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Development of Digital Subtraction Angiography for Coronary Artery

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The purpose of this research is to develop a new method of digital subtraction angiography (DSA) that can be applied to real time with reducing motion artifacts caused by heart movement and respiration. To create the mask image for DSA, the maximum pixel value at each pixel (which is the opposite pixel value to that of a vessel filled by contrast medium) was selected from the previous 14 image frames. The search area for the maximum pixel value was selected using the value of the standard deviation (SD) for each pixel from the previous 14 image frames. When the SD value in the 14 frames was greater than a threshold level, the search area of the maximum value became 1 pixel×1 pixel×14 frames; otherwise, 7 pixels×7 pixels×7 frames. The image quality of new DSA was evaluated on 20 coronary arteriogram images, including various degrees of occlusion or stenosis. The results indicated a considerable improvement in DSA image quality; thus, the coronary arteries, carotid artery, and vein were clearly enhanced.

KEY WORDS: Digital subtraction angiography (DSA), motion artifact, misregistration, coronary angiography

BACKGROUND

Digital subtraction angiography (DSA) is one of the most important examinations in the diagnosis and treatment of blood vessels. The radiation dose can be reduced using this examination because the vessels are visualized clearly; however, it is very difficult to apply the DSA technique to the coronary arteries because of the severe motion artifacts caused by cardiac motion and respiration. For the treatment of coronary stenosis, it is important to locate the position of the stenosis and evaluate the effect of interventional radiology (IVR) in real time.

Several methods have been proposed to reduce motion artifacts in DSA based on post-image-processing techniques: an image registration technique that uses a distorted vector in a partial domain,[1–4] a technique that calculates the amount of rotation movement and the amount of parallel translation on spatial frequency as position, much of which was performed on a rigid body model,[5,6] and a technique that calculates the amount of movement sequentially in real space.[7] The coronary artery sampling process uses a morphological operation.[8]

Both intravenous DSA and intra-arterial DSA have been studied from the viewpoints of assessing bypass graft visualization,[9] effect of percutaneous transluminal coronary angioplasty,[10,11] cardiac phase,[12] blood flow measurement,[13] and the degree

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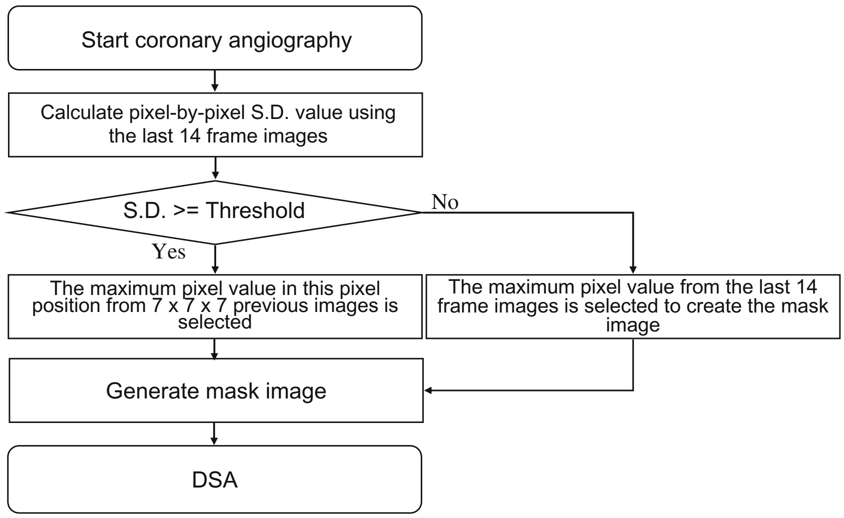


Fig 1. Overall scheme for new DSA technique.

of valvular regurgitation.[14] In contrast, Myerowitz et al. reported that the coronary arteries are difficult to visualize using intravenous DSA because of their small size, rapid movement, and overlying structures.[15] Therefore, many techniques have been studied to improve DSA image quality.[16–21] Bentoutou et al. used a template-matching technique and 3D space motion detection for improving the accuracy of registration.[22,23] A warping technique for the mask frame was used in a report by Meijering et al., with the aim of reducing motion artifacts.[24] These techniques require a relatively long computation time. Therefore, it would be difficult to apply these techniques clinically because most of them do not enable real-time image processing.

Given the above, we have developed a DSA technique that can be applied to real time, that uses a mask image that exploits short-duration density variations, and that can obtain high-quality DSA images without severe motion artifacts.

