Detectability improvement of early sign of acute stroke on brain CT images using an adaptive partial smoothing filter

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ABSTRACT

Detection of early infarct signs on non-enhanced CT is mandatory in patients with acute ischemic stroke. We present a method for improving the detectability of early infarct signs of acute ischemic stroke. This approach is considered as the first step for computer-aided diagnosis in acute ischemic stroke. Obscuration of the gray-white matter interface at the lentiform nucleus or the insular ribbon has been an important early infarct sign, which affects decisions on thrombolytic therapy. However, its detection is difficult, since the early infarct sign is subtle hypoattenuation. In order to improve the detectability of the early infarct sign, an image processing being able to reduce local noise with edges preserved is desirable. To cope with this issue, we devised an adaptive partial smoothing filter (APSF). Because the APSF can markedly improve the visibility of the normal gray-white matter interface, the detection of conspicuity of obscuration of gray-white matter interface due to hypoattenuation could be increased. The APSF is a specifically designed filter used to perform local smoothing using a variable filter size determined by the distribution of pixel values of edges in the region of interest. By adjusting four parameters of the APSF, an optimal condition for image enhancement can be obtained. In order to determine a major one of the parameters, preliminary simulation was performed by using composite images simulated the gray-white matter. The APSF based on preliminary simulation was applied to several clinical CT scans in hyperacute stroke patients. The results showed that the detectability of early infarct signs is much improved.

Keywords: Computed tomography, Cerebral infarction, Computer-aided diagnosis, Adaptive smoothing filter

1. INTRODUCTION

The mortality rate for cerebrovascular disease is approximately ten percents in all deaths in the world [1]. The cerebrovascular disease is a major cause of disability and is contained in three leading causes of death with heart disease and malignant neoplasm in several countries, e.g. Japan [2]. Cerebral infarction is a major cerebrovascular disease, and detection of its early signs is very important for survival and convalescence. Computed tomography (CT) is widely accepted as the imaging modality for the acute ischemic stroke investigation. The obscuration of the lenticular nuclei is one of early infarct sign on CT image [3-5]. However, the detection of obscure lenticular nuclei is considerably difficult and demands abundant diagnosis experience to radiologists. To overcome this issue, adaptive partial smoothing filter (APSF) is proposed in this study to improve the visibility and detectability of the lentiform nucleus. APSF is able to reduce noise component while preserving signal component. On CT image, the noise component is almost quantum noise, and the signal component in this study is subtle edge signal of lenticular nuclei. Obscure lenticular nuclei, namely an early infarct sign, become conspicuous by enhancing edge of lenticular nuclei by APSF. In this paper, APSF algorithm, preliminary simulation to determine an APSF parameter, result and discussion are described in order.

2. PROPOSED APSF ALGORITHM

APSF is a specially designed filter used to perform local smoothing using a variable filter size and shape. The approach of a part of APSF refers to a report related to adaptive neighborhood contrast enhancement [6]. The APSF's main steps are as follows, and Fig.1 shows a corresponding example with the each step.
(1) An averaging filter whose mask size is $M \times M$ is applied to the original image.

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(2) A window image whose initial size is $W_{max}\times W_{max}$ is assigned from the original image. W_{max} is an odd number. Fig.1(a) is an example of window image in the case of $W_{max}=9$.
(3) A mask image is generated by assigning a binary mask value 0 if $|I(i, j)-I(i_c, j_c)|>T$, and by assigning a binary mask value 1 else if $|I(i, j)-I(i_c, j_c)|\leq T$. $I(i_c, j_c)$ is defined as the pixel value of center pixel in the window image. $I(i, j)$ is also defined as the pixel value of the other pixel in the window image. Fig.1(b) shows a mask image obtained from Fig.1(a) in the case of T=5.
(4) For each window size $W\times W$ [W=3,5,…., W_{max}], the percentage P_0 of zeros in the mask image is computed over the

