Application of Temporal Subtraction for Detection of Interval Changes on Chest Radiographs: Improvement of Subtraction Images Using Automated Initial Image Matching

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The authors developed a temporal subtraction scheme based on a nonlinear geometric warping technique to assist radiologists in the detection of interval changes in chest radiographs obtained on different occasions. The performance of the current temporal subtraction scheme is reasonably good; however, severe misregistration can occur in some cases. The authors evaluated the quality of 100 chest temporal subtraction images selected from their clinical image database. Severe misregistration was mainly attributable to initial incorrect global matching. Therefore, they attempted to improve the quality of the subtraction images by applying a new initial image matching technique to determine the global shift value between the current and the previous chest images. A cross-correlation method was employed for the initial image matching by use of blurred low-resolution chest images. Nineteen cases (40.4%) among 47 poor registered subtraction images were improved. These results show that the new initial image matching technique is very effective for improving the quality of chest temporal subtraction images, which can greatly enhance subtle changes in chest radiographs.

KEY WORDS: computer-aided diagnosis, digital image subtraction, image matching, interval change, chest radiograph.

CHEST RADIOGRAPHS are commonly compared with previous chest radiographs of the same patient in order to detect interval changes, such as new or changed pulmonary infiltrates, tumor masses, pleural effusions, or changes in heart size.[1,2] However, it is a difficult task for radiologists to identify subtle interval change, particularly lesions that involve overlap with anatomic structures such as ribs, vessels, heart, and diaphragm. In cases with previous radiographs, subtraction of previous from current images can be useful to enhance any changes in local opacity. Therefore, we developed a temporal subtraction scheme based on a nonlinear geometric warping technique.[1] Temporal subtraction images for a normal case and an abnormal case with lung nodule are illustrated in Figs 1 and 2, respectively. In an observer study, the detection accuracy of interval changes in chest radiographs was improved significantly by using temporal subtraction images.[2]

With the original temporal subtraction scheme, approximately 70% of subtraction images showed reasonably good quality.[1] However, severe misregistration resulted in poor subtraction images in some cases. Therefore, in this study we attempted to reduce the misregistration error rate. In the original temporal subtraction scheme, the global shift value, which provides information for the initial matching of the coordinates of two images, was determined only by use of the crossing point of the midline of the chest with the top of the lungs. Therefore, if the midline of the chest or the top of the lungs was detected incorrectly, severe misregistration might occur. To improve the overall performance, we applied a new initial image matching technique based on the cross-correlation of blurred low-resolution chest images to determine the global shift values between the current and previous chest images.

MATERIALS AND METHODS

Materials

One hundred pairs of conventional chest radiographs were digitized with a pixel size of 0.173 mm and 4,096 gray levels by means of a Kodak FD-1 digitizer (Kodak Health Imaging Systems, Rochester, NY). Digitized images were subsampled to a 512 × 512 matrix size for temporal subtraction. This scheme was developed by use of a IBM RISC/6000 powerstation.

At the beginning of the study, 100 subtraction images, which included a number of misregistered cases as well as well registered cases, were classified into three groups based on subjective ratings of potential clinical utility, which were provided by two chest radiologists and one physicist, indepen-

