J of Nuclear Medicine Technology, first published online September 4, 2020 as doi:10.2967/jnmt.120.244731

Influence of a headrest on the process of image reconstruction and attenuation correction on human brain single-photon emission computed tomography

Running title: Influence of a headrest on human brain SPECT

Makoto Ohba[1], Yasuaki Kokubo[2], Koji Suzuki[1], Masafumi Kanoto[3], Yukihiko Sonoda[2]

[1]Department of Radiology, Yamagata University Hospital

[2]Department of Neurosurgery, Faculty of Medicine, Yamagata University

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

Corresponding author:

Yasuaki Kokubo

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

Fax: +81-628-5351

E-mail: ykokubo@med.id.yamagata-u.ac.jp

Abstract

Previous reports suggest that a headrest significantly influences cerebral blood flow (CBF) in the anterior and posterior regions by image reconstruction and attenuation correction (AC). The present study aimed to clarify the influence of a headrest on the process of reconstruction and AC of brain SPECT images.

Methods:

We evaluated the influence on CBF in the anterior, middle, and posterior regions of the brain in filtered back projection (FBP)-Chang AC, ordered subset expectation maximization method (OS-EM)-Chang AC, OS-EM-CT-based AC (CTAC), and OS-EM No-AC (no correction for attenuation) with /without a headrest. Subjects were Seventeen healthy volunteers who underwent ^{99m}Tc-ECD SPECT. We compared the anterior (A+B)/posterior (G) and the middle region (D+F)/posterior (G) ratios of ^{99m}Tc-ECD SPECT images in each group.

Results:

There are significant differences in A+B/G ratios between with and without a headrest in FBP-Chang AC, OS-EM-Chang AC, and NoAC. On the other hand, there are no significant differences in A+B/G ratios regardless of a headrest in OS-EM-CTAC. There are significant differences in D+F /G ratios between with and without a headrest in FBP-Chang AC, and NoAC. There are no significant differences in D+F /G ratios regardless of a headrest in OS-EM-CTAC and OS-EM-Chang AC.

Conclusion:

The headrest's influence on images reconstruction and AC should be considered in FBP-Chang AC, OS-EM-Chang AC, and NoAC except for OS-EM CTAC.

Key words: SPECT (single-photon emission computed tomography), headrest, image reconstruction, CT-based attenuation correction, Chang AC

Introduction

Cerebral blood flow (CBF) imaging by single-photon emission computed tomography (SPECT) plays an important role not only for the diagnosis of ischemic cerebrovascular disease but also for the diagnosis of dementia, other degenerative diseases, and psychiatric disorders. A statistical imaging analysis using an easy z-score imaging system (e-ZIS) (*1,2*) is established as a useful tool for the differential diagnosis of conditions such as Alzheimer's disease (*3,4*) and Lewy body dementia (*5,6*).

On the other hand, various interactions, such as image reconstruction and attenuation correction (AC) and scatter correction (SC), should also be considered in the imaging process. The influence of these interactions results in decreased image contrast and errors for which are compensated by AC and SC. At present, there are two methods for AC in SPECT images, such as Chang AC (*7*) and CT-based AC (CTAC) (*8,9*). Chang AC is based on the assumption of uniform attenuation of gamma-rays by intracranial tissues. However, there are complex structures, such as air, soft tissues, the paranasal sinus, and various skull thickness, attenuation is difficult to accurately correct (*10*). On the other hand, the recent widespread use of SPECT/CT has led to correction using X-ray CT data and AC by X-ray CT 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, it is expected to become CTAC is more accurate than Chang AC. Ishii et al. reported that the frontal dominant hyperperfusion and parieto-posterior and cerebellar hypo-perfusion in brain SPECT images reconstructed with Chang AC compared to those reconstructed with CTAC (*8,9*). Thus, CTAC could contribute to reduce the influence of the headrest compared to the Chang AC (*7*). However, at present, Chang AC is still using in the reconstruction process of SPECT since SPECT/CT is not widespread enough. Furthermore, they have shown that a headrest could significantly influence CBF in the anterior and posterior regions of the brain corrected by Chang AC (*7*).

