Original Article

A promising method of enhancement for early detection of ischemic stroke

Mehdi Sajjadi, Mehdi Karami[1], Rassoul Amirfattahi, Vahid Bateni[1], Mohammad R. Ahamadzadeh, Bahareh Ebrahimi[2]
Department of Electrical and Computer Engineering, Digital Signal Processing Research Lab Isfahan University of Technology, Isfahan, [1]Department of Radiology, [2]Skin Diseases and Leishmaniasis Research Center, Isfahan University of Medical Sciences, Isfahan, Iran

Background: Computed Tomography (CT) scan without contrast is the modality of choice for diagnosis of stroke. However, routine brain CT scan, with linear processing has some limitations in early diagnosis of ischemic stroke. The aim of this study was to evaluate and compare the sensitivity and specificity of processed CT images with conventional ones in early diagnosis of cerebrovascular attack (CVA). **Patients and Methods:** This was a self-controlled study conducted in a university referal hospital from 2010 to 2011. Seventy CT scans underwent a process using Laplacian Pyramid transform. Thirty five of participants were diagnosed with CVA while others had only headache and no ischemic stroke diagnosis based on the first and follow-up CT scans. A neuroradiologist made diagnosis with and without the help of processed CT scans. The McNemar and Wilcoxon analysis were used to compare the sensitivity, specificity, positive and negative predictive values of two methods. **Results:** The sensitivity (% 65.7 vs. %31.4, *P* value = 0.001), positive predictive value (% 85.2 vs. % 61, *P* value = 0.03) and negative predictive value (% 73.9% vs. %49, *P* value = 0.01) of the processed method were significantly higher than the routine one, while no difference was seen in specificity (% 88.6 vs. %77.1, *P* value = 0.15). Moreover, the accuracy of the processed method was significantly better than the linear one (*P* value < 0.001). **Conclusions:** It was concluded that nonlinear modified Laplacian Pyramid method can composed CT scans which can be more helpful in early detection of ischemic stroke.

Keywords: CT scan, early diagnosis, ischemic stroke, laplacian pyramid

INTRODUCTION

Stroke is the third cause of death in the USA and is one of the major causes of long-term disability. Ischemic stroke includes 75 percent of the stroke cases while the remaining is hemorrhagic type.[1,2]

Computed tomography (CT) is the method of choice in evaluation of suspected stroke patients.[3] Compared with magnetic resonance imaging (MRI), CT scan is more available, more affordable, and does not have contraindications.[4] Moreover, in severely ill patients, CT scan is performed with fewer limitations.[4] By the means of CT images, other diseases which cause symptoms similar to those occur in stroke will be excluded rapidly and the appropriate therapeutic approach would be selected. Also, hemorrhagic strokes can be easily diagnosed by CT scan.[5] However, with routine CT images constructed by linear processing, early diagnosis of the ischemic stroke faces some shortcomings.[6] For instance, Patel *et al*.[6] demonstrated that the sensitivity of CT scan in detection of early infarct signs within the first hours of stroke is 31%.

Today, to use thrombolytic agents in treatment of acute ischemic strokes, the earliest possible detection of the hypodense region in brain parenchyma is of great value.[7,8] On the other hand, reperfusion, particularly in patients with extensive stroke, is always accompanied with the risk of hemorrhage and death. Therefore, it is not possible to administer thrombolytic agents exclusively on the basis of clinical findings without imaging evidence in patients suspected of cerebrovascular accident (CVA).[9] Therefore, it is necessary to develop a method which can detect the early signs of ischemia in brain CT scan to initiate the appropriate treatment at the earliest time.

The early signs of brain infarction in CT scan, such as obscured lentiform nucleus, loss of sulcal delineation, loss of insular ribbon, and hyperdense middle cerebral artery (MCA), are very mild or not possible to be observed.[10] In this regard, previous studies have shown that the ability of neurologists, neuroradiologists, and general physicians is limited in detection of early signs of brain infarction

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Address for correspondence: Dr. Vahid Bateni, MD, Department of Radiology, Isfahan University of Medical Sciences, Isfahan, Iran.
E-mail: vahid_bateni@yahoo.com
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in CT scan.[11] Following reduced cerebral blood flow, the water content of the brain tissue undergoes some changes. Different studies have shown that increase in water content of brain parenchyma occurs four hours after the onset of MCA occlusion. This will be represented by hypodensity in CT images, as the most common sign of early ischemia.[5,12-14]