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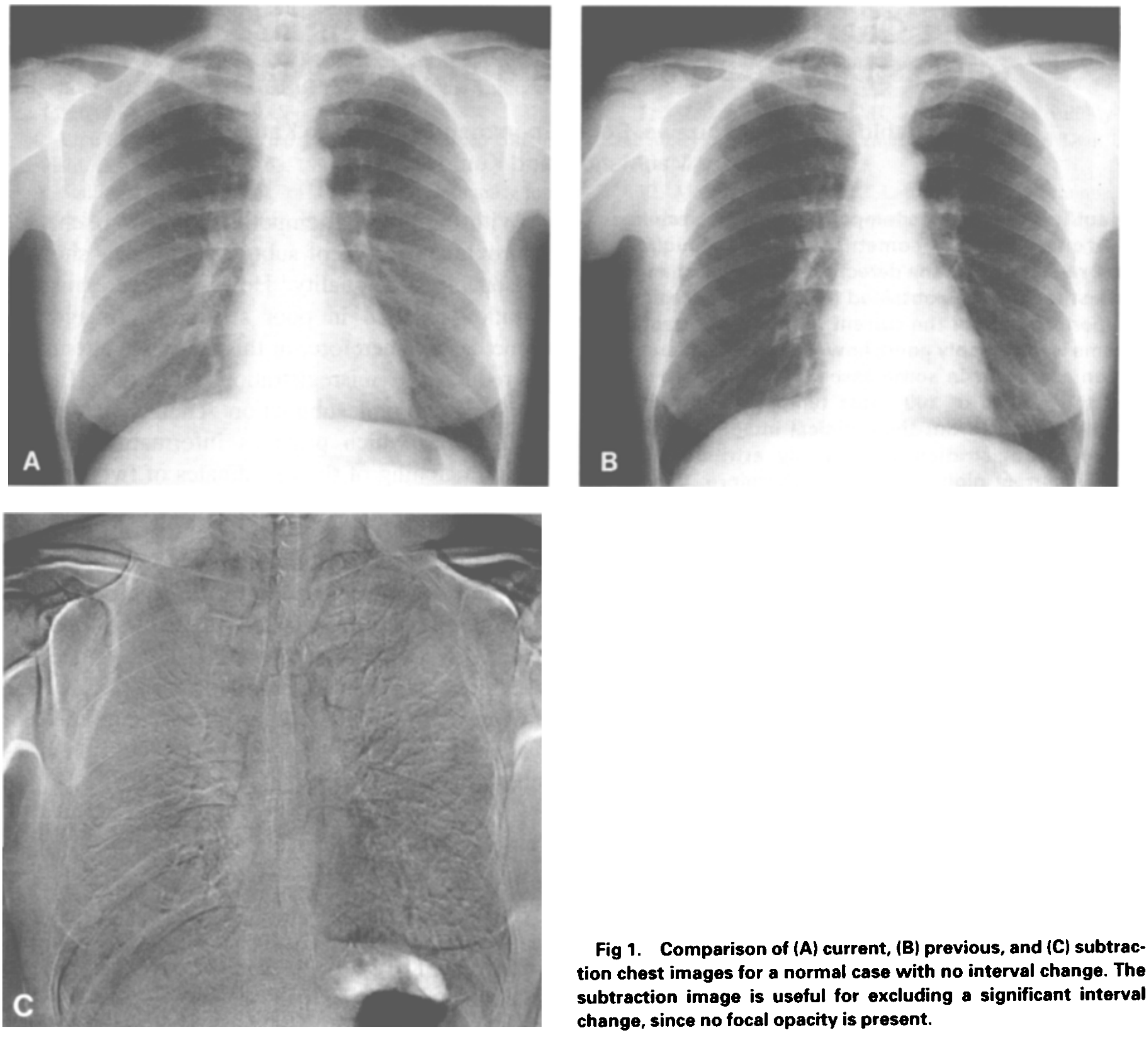

Fig 1. Comparison of (A) current, (B) previous, and (C) subtraction chest images for a normal case with no interval change. The subtraction image is useful for excluding a significant interval change, since no focal opacity is present.

dently. A rating scale from A to C was employed; A indicated a good-quality subtraction image, B indicated quality adequate for clinical use, and C indicated a poor-quality subtraction image. The final rating was determined by the average (or the majority) of the three observers' ratings. Sixteen subtraction images and 37 subtraction images were classified as A and B, respectively, and 47 subtraction images were classified as C. In this study, the 47 subtraction images classified as C were the main target cases used for development and evaluation of the new initial registration scheme.