Thus far, no reports have evaluated the effect of any type of AC with/without a headrest on the evaluation of CBF in the anterior and posterior region of the brain. These issues need to be resolved to reveal the influence of brain SPECT images by the headrest.

The present study aimed to clarify the influence of a headrest on the process of reconstruction and AC of brain SPECT images.

Materials and Methods

This study protocol was approved by the Ethical Review Committee of Yamagata University Faculty of Medicine for epidemiological research. All subjects signed written informed consent.

Subjects

We enrolled seventeen healthy men (mean age [range], 41.2 ± 11.38 [26-59] years) without a medical history of brain disease and who volunteered to participate in this study They had been assessed by ^{99m}Tc-ethyl cysteinate dimer (ECD) (*12*) brain SPECT with/without headrest from July 2016 to March 2018.

SPECT acquisition

Images were acquired by ^{99m}Tc-ECD-SPECT/CT using a Symbia T2 with a rotating, dual-detector gamma camera and low energy, a high-resolution collimator (Siemens Healthineers, Erlangen, Germany), with 360° continuous rotation acquisition (2.5 min/rotation × 6 rotations). For the acquisition of SPECT images without a headrest, subjects were placed in the lateral position to reduce the burden and motion artifact (Figure 1). SPECT images were acquired over a period of 15 minutes, followed by X-ray CT image acquisition. Subjects were intravenously injected with 600 MBq of ^{99m}Tc-ECD while in the supine position with their eyes closed and their head placed on a headrest. The acquisition conditions were as follows: magnification 1.45, 128 × 128 matrices (3.3 mm/pixel), main window, 140 ± 10.5 keV, and sub-window, 7%.

Image analysis

Images were reconstructed by filtered back projection (FBP) (*13*) and ordered subset expectation maximization method (OS-EM) (*14*) with combined AC and SC. The Chang AC used in FBP and OS-EM creates an attenuation coefficient distribution that does not consider the headrest, as a 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 the headrest. The manners of SC in SPECT were a multi-energy window, respectively.

^{99m}Tc-ECD SPECT was analyzed using a three-dimensional stereotaxic ROI template (3D-SRT) (FUJIFILM Toyama Chemical, Co., Ltd., Tokyo, Japan) (*15)* to verify the influence of the image reconstruction and correction methods. 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. 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 four groups based on the image reconstruction and AC manner: FBP-Chang AC, OS-EM-Chang AC, OS-EM-CTAC, No-AC (no correction for attenuation). The results of the four groups were compared with /without a headrest to clarify the headrest's influence.

All statistical analyses were performed using the SPSS software program (Ver. 26; SPSS Inc., Chicago, IL, USA). Differences in A+B/G and D+F/G ratios among images reconstruction and correction by different methods with/without a headrest were analyzed by unpaired t-test. P values of <0.05 were considered to indicate statistical significance.

Results

Table 1 shows the average A+B/G ratios of each group of ^{99m}Tc-ECD SPECT images. There are significant differences in A+B/G ratios between with and without a headrest in FBP-

Chang AC, OS-EM-Chang AC, and NoAC. On the other hand, there are no significant differences in A+B/G ratios regardless of a headrest in OS-EM-CTAC. Table 2 shows the average D+F/G ratios of each group of ^{99m}Tc-ECD SPECT images. There are significant differences in D+F /G ratios between with and without a headrest in FBP-Chang AC and NoAC. On the other hand, there are no significant differences in D+F /G ratios regardless of a headrest in OS-EM-CTAC and OS-EM-Chang AC.

Figure 3 shows representative images at the level of basal ganglia. These images using FBP-Chang AC, OS-EM-Chang AC, and NoAC on anterior brain region (A+B) with a headrest were higher than those obtained without headrest. These images using OS-EM-CTAC, on anterior brain region obtained with a headrest demonstrated no difference compared with those obtained without headrest. These images using FBP-Chang AC and NoAC on the middle brain region (F) with a headrest were higher than those obtained without headrest. These images using OS-EM-Chang AC and OS-EM-CTAC on the middle brain region (F) obtained with a headrest demonstrated no difference compared with those obtained without headrest.