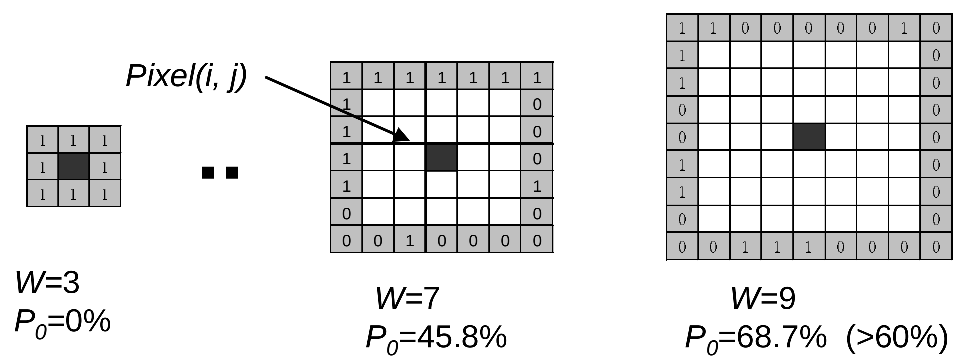
W_{max}

31	36	41	43	45	45	45	36	46
32	35	35	35	36	36	34	35	45
31	36	36	33	34	33	35	50	45
29	35	35	36	33	34	50	50	50
25	34	34	35	35	34	50	51	51
32	35	33	32	34	33	51	35	50
39	25	34	35	34	45	46	45	45
25	24	25	32	20	20	21	20	43
24	25	31	32	32	20	45	43	41

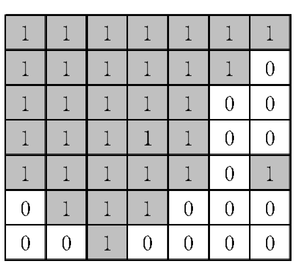
(a)

1	1	0	0	0	0	0	1	0
1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	0	0
0	1	1	1	1	1	0	0	0
0	1	1	1	1	1	0	0	0
1	1	1	1	1	1	0	1	0
1	0	1	1	1	0	0	0	0
0	0	0	1	0	0	0	0	0
0	0	1	1	1	0	0	0	0

(b)



(c)



(d)

Fig.1 Adaptive neighborhood selection with a threshold value of T=5.
(a) An example of window image (I) whose initial window size is 9×9 (W_{max}=9). The pixel value of center pixel in I is 35 [$I(i_c, j_c)$=35 (black)].
(b) Mask image generated from (a) in the case of T=5. For example, the pixel value $I(i, j)$ = 33 (gray) is assigned a binary mask value 1, because $|I(i, j)-I(i_c, j_c)|\leq T$ (i.e., |33-35|≤5).
(c) Determination of actual window size (W). The percentage of zeros (P_0) is computed over the region of external area (gray) of mask image in the case of window size W=3,5,7. The pixel (i,j) is assigned the mask image in the case of W=7, when P_0 is set at 60%.
(d) Final mask image obtained from (b) and (c). The pixel values of pixel (i, j) corresponding with mask value 1 in I are averaged.

region of external area of each window image. Actual window size is determined when the percentage P_0 is not greater than P%, and is closest to P%. Fig.1(c) shows external areas [W=3,7,9] and P_0 computed from each window image. W=7 was determined as actual window size in Fig.1(c).

(5) Finally, the pixel values $I(i, j)$ corresponding with mask value 1 in mask image are averaged, and the averaged value is used as output value at the center pixel (i_c, j_c). Fig.1(d) shows final mask image obtained from Fig.1(b) and Fig.1(c).

(6) Processes (2)~(5) are performed at each pixel as center pixel in the original image.