Overall Scheme of Initial Image Matching

Figure 3 shows the major steps involved in the improved temporal subtraction scheme using the new initial image matching technique. In this scheme, we first performed a density correction of the current and previous images to maintain consistent density and contrast of the images. We employ a nonlinear density correction technique using the H and D curve of the screen/film system used.[3] Our image database includes two types of screen/film systems and printed film images from a computed radiography (CR) system.[4] Chest radiographs obtained with the CR system maintain consistent density and contrast by use of an exposure data recognition (EDR) system.[5] Therefore, we do not apply our density correction scheme to CR images. However, the density and contrast of chest radiographs taken with screen/film systems are corrected automatically by our density correction scheme, with a different set of look-up tables used for each radiographic film. The lateral inclination caused by variations in patient positioning between the current and previous images is then corrected by image rotation. The angle between the two images is determined from the midlines of the images.[6] Next, the ribcage edges of the current and previous images are detected based on image profile analysis.[6]

To determine the global shift value between the images, which corresponds to the shift in the x and y coordinates of one image relative to another, we applied a new automated initial image matching technique based on a cross-correlation technique using low-resolution images. The low-resolution images, which are reduced to 128 × 128 matrix size by averaging, are blurred with a Gaussian filter. We selected the 128 × 128 image

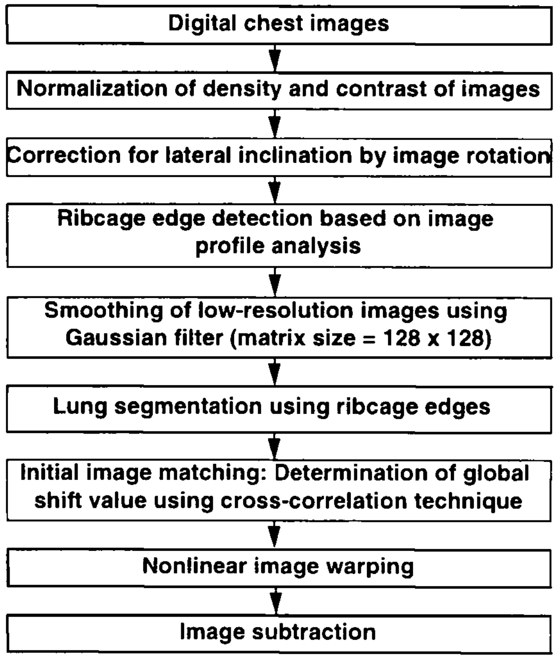

Fig 3. Scheme of chest temporal subtraction by automated initial image matching.

resolution for the initial image matching because the majority of structures in the chest image can be maintained clearly and also because the small-matrix image can be processed quickly. We found that the shape of the lung is visibly distorted on smaller matrix images of less than 64 × 64. We assumed that the fine structures in the lungs, such as small vessels, bronchi, devices, and catheters, would not affect the accuracy required for the initial image matching. Therefore, we blurred the low-resolution images by using a Gaussian filter, as illustrated in Fig 4. We then extracted the lungs from blurred low-resolution images by using ribcage edge information that was obtained based on image profile analysis.[6] The area outside the ribcage edges was ignored for the calculation of the cross-correlation of the current and previous images. The detected ribcage edges of the current and previous images are demonstrated by dark lines, as shown in Figs 5A and 5B (respectively), which are superimposed on the blurred low-resolution images. The images used for the initial image matching are shown in Figs 5C and 5D. The matrix size of the template image, which corresponds to the blurred previous image of Fig 5D, is 100 × 60. Using these images, we obtained cross-correlation values for determination of the best matching location between the images in Figs 5C and 5D. The cross-correlation values for this case are shown in Fig 6. In this case, the best matching point was located at a point shifted by 4 pixels to the right and 5 pixels in the upward direction from the

Fig 2. Comparison of (A) current, (B) previous, and (C) subtraction chest images for an abnormal case with interval enlargement of the right hilum. The subtraction image indicates the presence of a dark shadow in the lower right hilum (arrow) corresponding to the tumor.

