n=43)	Carbon	XPS	P value	Carbon	XPS	P value
FBP-ChangAC**	0.96±0.05	0.91±0.05	* P < 0.001	0.87±0.04	0.87±0.04	0.343
OSEM-ChangAC**	0.96±0.05	0.92±0.06	* P < 0.001	0.88±0.04	0.88±0.04	0.938
OSEM-CTAC	0.89±0.04	0.89±0.05	0.893	0.86±0.03	0.86±0.03	0.099

*P<0.01