The APSF depends on parameters M, W_{max}, T and P. T is very important parameter in particular because it determines boundary of object (i.e. lenticular nuclei). T distinguishes object region (mask value 1) and back ground region (mask value 0). Then only pixel values in object region are used for computation of smoothing. It means that the APSF is able to reduce local noise while preserving edge components between object and background regions. Therefore T was obtained by the preliminary simulation described in next Section. Other three parameters was determined experimentally, M=5, W_{max}=13, P=60%.

3. PRELIMINARY SIMULATION

In this preliminary simulation, composite images with simulated white matter (SWM) and simulated gray matter (SGM) were used to determine an adequate T for clinical images because the lenticular nuclei are gray matter, and the around lenticular nuclei are white matter. To generate the simulated images, first, cylindrical phantom which is catphan CT phantom CTP486 made by The Phantom Laboratories, Inc. was scanned by CT device which is SOMATOM Volume Zoom made by Siemens-Asahi Medical Technologies Ltd., as the SWM. Then the SGM was put on the CT image. Concretely, 6 HU (Hounsfield Unit) as SGM is simply added to the CT image because the contrast between normal gray matter and normal white matter is approximately 6 HU actually. Fig.2 shows a generated composite image. The CT scan specifications are Tube Voltage 120kV, Tube Current 400mAs, Slice Thickness 10mm, FOV (field of view) 250mm, and matrix size 512×512. The CT scan of the phantom was performed ten times on the same condition, and then ten composite images were generated for evaluation in this preliminary simulation.
The APSF with varied T was applied to the simulation images. T was varied from 0 to T_{max} at intervals of 0.5. T_{max} is the maximum value in scope of T. The standard deviation rate and edge slope ratio were used as two criteria for measuring the performance of the APSF. The standard deviation of the pixel values in a specified area, which is used to quantify the degree of noise reduction, was obtained from a region on the SGM, as shown in Fig.3. To investigate the extent of edge blurring, edge slope ratio was calculated from an average profile of pixel values, which was measured at the right angle with respect to the edge of object (simulated lenticular nucleus as SGM), as shown in Fig.3.

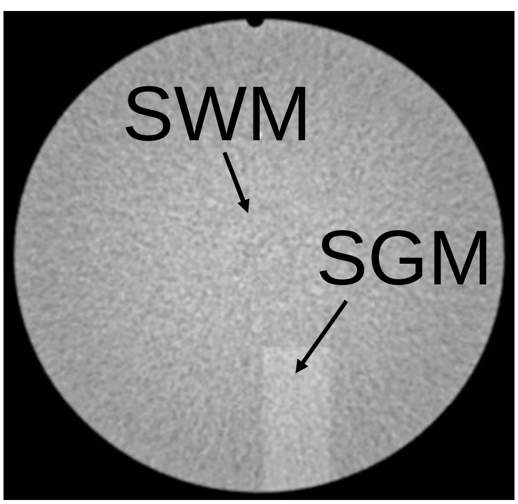


Fig.2 A composite image for simulation.

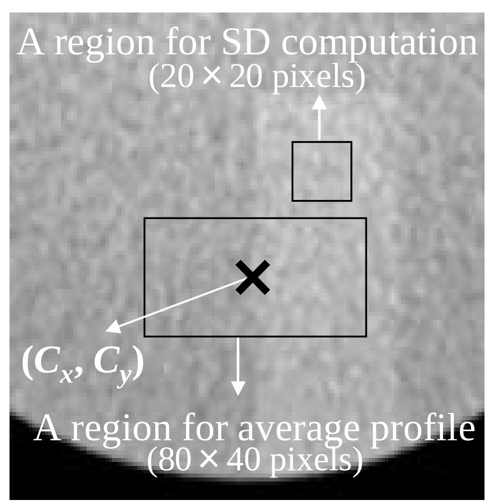


Fig.3 A part of magnified composite image with square regions for SD computation and for average profile.