Figure 4 shows representative images at the level of the ventricular body. These images using FBP-Chang AC, OS-EM-Chang AC, and NoAC on anterior brain region (A+B) with a headrest were higher than those obtained without headrest. These images using OS-EM-CTAC, on anterior brain region obtained with a headrest demonstrated no difference compared with those obtained without headrest. These images using FBP-Chang AC and NoAC on the middle brain region (D+F) with a headrest were higher than those obtained without headrest. These images using OS-EM-Chang AC and OS-EM-CTAC on the middle brain region (D+F) obtained with a headrest demonstrated no difference compared with those obtained without headrest.

Discussion

This study revealed significant differences in the A+B (anterior brain region)/G ratios in FBP-Chang AC, OS-EM-Chang AC, and NoAC between with and without a headrest. On the other hand, there were significant differences in the D+F (middle brain region)/G ratios in FBP-Chang AC and NoAC regardless of a headrest. Thus, the anterior brain region is more affected by a headrest in image reconstruction and AC. Ishii et al. reported that on SPECT images reconstructed using FBP and Chang AC, the CBF values in the anterior brain region tended to be higher than those in the posterior brain region (*11)*, which was in line with our results. They suggested that a headrest made of carbon might influence the attenuation of the posterior brain region when reconstructing SPECT images with FBP and Chang AC (*7*). An image reconstruction method should be considered the progression of gamma-rays from the intracranial tissue through the headrest to the detector.

According to our results, there was no significant difference in the A+B/G ratios only in OS-EM-CTAC regardless of a headrest. Therefore, The SPECT images corrected with Chang AC are more affected in the anterior region than those with CTAC by a headrest. As a reason for that, the CTAC used in OS-EM creates an attenuation coefficient distribution from X-ray CT data and corrects both the intracranial tissue and the headrest. On the other hand, Chang

AC, based on the assumption of uniform attenuation of gamma-rays by intracranial tissues, is not considered the headrest, as the correction only applies to intracranial tissue. Since the brain parenchyma and skull that are structurally heterogeneous attenuate gamma-rays considerably, attenuation in intracranial tissue is unlikely to be uniform (*16*). A previous report also indicated that the region contacting the headrest might be overcorrected (*11*). Another investigator previously reported that SPECT image reconstruction by OS-EM with CTAC that considered the influence of the headrest was minimum (*10*).

The principle of FBP is to obtain the SPECT image by back-projecting the obtained projection data by filtering the obtained projection data (*13*). On the other hand, it is well known that OS-EM (*14*), which obtains the tomographic image by estimating the image with the highest probability from the projection data based on the radioactive distribution in the body using a statistical method, has higher accuracy than FBP. However, according to our results, OS-EM Chang AC still has the effect of a headrest, even if the image reconstruction method is OS-EM, if AC is Chang, it should be considered that there is the effect of a headrest.

At present, there is a high possibility of being affected by a headrest in the process of reconstruction and AC of SPECT images except for OS-EM CTAC. Therefore, basically, OS-EM CTAC as the process of reconstruction and AC is desirable. Otherwise, it should be considered that the anterior brain region may be higher value than the posterior brain region when using other methods except for OS-EM CTAC.

Since the headrest is generally made of carbon, which has a CT value of approximately 300 Hounsfield units (HUs), the headrest might cause gamma-ray attenuation. In the future, one possibility would be to construct a headrest of a material with a CT value close to air.

There are limitations to this study. Firstly, SPECT acquisition with the head floating in the air without a headrest might result in the generation of other influences, such as motion artifacts. Secondly, since only healthy volunteers were scanned in this study, there is a limitation to the possibility of assessing the impact of different reconstruction algorithms on clinical practice.

Conclusions

There were significant differences in the A+B (anterior region)/G ratios in FBP-Chang AC, OS-EM-Chang AC, and NoAC between with and without a headrest. On the other hand, there are no significant differences in A+B/G ratios regardless of a headrest in OS-EM-CTAC. Thus, the influence of the headrest on images reconstruction and AC should not be considered in OS-EM-CTAC. However, it should be taken into consideration that the A+B/G ratio may be of higher value when using other methods except for OS-EM CTAC.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

1. Matsuda H, Mizumura S, Soma T, Takemura N. Conversion of brain SPECT images between different collimators and reconstruction processes for analysis using statistical parametric mapping. *Nucl Med Commun*. 2004 ;25:67-74.