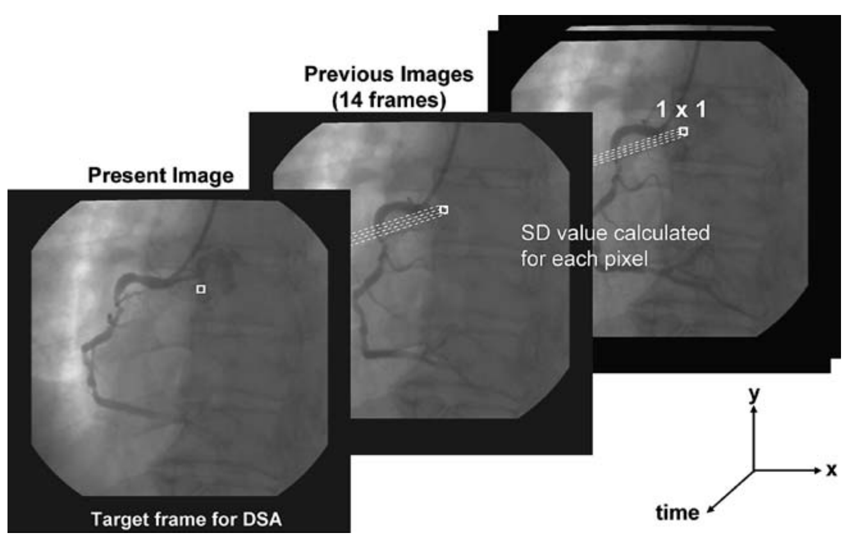


Fig 2. Method for determining whether the pixel is included in the vessel image or not.

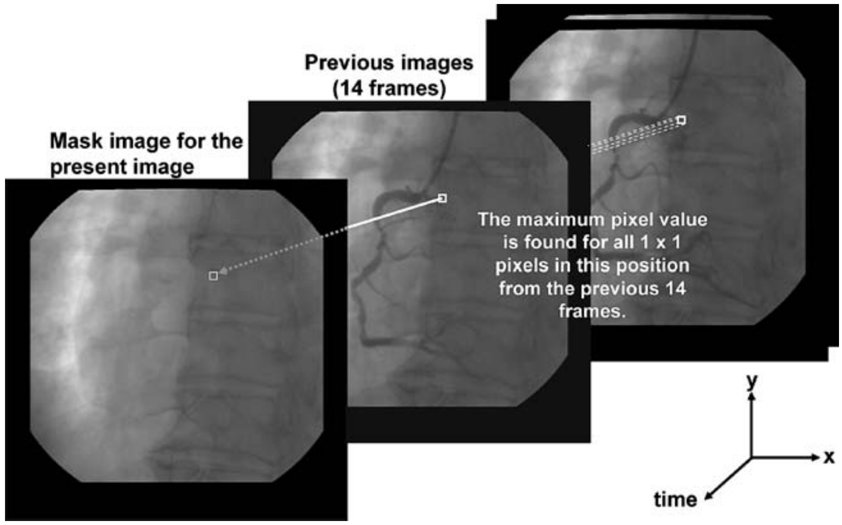


Fig 3. Selection scheme of the pixel values for mask image (1).

MATERIALS AND METHODS

An image database consisting of 20 cases of intra-arterial coronary angiograms was used in this analysis. We got licensing for clinical images in the Ethical Review Board of Hiroshima City hospital.

Each angiogram was acquired at Hiroshima City Hospital using a digital angiography system (Philips Medical Systems, Best, The Netherlands) with a matrix size of 512×512, gray level of 8 bits per pixel, and 30 frames/s. In all cases, a high pixel value represented a high-intensity (bright) area, and a low pixel value corresponded to low intensity.

In this study, “conventional DSA” was performed as follows. First, we decide an image that was not enhanced by contrast medium as a mask image. The DSA system used in this study selects the third frame as mask image. Second, we subtracted the mask image from contrast-enhanced