In routine brain CT images, the window width (WW) of 70-80 HU and window level of 35-40 HU is used but the human eye can differentiates about only 20 grey shades. Therefore, the resolution is roughly limited to 4 HU in these images. However, within the first four hours of ischemic stroke onset, just one to two changes in grey shade will occur which these change are not observable in a WW of 80 HU. Although a narrower WW would enhance the contrast resolution, simultaneously it decreases the signal-to-noise ratio.[14]

There are lots of methods for enhancement of region of interest in images. Classical approaches like unsharp masking and histogram equalization were being extensively used in contrast enhancement of different types of medical images. However, today, with advent of more powerful computers, more advanced and sophisticated algorithms of contrast enhancements have been emerged. Multiscale transforms have been widely used in many medical image processing applications.[15-18]

In the present study, in order to enhance the differentiation of infarcted hypodense area from its adjacent normal parenchyma within the early hours of stroke onset, the brain CT image using Laplacian Pyramid which is one the most popular multiscale transforms was composed.[15,16] The aim of the present study was to compare the routine brain images with processed ones in early detection of ischemic stroke.

PATIENTS AND METHODS

Image processing

Our general approach is to decompose the brain CT image using Laplacian Pyramid which is one of the most popular multiscale transforms. Therefore, we are able to extract desired features out of brain CT images. In this study, preferred features are stroke sensitive parts of the brain. Then, these parts can be enhanced by proper modification of decomposition coefficients.

Laplacian Pyramid is one of the most commonly used multiscale transforms which is introduced by Burt and Adelson as an effective method for image compression.[19] This structure is shown in Figure 1. Also, Laplacian Pyramid can be used for enhancement of medical images. The Laplacian Pyramid extracts the edge information of the original image in different scales. In the other words, contrast enhancement using Laplacian Pyramid can be considered an edge enhancement technique. An effective contrast enhancement method should enhance areas of lower contrast more than areas of higher contrast, which

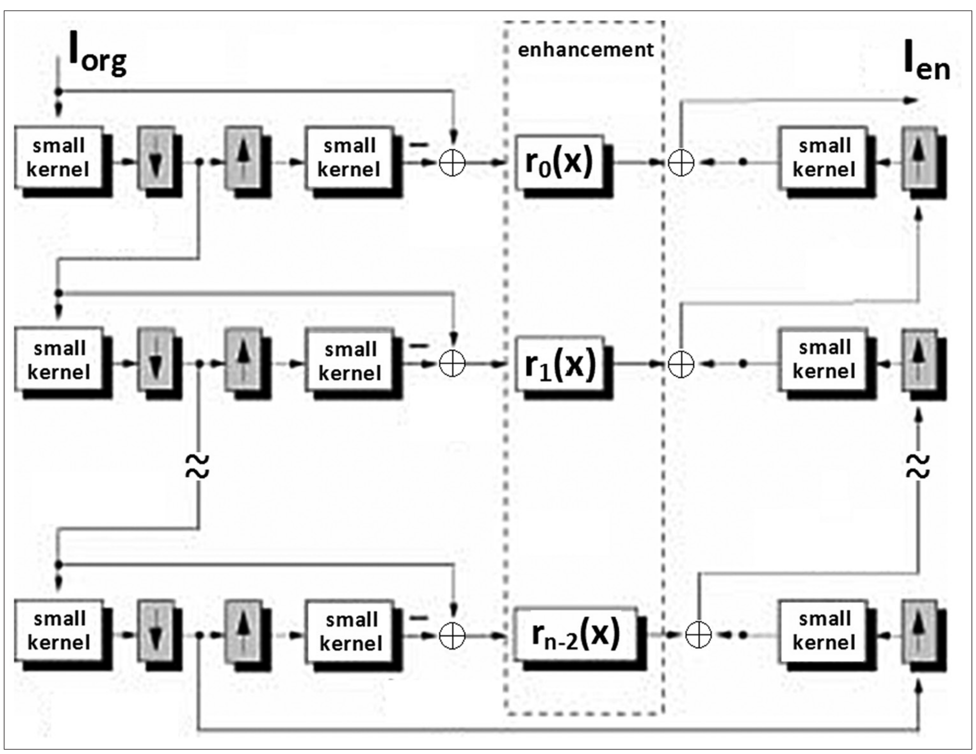

Figure 1: Image enhancement using Laplacian Pyramid[19]

means that weaker edges must be enhanced more than stronger edges. To this end, pixel values of bandpass images (images produced in every level of decomposition and contain edge information in different scales) will be modified using a mapping function, which is usually a nonlinear function. This function is shown by $r_1(x)$ in Figure 1. Two exemplar nonlinear enhancement functions are proposed in the work of Li *et al*.[20] and also Xue *et al*.[21] Modified bandpass images will be used to reconstruct the enhanced image.