2. Kanetaka H, Matsuda H, Asada T, et al. Effects of partial volume correction on discrimination between very early Alzheimer's dementia and controls using brain perfusion SPECT. *Eur J Nucl Med Mol Imaging*. 2004 ;31:975-980.

3. Johnson K, Mueller S, Walshe T, English R, Holman BL. Cerebral perfusion imaging in Alzheimer's disease use of single photon emission computed tomography and Iofetamine hydrochloride I 123. *Arch Neurol*. 1987 ;44:165-168.

4. Cohen M, Graham L, Lake R, et al. Diagnosis of Alzheimer's disease and multiple infarct dementia by tomographic imaging of iodine-123 IMP. *J Nucl Med*.1986 ;27:769-774.

5. Imamura T, Ishii K, Sasaki M, et al. Regional cerebral glucose metabolism in dementia with Lewy bodies and Alzheimer's disease: A comparative study using positron emission

tomography. *Neuroscience letters*.1997 ;235:49-52.

6. Donnemiller E, Heilmann J, Wenning G, et al. Brain perfusion scintigraphy with ^{99m}Tc-HMPAO or ^{99m}Tc-ECD and ^{123}I-beta-CIT single-photon emission tomography in dementia of the Alzheimer-type and diffuse Lewy body disease. *Eur J Nunl Med*. 1997 ;24:320-325.

7. Lee-Tzuu Chang. A Method for Attenuation Correction in Radionuclide Computed Tomography. *IEEE Transactions on Nuclear Science*. 1978 ;25:638–643.

8. Seo Y, Wong K, Sun M, Franc B, Hawkins R. Hasegawa B. Correction of photon attenuation and collimator response for a body-contouring SPECT/CT imaging system. *J Nucl Med*. 2005 ;46:868-877.

9. Licho R, Glick S, Xia W, Pan T, Penney B, King M. Attenuation compensation in ^{99m}Tc SPECT brain imaging: a comparison of the use of attenuation maps derived from transmission versus emission data in normal scans. *J Nucl Med*. 1999 ;40:456-463.

10. Stodilka R, Kemp B, Prato F, Kertesz A, Kuhl D, Nicholson R. Scatter and attenuation correction for brain SPECT using attenuation distributions inferred from a head atlas. *J Nucl*

Med. 2000 ;41:1569-1578.

11. Ishii K, Hanaoka K, Okada M, et al. Impact of CT attenuation correction by SPECT/CT in brain perfusion images. *Ann Nucl Med*. 2012 ;26:241-247.

12. Vallabhajosula S, Zimmerman R, Picard M, Stritzke P, Mena I, Hellman RS. Technetium-99m ECD: a new brain imaging agent: in vivo kinetics and biodistribution studies in normal human subjects. *J Nucl Med*. 1989 ;30:599-604.

13. Radon J. Uber die Bestimmung von Funktionen durch ihre Integralwerte lamgs gewisser Mannigfaltigkeiten. *Ber Sachs Akad Wiss*. 1917 ;69:262-277.

14. Hudson H, Larkin R. Accelerated image reconstruction using ordered subsets of projection data. *IEEE Trans Med Image*. 1994 ;13:100-108.

15. Takeuchi R, Yonekura Y, Matsuda H, Konishi J. Usefulness of a three-dimensional stereotaxic ROI template on anatomically standardised ^{99m}Tc-ECD SPECT. *Eur J Nucl Med Mol Imaging*. 2002 ; 29:331-341.

15. Farid K, Habert M, Martineau A, Caillat-Vigneron N, Sibon I. CT nonuniform attenuation

and TEW scatter corrections in brain Tc-99m ECD SPECT. *Clin Nucl Med*. 2011 ;36:665-668.

Table1: Comparison of A+B/G ratios between with and without a headrest in FBP-Chang AC, OS-EM-CTAC, OS-EM-Chang AC, and NoAC.

A+B/G ratio (n=17)	with Headrest	without Headrest	P value
FBP-ChangAC**	0.97	0.91	0.008
OSEM-CTAC	0.91	0.92	0.35
OSEM-ChangAC*	0.98	0.92	0.03
NoAC**	1.04	0.98	0.002

*$P<0.05$,

**$P<0.01$

Table2: Comparison of D+F/G ratios between with and without a headrest in FBP-Chang AC, OS-EM-CTAC, OS-EM-Chang AC, and NoAC.