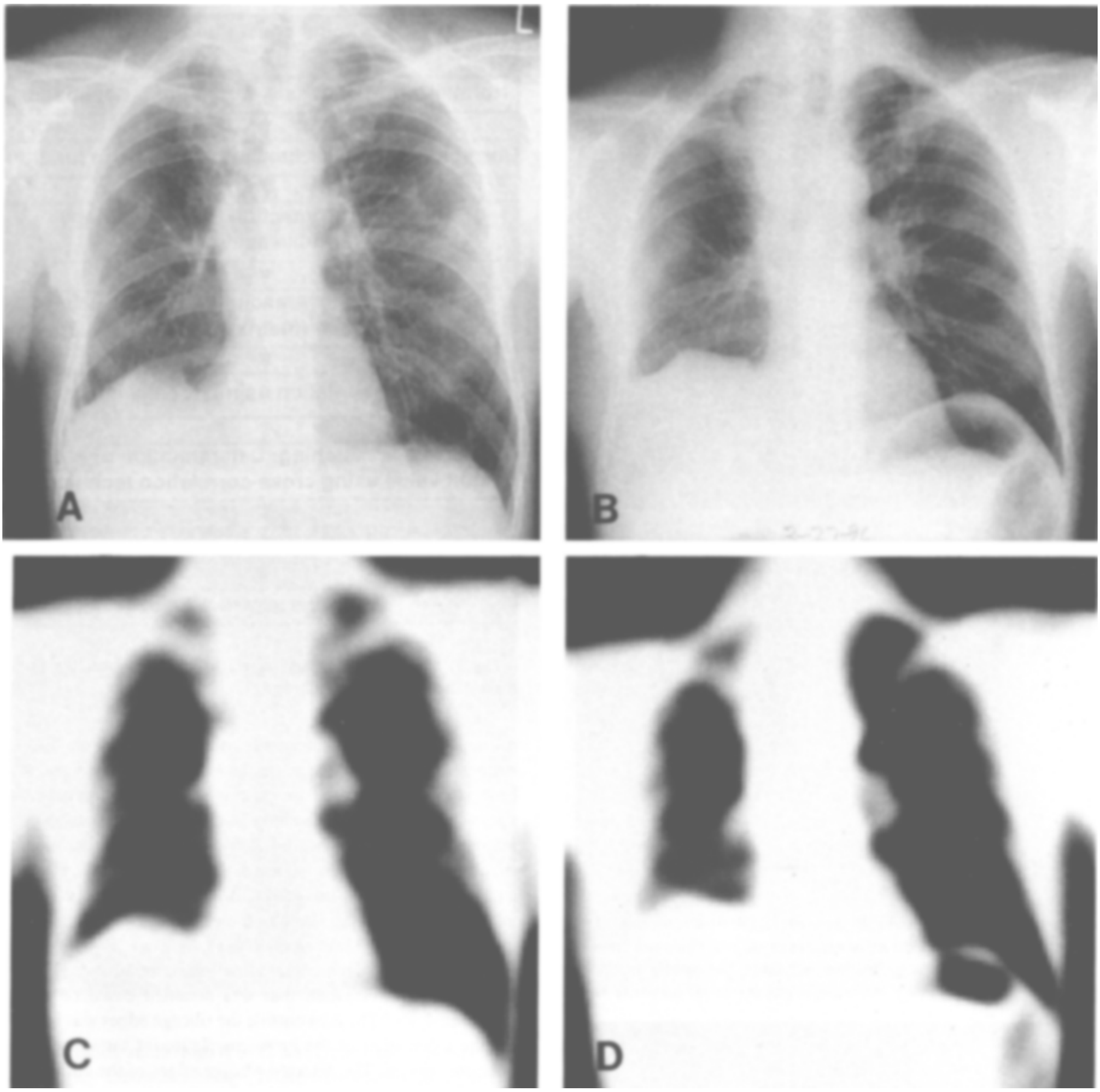

Fig 4. (A) Current chest image taken with CR. (B) Previous chest image taken with conventional screen/film system. (C) Low-resolution image blurred with Gaussian filter for current image. (D) Low-resolution image blurred with Gaussian filter for previous image. The size of the images in C and D had been magnified by a factor of four for illustration.

crossing point of the midline of the previous chest image with the top of the lungs. The previous image was shifted relative to the current image. Because these shift values are determined from low-resolution images, actual global shift values on the original image were obtained by multiplication by a factor of four. After the initial image matching was completed, a nonlinear geometric warping was performed for the local matching of multiple ROIs selected from the lung fields, as described in a previous publication.[1] Thus, we obtained the temporal subtraction image.

