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*Laboratory Investigations*

# Nonlinear Geometric Warping of the Mask Image: A New Method for Reducing Misregistration Artifacts in Digital Subtraction Angiography

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**Abstract**
*Purpose:* Misregistration artifact is the major cause of image degradation in digital subtraction angiography (DSA). The purpose of this study was to evaluate the efficacy of a newly developed nonlinear geometric warping method to reduce misregistration artifact in DSA.
*Methods:* The processing of the images was carried out on a workstation with a fully automatic computerized program. After making differential images with a lapracian filter, 49 regions of interest (ROIs) were set in the image to be processed. Each ROI of the live image scanned the corresponding ROI of the mask image searching for the best position to match itself. Each pixel of the mask image was shifted individually following the data calculated from the shifts of the ROIs. Five radiologists compared the images produced by the conventional parallel shift technique and those processed with this new method in 16 series of cerebral DSA.
*Results:* In 14 of 16 series (88%), more radiologists judged the images processed with the new method to be better in quality. Small arteries near the skull base and veins of low density were clearly visualized in the images processed by the new method.
*Conclusion:* This newly proposed method could be a simple and practical way to automatically reduce misregistration artifacts in DSA.

**Key words:** Angiography, technology—Digital subtraction angiography, technology

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Misregistration artifacts produced by motion of the patient are the major cause of image degradation in digital subtraction angiography (DSA). While every DSA unit is equipped with software for reducing such artifacts by shifting the mask image manually, the structures to be masked almost never disappear completely, and this misregistration often causes serious problems in the interpretation of subtraction angiography. The reason for this incompleteness is that the directions of the patient's movements are not uniform, point to point, within the image area when the registration procedure is carried out by the customary method of a parallel shift of the entire mask image.

Recently we reported a new computerized automatic registration technique to erase the structures of the mask image by nonlinear geometric warping of the mask image [1], meaning that each pixel of the mask image is individually moved in the most appropriate direction and to a distance that matches the corresponding live image. This report summarizes how this technique succeeds in improving the image quality of cerebral DSA.

## Materials and Methods

The images processed included 16 series of cerebral angiography. The angiography unit used was a mobile C-arm system (Integris V3000, Philips, Best, The Netherlands) with a digital imaging system. Digital images were acquired with a 25-cm-diameter image intensifier in a 1024 × 1024 matrix × 10 bit. The digital data obtained were directly transferred on line to the workstation (Ultrasparc-1, Sun Microsystems, Mountain View, CA, USA) with a matrix size of 1280 × 940 × 8 bit. Within each series, an area of 512 × 512 × 8 bit

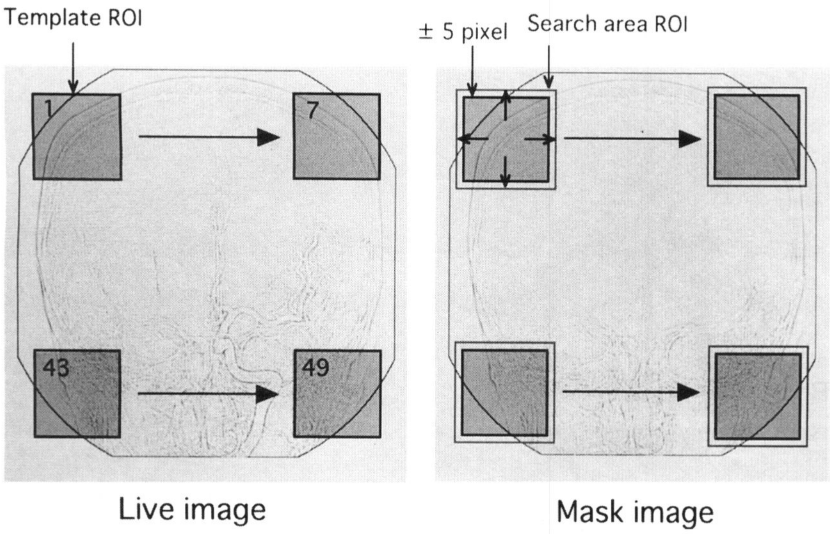


**Fig. 1.** Scanning of the template region of interest (ROI), searching for the best position. The 49 template ROIs of the live image were shifted in parallel, pixel by pixel, in the corresponding search area ROIs of the mask image, which were 5 pixels larger in each direction.