The standard deviation rate (*SDR*) was computed by

$$SDR(\%) = \left(SD_{org} - SD_{prc}\right) / SD_{org} \times 100$$

where SD_{org} is standard deviation calculated from original composite images, and SD_{prc} is standard deviation calculated from APSF images. The edge slope rate (*ESR*) was computed by

$$ESR(\%) = ES_{prc} / ES_{org} \times 100$$

where ES_{org} is average edge slope value calculated from original composite images, and ES_{prc} is average edge slope value calculated from APSF images. Fig.4 shows the details of ES_{prc} and ES_{org} computations. C_x in Fig.4 corresponds to

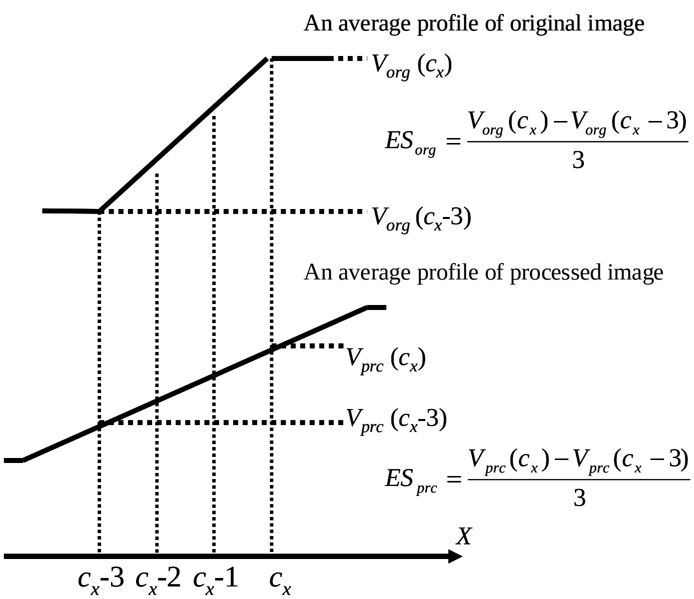


Fig.4 Definition of edge slope computation (ES_{prc} and ES_{org}).

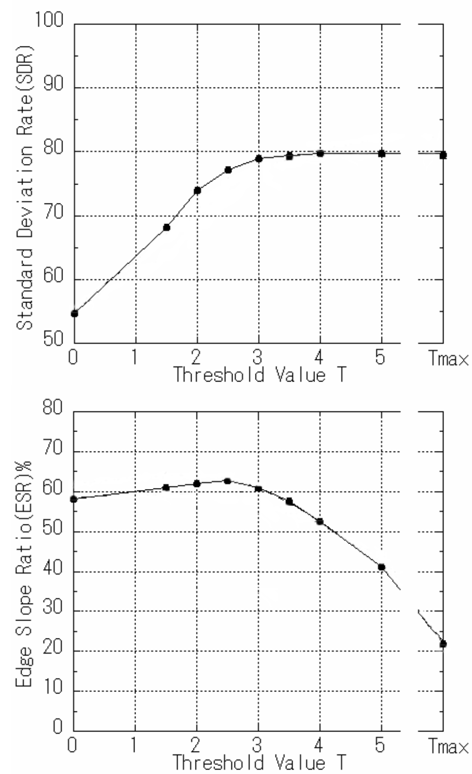
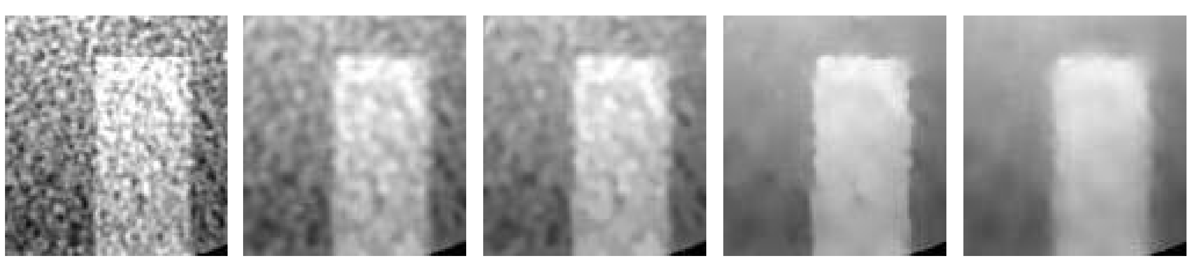


Fig.5 Graphs of *SD* and *ESR* as function of the threshold value *T*.