In this paper, we skip the details of image decomposition and reconstruction using Laplacian Pyramid and also details about selection of other parameters used in contrast enhancement of brain CT images. We just briefly note that the Burt filter with $\alpha = 0.4$ is used in Laplacian Pyramid structure and a simple nonlinear enhancement function proposed in the study of Laine *et al*.[22] used for modification of bandpass images:

$$E(x) = \begin{cases} x - (k-1)T, & \text{if } x < -T \\ kx, & \text{if } |x| < T \\ x + (k-1)T, & \text{if } x > T \end{cases}$$

This function is shown in Figure 2. In this function, T is the threshold parameter and K is the gain parameter. Pixel values smaller than T are considered to belong to weak edges while pixel values greater than T are considered to belong to strong edges. Pixel values belonging to weak edges will be amplified with gain K.

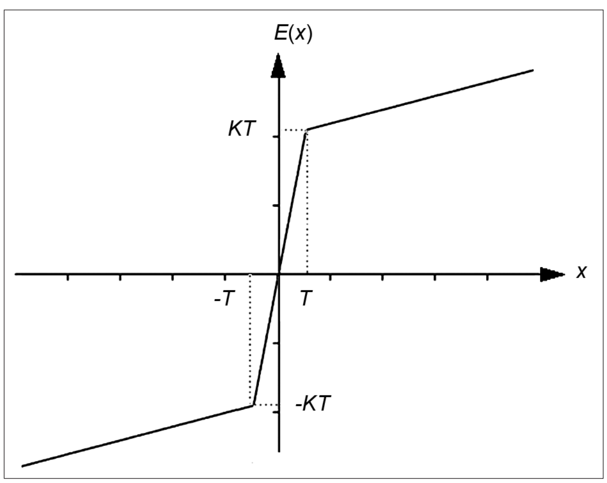

Figure 2: Nonlinear enhancement function

It should be noted that the edge information extracted in different scales is not equally important. It can be shown by an example. Consider the pathologic brain CT image shown in Figure 3a. This image was decomposed using Laplacian Pyramid in 5 levels. For illustration purposes, every time we only amplified pixel values of the bandpass image obtained in one specific level of decomposition. Enhancement parameters are selected as $T = 0.05$ and $K = 20$. Figure 3 shows five enhanced versions of original CT image. Each of these images is obtained by enhancement of just one specific scale and the scale number increases from left image to right image. It is observed that as the scale number increases, the size of enhanced details will also increase.

It can be observed that enhanced details of first and second images are mostly noise. Revealed details in enhanced image of third scale is also too small to be useful. Our main attention is on the enhanced image of fourth scale since details at the size of cortical gray matter are obviously more visible in this image. In fact, not only the gray matter/white matter differentiation is more noticeable in this image, but also the stroke lesion is more prominent. We experimentally found that the enhanced image of fourth scale can also put emphasis on the other stroke-sensitive parts of the brain. These parts include insular ribbon, basal ganglia and especially lentiform nucleus. Enhanced details of fifth scale are too big to be useful. Therefore, we only apply the nonlinear enhancement function to pixel values of the bandpass image obtained in the fourth level of decomposition. The enhancement parameters are selected as: $T = 0.05$ and $K = 15$. Three brain CT images and their enhanced counterparts are shown in Figure 4. Gray matter/white matter delineation and stroke lesion are obviously more noticeable in the enhanced images.