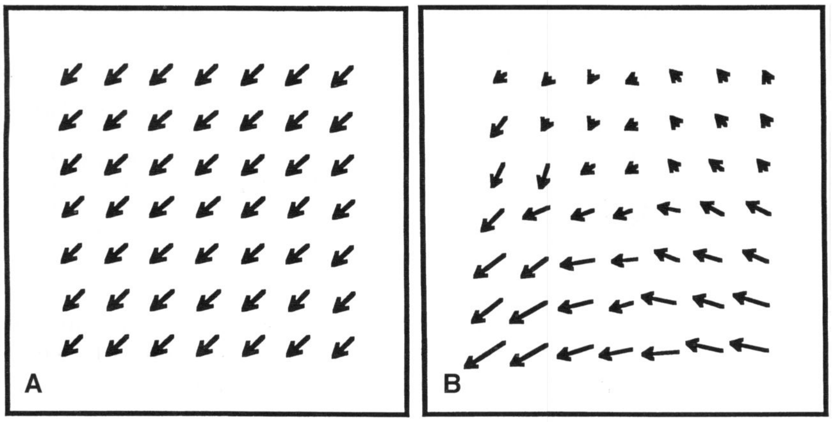


**Fig. 2.** Illustration of distortion vectors. **A** An example of shift vectors in the conventional parallel shift technique. All the vectors are the same in size and direction. **B** An example of the distortion vectors determined at 49 locations. Note that these vectors are different in size and direction, but should individually indicate the best direction and distance to shift in order to match the mask and live images.

covering most of the brain was set on the workstation, which received the further processing according to the algorithm that follows.

## *Processing Algorithm*

### Differential Processing Using a Lapracian Filter

Both the mask and the live images were processed with a lapracian filter with a kernel size of 3 × 3, so that only high-frequency data were selected for the differential images. This process was used to eliminate low-frequency background noise so that computerized matching of the images as follows could be precisely carried out.

### ROI Setting and Template Matching

Forty-nine (7 × 7) template regions of interest (ROIs) with the size of 100 × 100 pixels were uniformly arranged within a live image. The search area ROIs, larger than the corresponding template ROIs by 5 pixels in each direction, were also set at the same center locations in the mask image. Each template ROI scanned the corresponding search area ROI until it found the best direction and distance to match itself. In practice, the fully automatic computerized program let each template ROI shift in parallel 1 pixel at a time within the corresponding search area ROI (Fig. 1). The directions and distances of the shifts which produced the sum of the least differences in the pixel densities between the live and corresponding mask images were determined using the least-square matching method. The shift data obtained were called distortion vectors. The same template matching process was carried out a second time, 0.1 pixel by 0.1 pixel, for increased precision. Thus, the distortion vectors were determined at 49 ROIs, as illustrated in Fig. 2.

### Nonuniform Warped Shift of the Mask Image, Pixel by Pixel

The direction and distance of the shift of each pixel of the mask image were obtained from the previously determined distortion vectors by interpolating their data with a third-degree B spline function. Finally, each pixel of the mask image was individually shifted according to the data thus determined, and the density of the mask image was