D+F/G ratio (n=17)	with Headrest	without Headrest	P value
FBP-ChangAC**	0.90	0.86	0.01
OSEM-CTAC	0.88	0.88	0.97
OSEM-ChangAC	0.90	0.87	0.06
NoAC*	0.96	0.93	0.034

*$P<0.05$,

**$P<0.01$

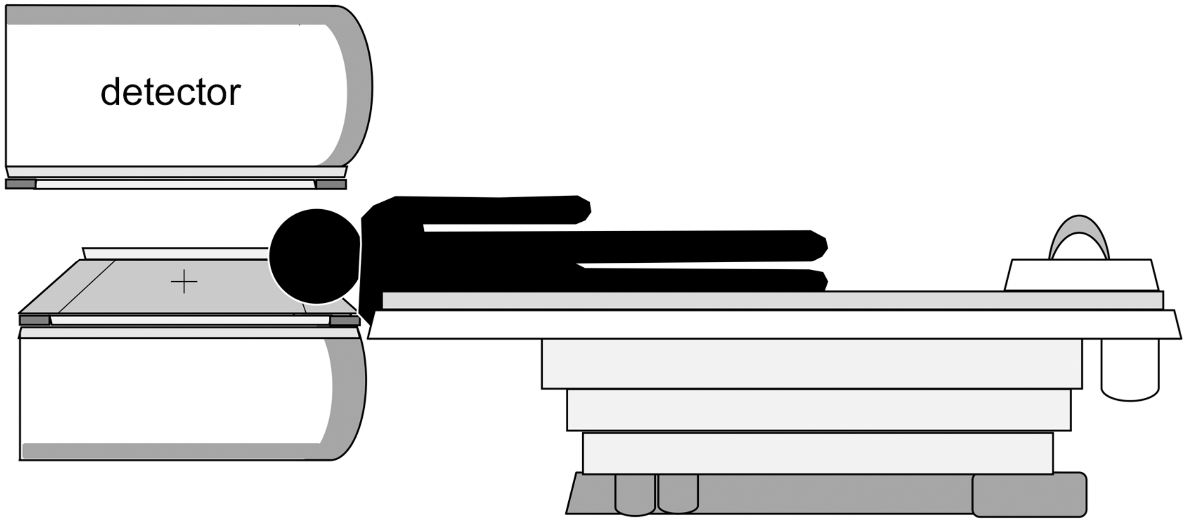

Figure 1: This schema demonstrates that subjects were placed in the lateral position to reduce the burden and motion artifact for the acquisition of SPECT images without a headrest.

Figure 2: A three-dimensional stereotaxic ROI template (3D-SRT)

Region “A”, which is the territory of the callosomarginal and Region “B”, which is the territory of the precentral, defined as the anterior brain region.

Region “D”, which is the territory of the parietal and Region “F”, which is the territory of the temporal, defined as the middle brain region. Region “G”, which is the territory of the posterior, is defined as the posterior brain region