Original | *T*=0 | *T*=1.0 | *T*=3.0 | *T*=5.0

Fig.6 Processed APSF images obtained by varying the threshold value *T*.

C_x in Fig.3. Graphs of *SDR* and *ESR* as function of the parameter *T* were shown in Fig.5. The higher *SDR* means the noise was decreased well. The higher *ESR* means the edge blurring is scarce. Concerning simulation results as shown in Fig.5, *SDR* almost stop increasing from T>3.0, and *ESR* began to decrease sharply from T>3.0. Fig.6 shows the processed APSF images obtained by varying the threshold value *T* [*T*=0, 1.0, 2.0, 3.0, 5.0]. The APSF image at *T*=3.0 looks very well with regard to edge sharpness and noise reduction. The APSF image at *T*=1.0 is insufficient on the degree of noise reduction, and the APSF image at *T*=5.0 is too blurry. Considering these data, *T*=3.0 might be an adequate threshold value. Therefore, *T*=3.0 was determined as an adequate parameter for applying to clinical CT images.

4. RESULT

The APSF at *T*=3.0 is applied to four non-enhanced CT images scanned for the acute ischemic stroke. The images were scanned by ProSeed Accell made by GE Yokogawa Medical System, whose specifications are Tube Voltage 120kV, Tube Current 400mAs, Slice Thickness 10mm, FOV (field of view) 250mm, and matrix size 512×512. Fig.7 shows original images, APSF images, and progressed images obtained several days after the onset of symptoms. The detail of each case is described as follows.

[Case 1] Fig.7(a),(b),(c) are CT images for this case. The original image [Fig.7(a)] was scanned 1¾ hours after the acute ischemic stroke caused by the acute left-middle cerebral artery infraction. Partial disappearance of left lenticular nucleus was hard to detect from the original image. However, the subtle infarct sign was easy to detect from APSF image [Fig.7(b)]. From progressed image obtained 7 days after the onset of symptoms [Fig.7(c)], it was clear that CT values around left-middle cerebral artery became lower by cause for infarct.

[Case 2] Fig.7(d),(e),(f) are CT images for this case. The original image [Fig.7(d)] was scanned 1½ hours after the acute ischemic stroke caused by the acute left-middle cerebral artery infraction. It was too hard to detect obscuration of left lenticular nucleus from the original image. Actually, this case was considered to be normal at first diagnosis with CT image (original image). Fortunately, infarct sign was detected by MRI scan performed immediately after the CT scan. On even such hard case, APSF image [Fig.7(e)] clearly detected the subtle infarct sign. From progressed image obtained 7 days after the onset of symptoms [Fig.7(f)], it was clear that CT values around left lenticular nucleus became lower, and this case was hemorrhagic infarct.

[Case 3] Fig.7(g),(h),(i) are CT images for this case. The original image [Fig.7(g)] was scanned 1 hours after the acute ischemic stroke caused by the acute left-middle cerebral artery infraction. It was too hard to detect obscuration of left lenticular nucleus from the original image. However, it was easy to detect the subtle infarct sign from APSF image [Fig.7(h)]. From progressed image obtained 7 days after the onset of symptoms [Fig.7(i)], it was certified that the APSF image precisely indicated early sign of acute cerebral infarct.