Based on our experimental results, we found that this proposed method is best suited for stroke lesions of smaller sizes. Stroke lesions which are nearly dominant in one or both of hemispheres cannot be properly enhanced using this method. This is because that the size of enhanced details depends on the number of decomposition levels and if

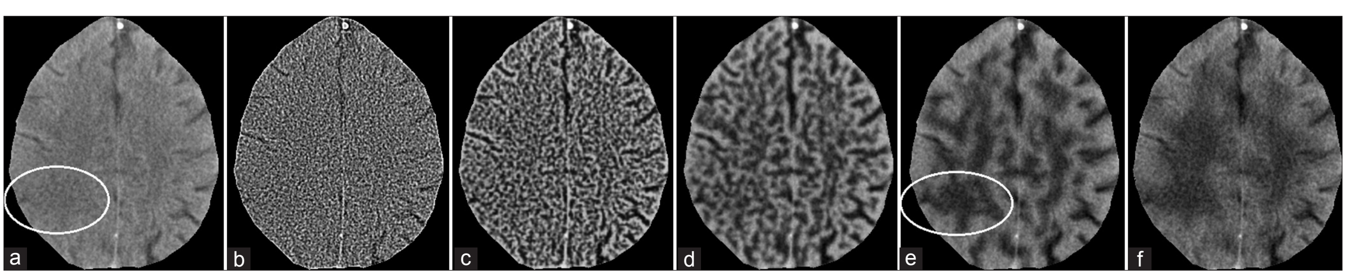

Figure 3: Enhancement of only one specific scale. (**a**) Original CT image. (**b**) through (**d**): Enhancement of error images of scales 1 through 5

the levels of decomposition extensively increase, general appearance of the image would be adversely affected. For comparison, we enhanced brain CT images using a slightly modified version of histogram equalization. The results showed that histogram equalization performs better in enhancement of large stroke lesions. However, it must be noted that most of ischemic strokes are not massive and generally affect only a specific part of the brain.

Study design

This was a self-controlled study. The target population was selected from patients refering to Al-Zahra university hospital, Isfahan, Iran from October 2010 to June 2011 (registration number = 389148). The permision for using the CT images was obtained form each patients. In all steps of the study, one expert neuroradiologists, which evaluate the images to find the ischemic region, was blind.

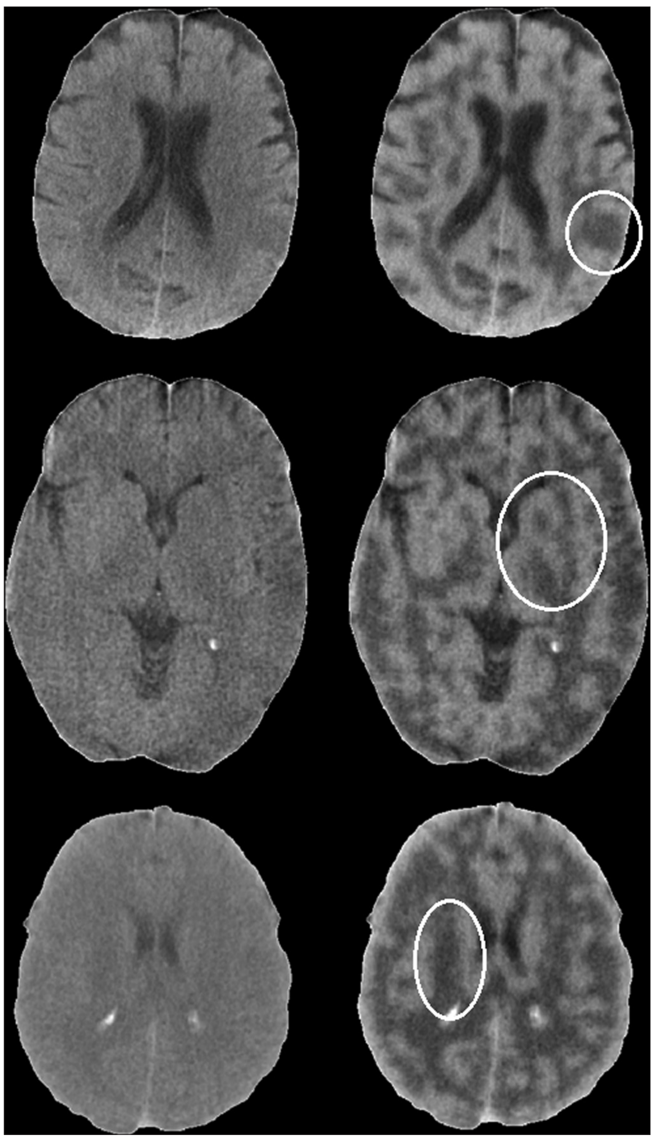

Figure 4: Three pathologic brain CT images enhanced using proposed method. Left: Original image. Right: Enhanced image

The population size for this study was calculated as 70. Thirthy five of the participants were selected among patients with diagnosis of supratentorial infarction who were admited to neurology department of the hospital and had a brain CT scan in first hours of admission and a follow-up CT scan after 24-48 h of symptom onset which showed the infarct region clearly. Moreover, the remaining participants were selected among ones who refer to hospital with the chief complaint of headache and the first and follow-up CT scans did not show any pathological sign. Such patients were discharged from the hospital after signs and symptoms were resolved.