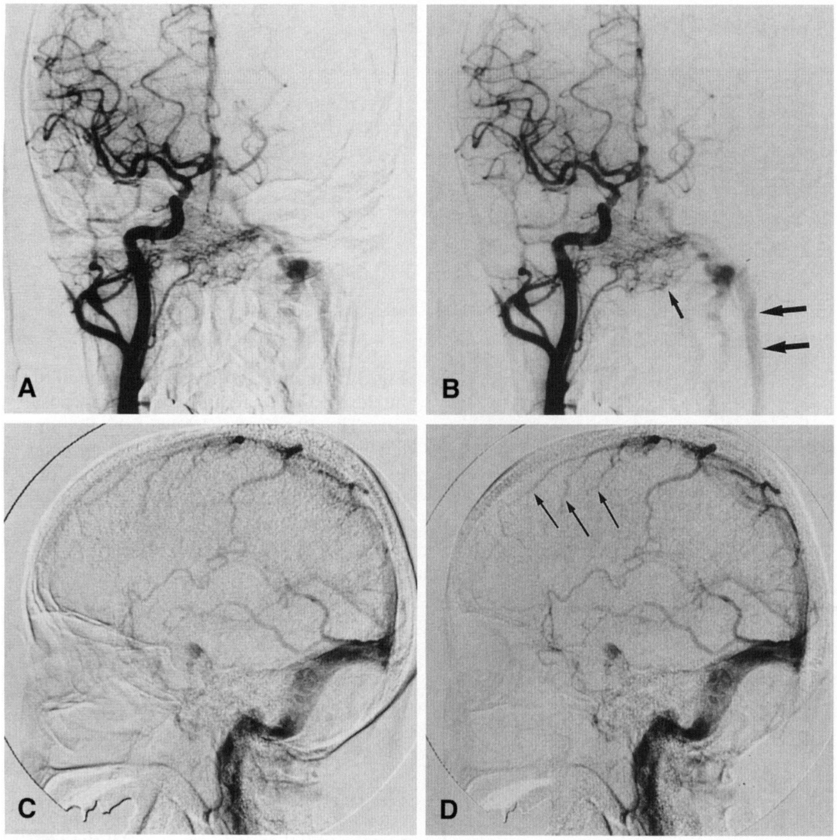


**Fig. 3.** Evaluation of the nonlinear geometric warping method in comparison with the conventional parallel shift technique. **A** Frontal image at a late arterial phase, processed with conventional parallel shift. **B** The same image as **A** processed with the new method. Note that the small arteries at the skull base are better visualized (small arrow), and the draining veins are more completely imaged (large arrows). **C** Lateral image at a venous phase, processed with the conventional parallel shift technique. **D** The same image as **C** processed with the new method. Note that the low-contrast veins (arrows) are more clearly visualized.

reduced from that of the live image to complete the subtraction image.

### *Evaluation*

Five radiologists compared the subtraction images registered with the conventional parallel shift technique of the entire mask image and those processed with this nonlinear geometric warping method (Fig. 3), in 16 series of cerebral DSA including 10 arterial and 6 venous phases. They chose the superior image in each set without knowing which image was processed with the new technique.

## Results

The time required for the workstation to process one series was approximately 8 min. In 14 of 16 pairs (88%), the images processed by the new method were rated by at least 3 and sometimes all of the radiologists as having better image quality. The reasons for this preference were obvious in the detailed visualization of the small vessels near the skull base and the clearer visualization of the low-contrast venous systems. The two cases in which the images processed by the new method were not rated as having better image quality both had very little misregistration on either of the images of the pair, because the motion of the patient was minimal. In these two cases the decision as to which image was superior was difficult to make.

## Discussion

Complete cancellation of the structures in the mask is the ultimate goal in subtraction angiography. In the era of cut films, it was the hardest process for the radiology technicians or for the residents and fellows in the angiography suite. Even in this time of digital imaging, angiographers are often disappointed by the subtracted images when patient movement could not be controlled. Manual shifting of the mask image using software mounted on a digital angiography unit is another nightmare for the operators, because it hardly achieves its final goal no matter how much the entire mask image is shifted in parallel.

In 1986, Takahashi et al. [2] reported an automatic reregistration technique of DSA images, and in 1994, Kano et al. [3] reported the application of a nonlinear geometric warping technique to detect interval changes in chest radiographs. Our method is a combination of these techniques, and is a fully computerized automatic registration technique which utilizes nonlinear geometric warping of the mask image. The results obtained are encouraging in that this new method is an excellent technique for further eliminating misregistration artifacts effectively with an automatic process. Currently the process has to be transferred to the workstation, and it takes approximately 8 min to produce the subtraction image at the station. However, if the entire algorithm of this method can be made more sophisticated and the abilities of the computer mounted on the digital angiography unit improve, it is hoped to apply this new nonlinear geometric warping method readily in an angiography suite in the future.

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