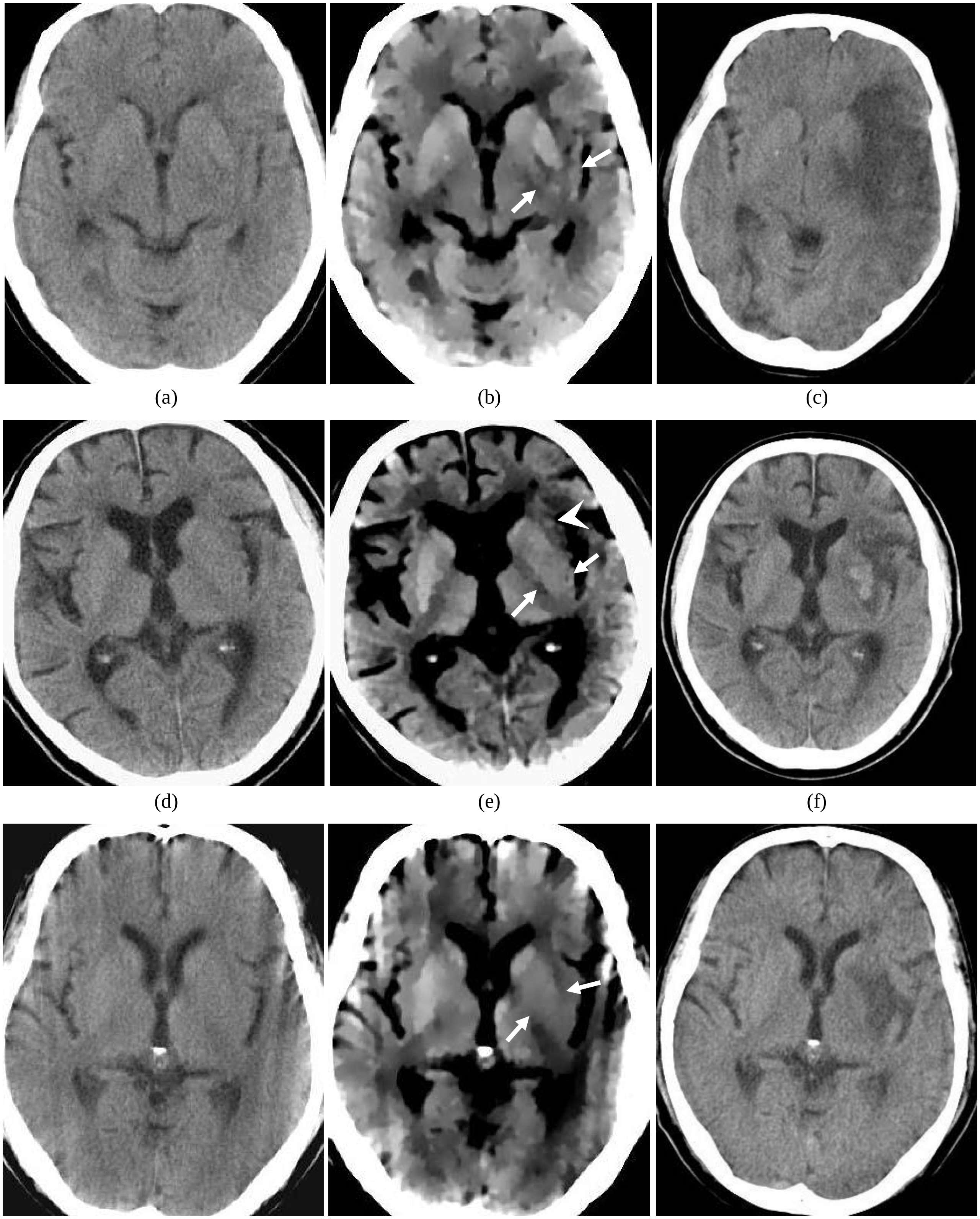
[Case 4] Fig.7(j),(k),(l) are CT images for this case. The original image [Fig.7(j)] was scanned 1½ hours after the acute ischemic stroke caused by the acute left-middle cerebral artery infraction. It was too hard to detect partial disappearance of left lenticular nucleus from the original image. However, it was easy to detect the subtle infarct sign from APSF image [Fig.7(k)]. From progressed image obtained 4 days after the onset of symptoms [Fig.7(l)], falling-off of CT values in left brain as the infarct evidence was clearly.