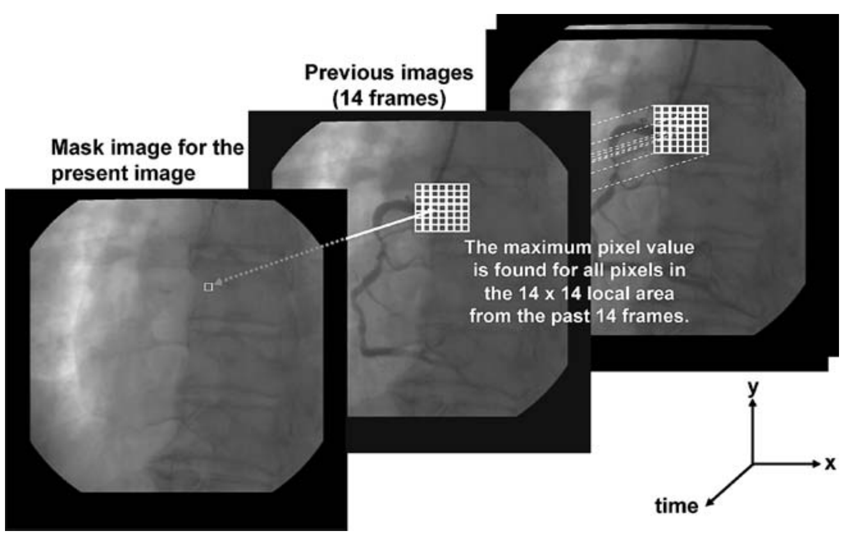


Fig 4. Selection scheme of the pixel values for mask image (2).

images. Then DSA images were obtained and were viewed in display.

Figure 1 shows the overall scheme of our proposed method. The dynamic range compression technique[25] based on the highest and average pixel values was applied as preprocessing to improve the resultant DSA image visibility. To generate the mask images, we employed a maximum pixel value selection technique within $1\times1\times14$ previous frames, as shown in Figure 2. The number of previous frames was decided as results of preliminary experiments. For cases where the pixel was in a relatively large vessel and vessel motion was slow, we used the highest pixel value in the previous frames that approximated the pixel value of the vessel. As a result, the vessel image appeared in the mask image and partially disappeared on the DSA image. To avoid this phenomenon, in such cases, we selected a wide search area in selecting the maximum pixel value. Because the representative diameter of the large vessels used in this study was 14 pixels, we applied $7\times7\times7$ frames to a wide search area (Fig. 3). We used the standard deviation (SD) of $1\times1\times14$ pixels from the previous frames and chose the search areas according to the following criteria: If the SD was less than 1.0, the search area was $1\times1\times14$ frames; if the SD was greater than or equal to 1.0, the search area was $7\times7\times7$ frames (Fig. 4). Each pixel value in the mask image was generated using one of these two search areas; consequently, our method generates a mask image that excludes vessels. The search area size and number of frame described above were decided according to results of preliminary studies. Finally, DSA images were generated by subtracting the mask images from the live images; the resultant images were then stored as raw data.

We developed a computer software to perform our DSA method in "C" language, and it was compiled by using "Inter C++ Compiler ver.9.0."

Subjective Study

Three radiological technologists with 9, 10, and 10 years of clinical experience independently classified the images into five categories using a subjective rating scale that ranged from +2 to −2, as listed below.[26] The image quality of our new method compared to conventional DSA method was rated as:

+2	greatly improved
+1	slightly improved
0	unchanged
−1	slightly deteriorated
−2	greatly deteriorated

Objective Study

A second evaluation was performed to objectively assess the degree of motion artifacts. Three ROIs that included vessels were manually located

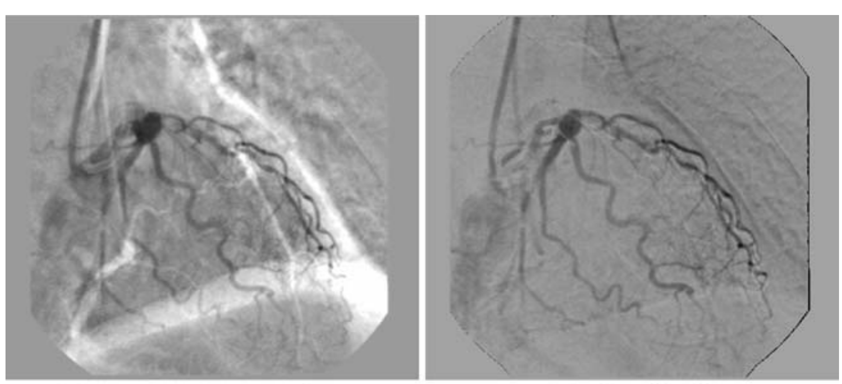


Fig 5. DSA image obtained by conventional DSA and our DSA (LAD and LCX). The movement of the diaphragm, ribs, and heart beats are large. This movement generates the live image largely changed from the mask image. Then, the influence of the motion artifacts became large.