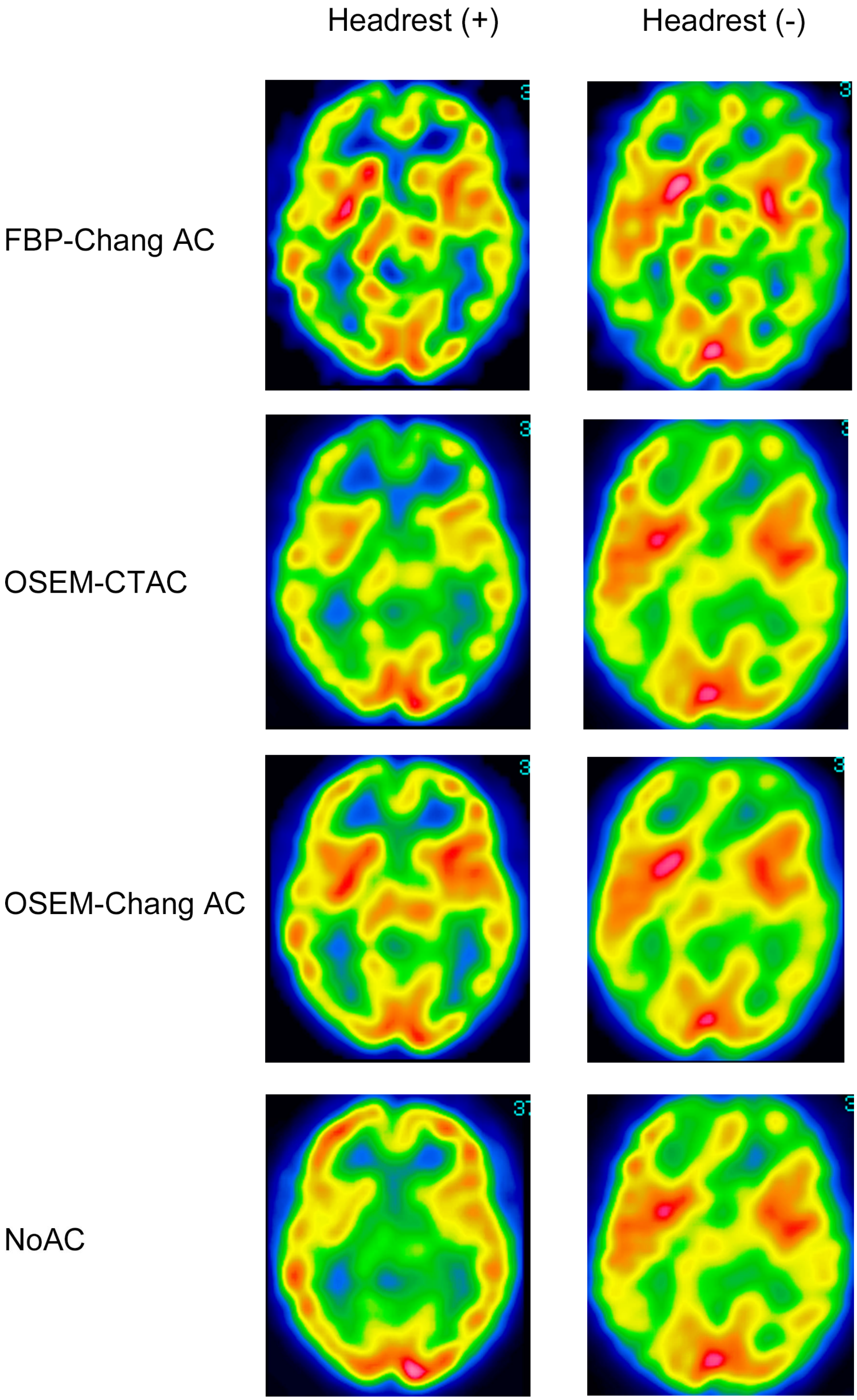
Headrest (+)
Headrest (-)
FBP-Chang AC
OSEM-CTAC
OSEM-Chang AC
NoAC

Figure 3: ^{99m}Tc-ECD SPECT images at level of basal ganglia with and without a headrest processing by FBP-Chang AC, OS-EM-CTAC, OS-EM-Chang AC, and NoAC.

These images using FBP-Chang AC, OS-EM-Chang AC, and NoAC on anterior brain region (A+B) with a headrest were higher than those obtained without headrest. These images using OS-EM-CTAC, on anterior brain region obtained with a headrest demonstrated no difference compared with those obtained without headrest. These images using FBP-Chang AC and NoAC on middle brain region (F) with a headrest were higher than those obtained without headrest. These images using OS-EM-Chang AC and OS-EM-CTAC on middle brain region (F) obtained with a headrest demonstrated no difference compared with those obtained without headrest.