According to these evaluation results, it was obvious that proposed APSF let detectibility of early infarct signs improve remarkably.

5. DISCUSSION

APSF was compared with basic noise-reduction filters, which are simple averaging filter and median filter. For the comparison, averaging filter and median filter were applied to composite images for preliminary simulation in Section 2, and then *SDR* and *ESR* were also calculated with varying filter size from 5×5 to 17×17. Fig.8 shows the graphs of *SDR* and *ESR* as function of filter size, and two images processed against original image in Fig.6. Generally, as filter size for averaging filter and median filter become larger, edges become blurrier, namely, *SDR* increases, and *ESR* decreases. *ESR*s were compared at the almost same *SDR* between Fig.5 and Fig.8 as follows:

APSF (*T*=3.0)	: *SDR* =78.2,	*ESR*=60.7
Averaging filter 15×15	: *SDR* =78.8,	*ESR*=19.2
Median filter 17×17	: *SDR* =77.5,	*ESR*=25.1.

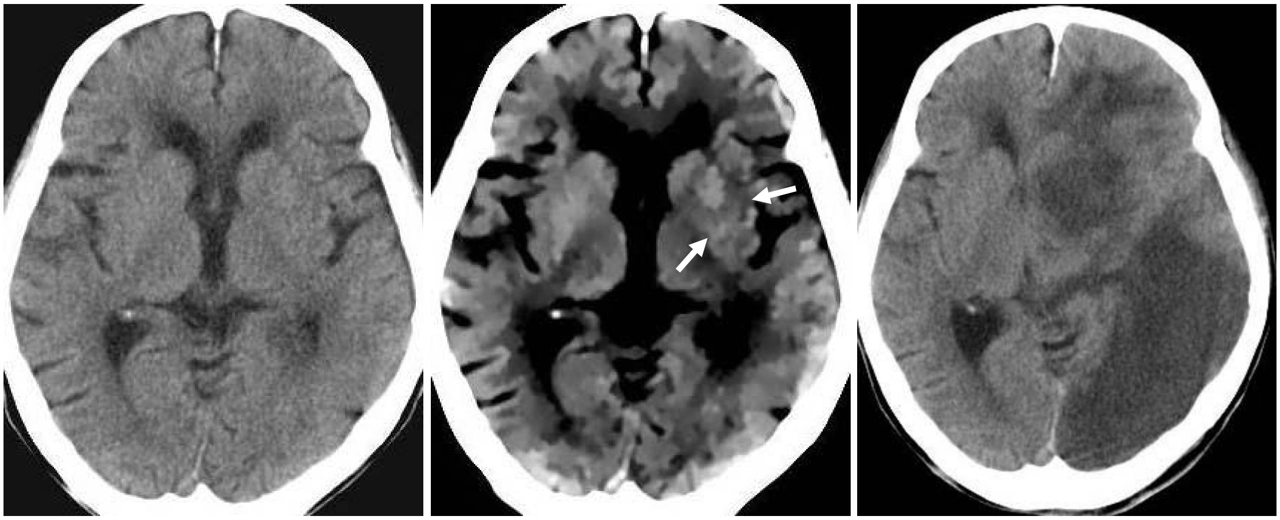


(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

*) to be continued



(j) (k) (l)

Fig. 7 Non-enhanced CT images of four cases of acute ischemic stroke.

(a) Case1: original image obtained at 1¾ hours after stroke onset.

(b) Processed image after applying APSF (T=3.0) to (a).
Arrows indicate partial disappearance of the lentiform nucleus.