Quantitative Evaluation of Subtraction Image

To evaluate the quality of the subtraction image, we employed an automated method by using a physical measure, which is the width of the histogram of pixel values for the right and left lung area of the subtraction image. In the case of subtraction images without actual change, a high-quality subtraction yields a low-contrast image, whereas the contrast of poor subtraction images tends to be high because such subtraction images contain partly very dark and/or very light areas owing to misregistration. Therefore, we employ a histogram of pixel values in each lung field of the subtraction image to evaluate the image quality.

RESULTS

We initially selected seven cases that showed severe misregistration errors, obtained by the previous temporal subtraction scheme. These misregis-

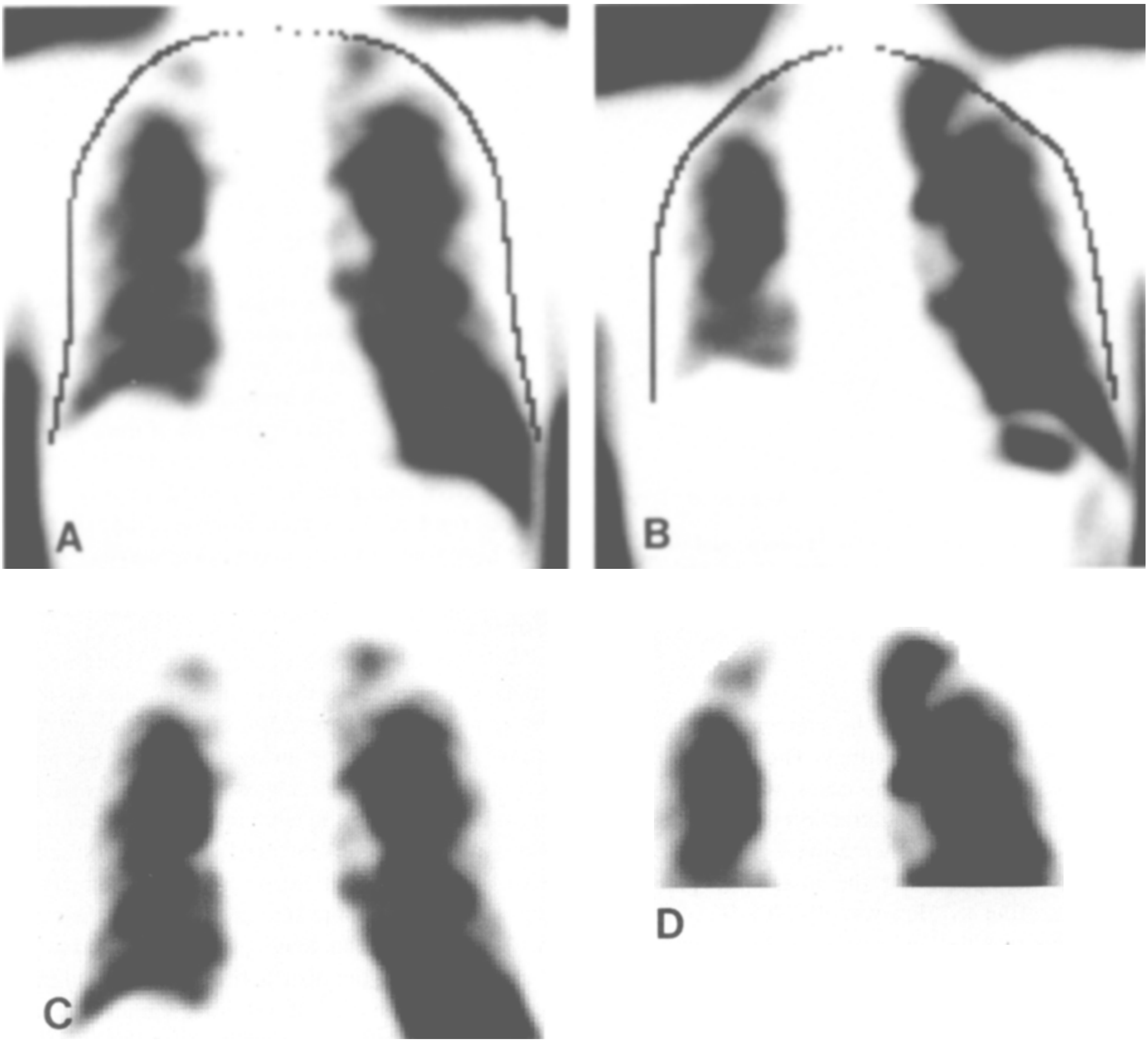

Fig 5. (A) Detected ribcage edges for current image (black line) were overlaid on a blurred low-resolution image. (B) Detected ribcage edges for previous image (black line) were overlaid on a blurred low-resolution image. (C) Lung image was segmented from current blurred low-resolution image for automated initial image matching. (D) Lung image is segmented from previous blurred low-resolution image.

tration cases were caused by failure in the determination of the global shift values. One of these cases, obtained by the previous temporal subtraction scheme with and without the warping technique, is shown in Figs 7A and 7B (respectively). It is obvious that the quality of the subtraction images without, and even with, the warping technique is quite poor. However, with the new initial image matching technique, the subtraction image is improved significantly, as shown in Figs 7C and 7D, which show the subtraction image without and with the warping technique (respectively). This illustrates clearly that the determination of proper global shift values is important for improvement of the quality of the temporal subtraction images.