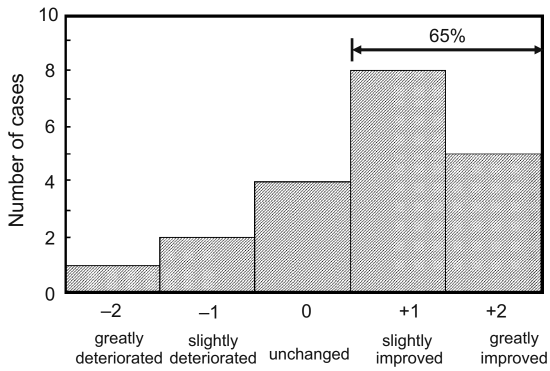


Fig 6. Result of subjective evaluation of motion artifacts in the our DSA images.

for one series in conventional DSA and in DSA images obtained using the new technique. The ROI matrix size was 150×150 pixels. We calculated the averaged pixel value in ROIs in 30 cases and also calculated standard deviation of the averaged pixel values. If motion artifacts were severe throughout the series, standard deviation will be a large value because both low pixel value and high pixel value is generated by motion artifacts.

RESULTS

Examples of representative images from conventional DSA and DSA images obtained using the new technique are shown in Figure 5. Motion artifacts were less pronounced on the DSA images obtained using our method. For these cases, the calculation time was approximately 0.03 s per frame.

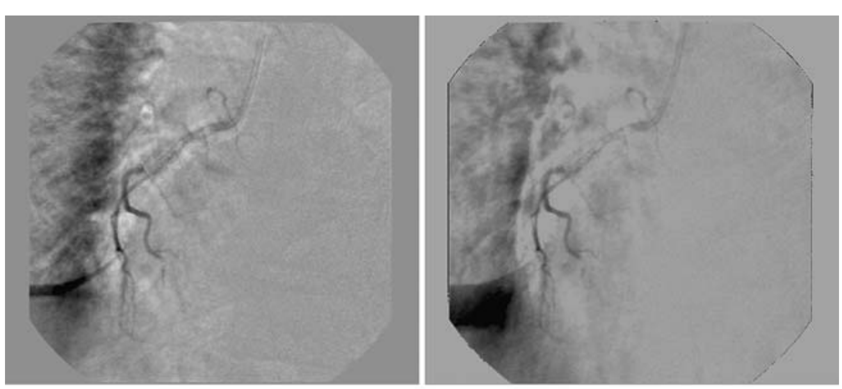
Figure 6 shows the results of subjective evaluation: Motion artifacts were reduced in 65% of the DSA images obtained using the new technique compared to conventional DSA.

The average standard deviation of the pixel values calculated using our method was 6.64, compared with 10.0 by conventional DSA.

DISCUSSION

We propose a simple but effective technique for reducing motion artifacts in DSA. This method will be useful in the clinical environment because it enables real-time processing. In the present study, the average time taken to create DSA images of the coronary artery was 0.03 s per frame, without any special hardware board. In addition, our method can be performed by a commercially available stand-alone PC. Our DSA technique is easily installed into catheterization laboratories in hospitals.

The results of subjective and objective evaluation showed that motion artifacts in DSA images were effectively reduced using our method. Because the average standard deviation of the pixel value of DSA images obtained using the new technique was 2.36 less than that of the conventional DSA images, motion artifacts caused by rapid movement were decreased. Therefore, our method will be useful in cardiologists' decision making, especially for the peripheral blood vessels.



(a) Conventional DSA (b) Our DSA

Fig 7. DSA image obtained by conventional DSA and our DSA (RCA).

DSA images evaluated as having poor image quality had vessels overlapping the heart edges, lung, and ribs. These results might be negligible because the present study focused on the reduction of vessel motion artifacts; however, cardiologist diagnosis might be influenced by the heart edges, lung, and ribs in the clinical environment. It is necessary to consider the method used in the vicinity of structures such as these. Figure 7 shows an image that was evaluated as having motion artifacts "greatly deteriorated," which is the only case that was categorized as "−2." In this case, the motion artifacts around the vessels were considerably decreased; however, observers considered the small vessels to be imperceptible against the relatively complex background structures in the DSA images obtained using the new technique. Thus, the visualization of small vessels may tend to be influenced by the complexity of the background structure; this point is worthy of further investigation.

CONCLUSION

We developed a new method for generating DSA images for coronary angiography, in which a mask frame that does not include blood vessels is created for every live frame. The motion artifacts in the DSA images were effectively reduced using our DSA method. The DSA images could be obtained in real time because the processing time is short; however, there was insufficient reduction in motion artifacts for regions on the heart edge, over the lungs due to breathing, and where the ribs overlapped the heart.

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