The patients with history of head trauma, previous brain surgery, brain radiotherapy, or any space occupying lesion in their CT scan were not included in the study. It is noteworthy to mention that all the CT scans were produced with a same spiral CT scan machine (Spiral *Shimadzu 7800, JAPAN, 2004*) and were displayed in brain window settings.

These CT scans were displayed for one expert neuroradiologist to detect any infarction pathology and its region. Then, all the CT scans were undergone the mentioned process and the processed images along with non-processed ones (source images) were displayed again for the neuroradiologist to rediagnosis of them [Figure 5]. The McNemar analysis was used to compare the sensibility and specificity of processed and non-processed CT scans in early diagnosis of CVA.

Then, for the patients with CVA the follow-up CT scans along with two other images were displayed again for the expert neuroradiologist [Figure 6]. The follow-up CTs showed the infarction clearly and the neuroradiologist was asked if the processed images facilitate the early diagnosis of CVA and to grade it from 0 to 3. In this case, the help of processed image in early diagnosis of CVA was graded along four scales: 0 = misdiagnosis, 1 = no

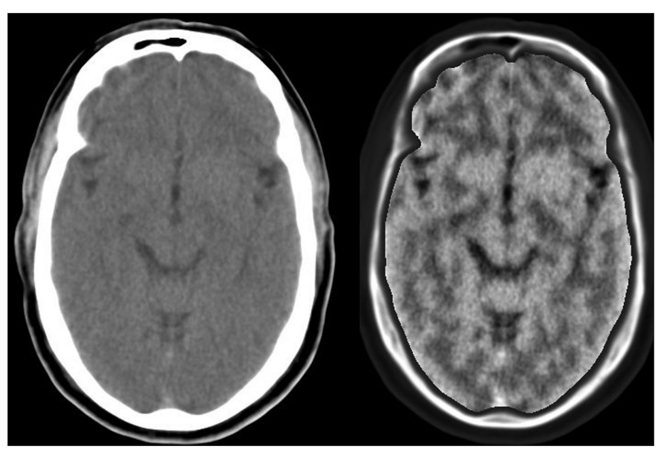

Figure 5: The source (left) and processed (right) CT images of first hours of stroke onset

facilitation, 2 = little facilitation, 3 = great facilitation. Wilcoxon analysis was used to evaluate the specificity of the process on images in early diagnosis of CVA.

RESULTS

Table 1 shows the sensitivity, specificity, positive predictive value, and negative predictive value for the source and processed CT scans.

The results showed that the sensitivity of the processed images in early diagnosis of CVA was significantly more than the routine CT scans (% 65.7 vs. % 31.4, *P* value = 0.001) while there was no significance difference between two methods in the specificity (% 88.6 vs. % 77.1, *P* value = 0.15). In addition, both the positive and negative predictive value were significantly more in new method than the routine one (% 85.2 vs. % 61, *P* value = 0.03) (% 73.9 vs. % 49, *P* value = 0.01).

The neuroradiologist assessed the facilitation of diagnosis by processed images as following: in six patient's great facilitation, in 19 ones little facilitation, and in nine of them no facilitation. No misdiagnosis was mentioned. Therefore, the Wilcoxon analysis showed that the accuracy of this new method was significantly better than the linear one (*P* value < 0.001).

DISCUSSION

The aim of this study was to compare the modified Laplacian Pyramid with conventional method of composing CT images in early diagnosis of ischemic stroke. The result showed that the sensitivity, positive and negative predictive values of the modified Laplacian Pyramid were significantly higher than the routine one while no difference was seen for the specificity. In addition the accuracy of the new method was significantly better that the old one.