We obtained 100 temporal subtraction images using the improved temporal subtraction scheme based on the new initial image matching technique. To evaluate the quality of the subtraction images, we classified these subtraction images into five categories, using a subjective rating scale employed by two chest radiologists and one physicist, independently. A rating scale from +2 to −2 was employed: +2 if the quality of the subtraction image was clearly improved; +1 if the quality of the subtraction image was moderately improved; 0 if the quality of the subtraction image was unchanged; −1 if the quality of the subtraction image was moderately decreased; −2 if the quality of the subtraction image was clearly decreased. The final

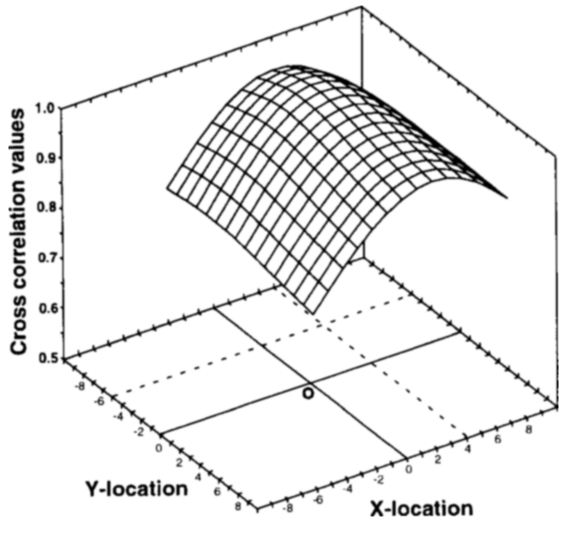

Fig 6. Cross-correlation values obtained from the automated initial image matching scheme. X-location and Y-location denote horizontal direction and vertical direction (respectively) on the previous image. Origin in the graph is the crossing point of the midline of the chest with the top of the lung.

rating was determined by the average (or majority) of the three observers' ratings. The results for the subjective ratings for all cases were plotted as shown in Fig 8. Many subtraction images obtained with the improved scheme were unchanged in terms of the quality of the image for potential clinical usefulness. However, 19 (40.4%) of the 47 cases that resulted in a poor-quality subtraction images by the previous technique were improved by applying the new automated initial image matching technique.