(c) Non-enhanced CT image obtained 7 days after the onset of symptoms in Case 1.

(d) Case2: original image obtained at 1½ hours after stroke onset.

(e) Processed image after applying APSF (T=3.0) to (d).
Arrows indicate obscuration of the lentiform nucleus. Arrowhead indicates loss of the insular ribbon.

(f) Non-enhanced CT image obtained 7 days after the onset of symptoms in Case 2.

(g) Case3: original image obtained at 1 hours after stroke onset.

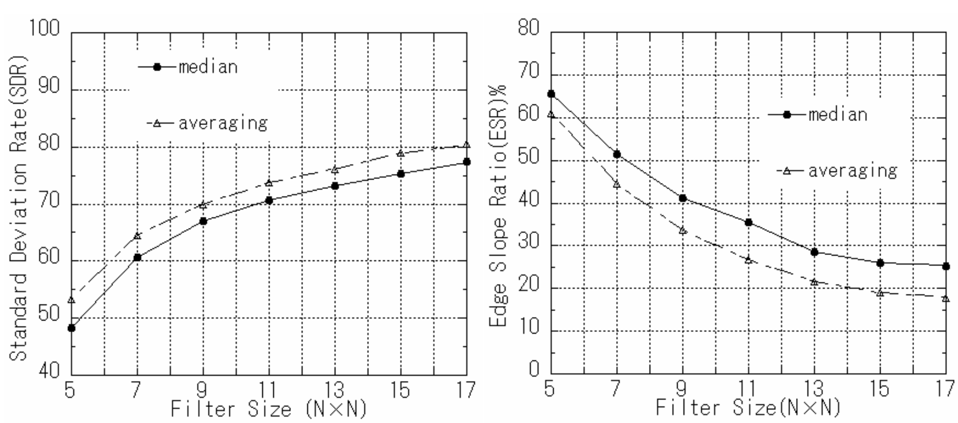
(h) Processed image after applying APSF (T=3.0) to (g).
Arrows indicate obscuration of the lentiform nucleus.

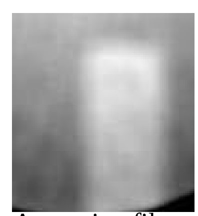
(i) Non-enhanced CT image obtained 7 days after the onset of symptoms in Case 3.

(j) Case4: original image obtained at 1¾ hours after stroke onset.

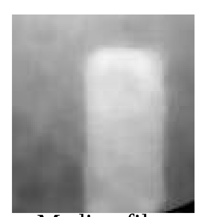
(k) Processed image after applying APSF (T=3.0) to (j).
Arrows indicate partial disappearance of the lentiform nucleus.

(l) Non-enhanced CT image obtained 4 days after the onset of symptoms in Case 4.





Averaging filter
15×15



Median filter
17×17

Fig.8 Graphs of *SDR* and *ESR* as function of filter size for averaging filter and median filter, and two images processed against original image in Fig.6.

ESR of APSF was largest in three filters. It means that APSF can reduce noise component while best preserving edge component. Compared between APSF image (*T*=3.0) in Fig.6 and processed images in Fig.8, it was found that images in Fig.8 were blurrier than the APSF image in Fig.6. These comparison results also indicate the validity of APSF.

6. CONCLUSION

In order to improve the detectability of early signs for acute ischemic stroke on CT images, a novel adaptive partial smoothing filter (APSF) was proposed. Preliminary simulation using composite images simulated gray-white matters was performed to determine a major parameter of APSF for application to clinical images. The APSF was applied to four clinical CT images obtained within two hours after stroke onset. In consequence, the detectability of early infarct sign, namely obscuration of lenticular nucleus, was remarkably improved. Moreover, comparison between APSF and conventional basic noise-reduction filters, which are averaging filter and median filter, was made and the validity of APSF was reconfirmed.

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