Table 1: The sensitivity, specificity, positive, and negative predictive value for two types of CT scans

	Source CT scan	Processed CT scan	*P*-value
Sensitivity	% 31.4 (% 15.3, % 47.6)	% 65.7 (% 49.7, % 81.7)	0.001
Specificity	% 77.1 (% 62.5, % 91.8)	% 88.6 (% 77.5, % 99.7)	0.15
Positive predictive value	% 61 (% 43.9, % 78.1)	% 85.2 (% 73.1, % 97.4)	0.03
Negative predictive value	% 49 (% 31.1, % 66.1)	% 73.9 (% 58.8, % 89.2)	0.01

The early detection of ischemic stroke is crucial to start thrombolytic therapy as soon as possible and decrease the mortality and morbidity of CVA. Since early signs of ischemic stroke are very hard to notice in brain CT images, a suitable contrast enhancement technique should be used to make subtle details more visible to human eyes. There are lots of methods for contrast enhancement of images.[16,23]

In recent years, attempts to find a promising method of modifying CT images have been arise to facilitate the diagnosis. Therefore, some studies focused on finding a method of enhancement and improving the visibility of ischemic stroke signs in CT scans. Some of them included 2D dyadic wavelet transform, heuristic algorithm, adaptive partial median filter (APMF), and Laplacian Pyramid transform.[3,24-26]

In one study, Dippel *et al*.[15] compared two methods of CT images enhancement, the Laplacian Pyramid and the fast wavelet transform (FWT). Finally, it was concluded that Laplacian Pyramid method had superiority toward FWT because it can avoid the visible artifacts by a smooth enhancement of large structures while FWT suffer from the lack of such characteristics. Therefore, the Laplacian Pyramid method can produce a very balanced image impression. Another advantage of Laplacian Pyramid is producing only one bandpass image in every step of decomposition.[19] Therefore, we are not concerned about directional bandpass images and orientation distortions.

Although, Laplacian Pyramid is being extensively used for medical image enhancement, we did not find any relative work in the literature applying this method to brain images. Another advantage of this study is that the enhancement

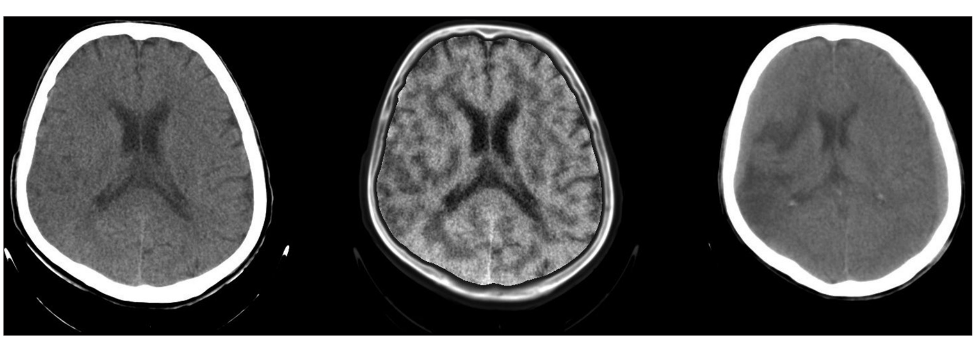

Figure 6: The source (left) and processed (middle) CT images of first hours of stroke onset and the follow up (right) CT images

parameters were selected adaptively for different bandpass images. In fact, the enhancement method was customized for brain CT images and early detection of ischemic stroke. This is the uniqueness of this research. Other multiscale-based contrast enhancement methods (at least the ones focusing on brain CT images and ischemic stroke) treat the decomposition coefficients of different scales almost equally. The same linear/nonlinear mapping function with the same parameters is applied to decomposition coefficients of every scale.

This customization was necessary since most of existing multiscale-based contrast enhancement methods focused on chest radiographies and mammograms.[15,27] In these images, small and fine details are very important. These small details will be extracted in the first and second scale of decomposition and information extracted higher scales are less important. However, we showed that in case of brain CT images, the information extracted in first and second scales mostly contribute to noise and should not be enhanced. On the other hand, the information extracted in higher scales is very important in early detection of ischemic stroke.

In the present study, not only more population size were enrolled, but also conducted as a self-controlled study makes the result of this trial much more valuable. We conclude that our nonlinear modified Laplacian Pyramid method can composed CT scans, which can be more helpful in early detection of ischemic stroke.

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