Figures 9A and 9B show histograms for the right and left lungs in a good subtraction case and a poor subtraction case, respectively. It is obvious that the widths of the histogram for the poor case are wider than those of the good case. Although an actual interval change in chest images can broaden the histogram of the subtraction image, the "misregistration" related to any pathological change in the database cases was localized and small compared with the global misregistration attributable to failure in the initial image matching. Therefore, we were able to evaluate the quality of the subtraction image by using the width of the histogram. We found that the width at a low position of the histogram peak was very sensitive for detection of poor subtraction images. The distribution of the widths of the histograms at 10% of maximum peak level is shown in Fig 10. The horizontal and vertical axes in Fig 10 correspond to the width of the histogram in the right lung and left lung, respectively. The good subtraction images, as represented by a subjective rating of A, tend to be characterized by a narrow histogram width, as shown in Fig 10. The distribution of the widths of the histograms for adequate subtraction images (subjective rating of B) is shifted slightly to the upper right in this graph. However, the widths of the histograms of poor subtraction images (subjective rating of C) obviously have a large-range distribution.

Table 1. Combinations of Receptor Systems Used for Temporal Subtraction (100 Cases)

	No. of Cases	A	B	C
S/F *v* S/F	50	8 (16%)	18 (36%)	24 (48%)
CR *v* S/F	43	6 (14%)	17 (40%)	20 (46%)
CR *v* CR	7	2 (29%)	2 (29%)	3 (42%)

Abbreviations: S/F, radiograph taken with screen/film system; CR, radiograph taken with CR system.

We investigated the quality of 100 subtraction images without and with the initial image matching in terms of histogram width. Figures 11A and 11B show distributions of histogram widths for three groups of subtraction images without and with the initial image matching technique. The distributions for good subtraction cases and adequate subtraction cases without initial image matching (subjective ratings of A and B) are similar to those for the cases with initial image matching. However, it is important to note that the distributions for poor subtraction cases with the initial image matching are shifted to the left, ie, use of the new initial image matching technique tends to decrease the histogram width of subtraction images, indicating improvement in quality.

DISCUSSION

As described above, our database include images obtained by three types of recording systems (ie, two kinds of screen/film systems and a CR system). When the imaging system is different for the current and previous images, it can be difficult to obtain good-quality subtraction images because of differences in the quality of images obtained with the two systems. In the case of the CR system, image quality usually differs substantially from that of a screen/film system because of the unsharp masking technique used. Therefore, we compared the number of subtraction images assigned to the different categories (A, B, or C) obtained by the