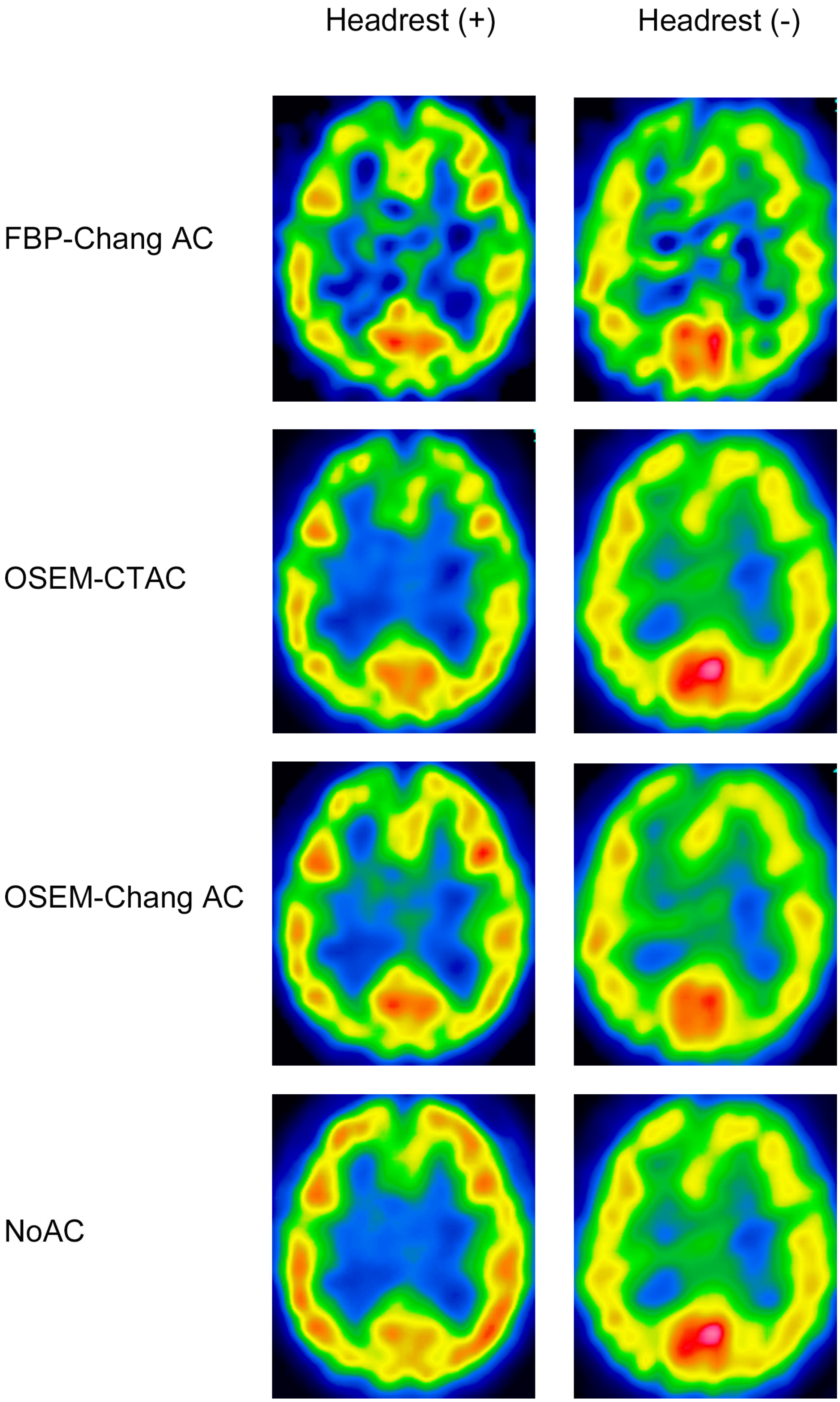
Headrest (+)
Headrest (-)
FBP-Chang AC
OSEM-CTAC
OSEM-Chang AC
NoAC

Figure 4: ^{99m}Tc-ECD SPECT images at level of ventricular body with and without a headrest processing by FBP-Chang AC, OS-EM-CTAC, OS-EM-Chang AC, and NoAC.

These images using FBP-Chang AC, OS-EM-Chang AC, and NoAC on anterior brain region (A+B) with a headrest were higher than those obtained without headrest. These images using OS-EM-CTAC, on anterior brain region obtained with a headrest demonstrated no difference compared with those obtained without headrest. These images using FBP-Chang AC and NoAC on middle brain region (D+F) with a headrest were higher than those obtained without headrest. These images using OS-EM-Chang AC and OS-EM-CTAC on middle brain region (D+F) obtained with a headrest demonstrated no difference compared with those obtained without headrest.