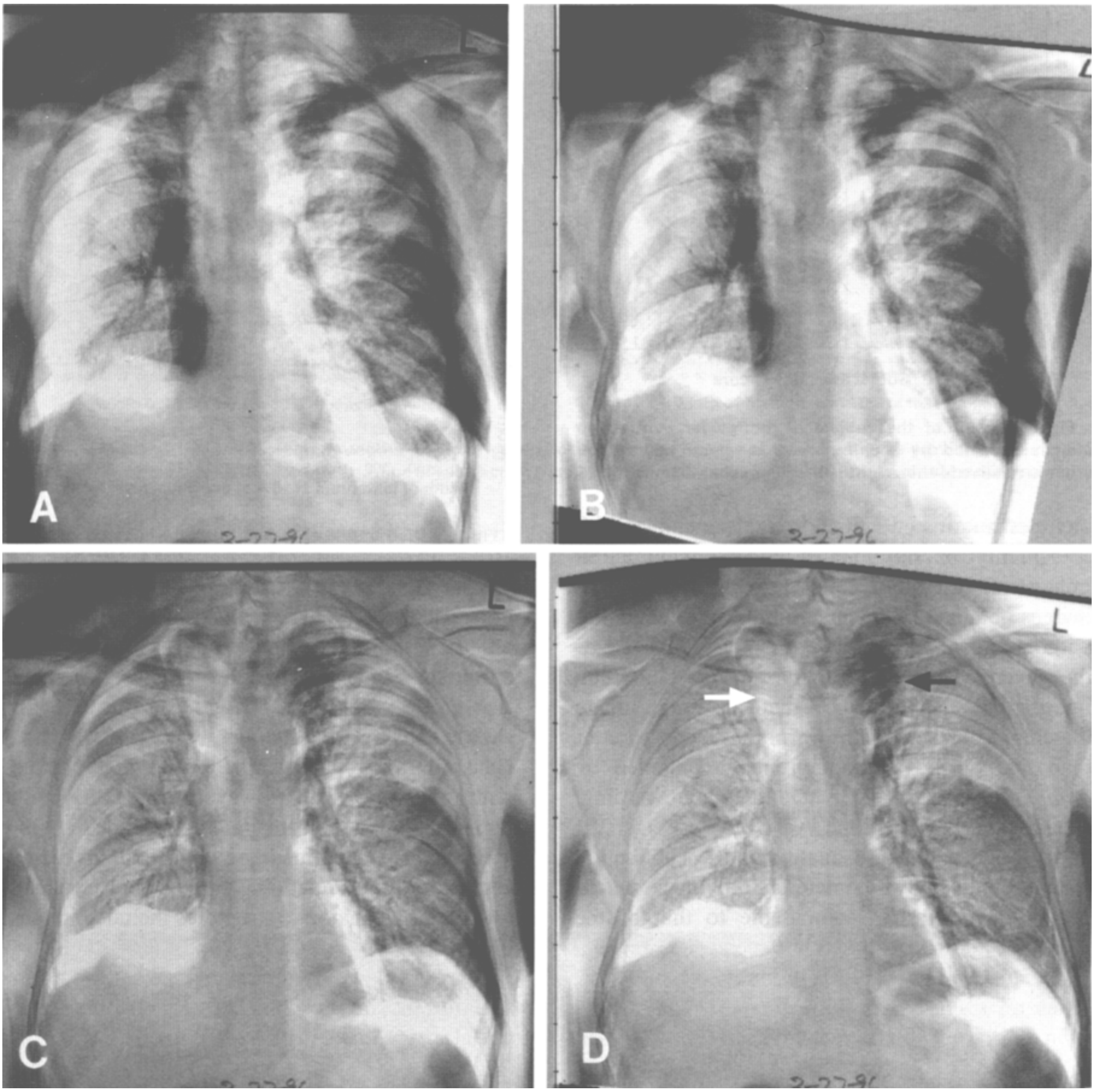

Fig 7. (A) Subtraction image without warping obtained with the previous temporal subtraction scheme showing complete failure of registration. (B) Subtraction image with warping obtained with the previous temporal subtraction scheme showing no substantial improvement. (C) Subtraction image without warping obtained with the improved temporal subtraction scheme showing moderate registration. (D) Subtraction image with warping obtained with the improved temporal subtraction scheme showing good registration. The improved subtraction image clearly shows the interval changes in the upper left and upper right lung fields. The faint white shadow around the right edge of the third thoracic vertebra (white arrow), indicates interval resolution of a hematoma that was present in the previous chest radiograph. The dark shadow on the upper left lung (black arrow) represents scarring due to interval surgery. The white shadows at the hemidiaphragms indicate a difference in lung expansion.

previous scheme for three combinations of imaging systems (ie, screen/film *v* screen/film, screen/film *v* CR, and CR *v* CR) (Table 1). The percentages (42%, 46%, and 48%) of poor-subtraction cases (C) in each of the three combinations are similar. This result indicates that our temporal subtraction scheme is not influenced substantially by the image recording systems used.

We made temporal subtraction images for seven cases by using a *manual* initial image matching technique. With manual adjustment, a chest radiologist determined the rotation angle and the global shift values interactively. Thus, "ideal" subtraction images without and with warping were obtained. Then we compared the quality of the subtraction images obtained by the improved scheme, which

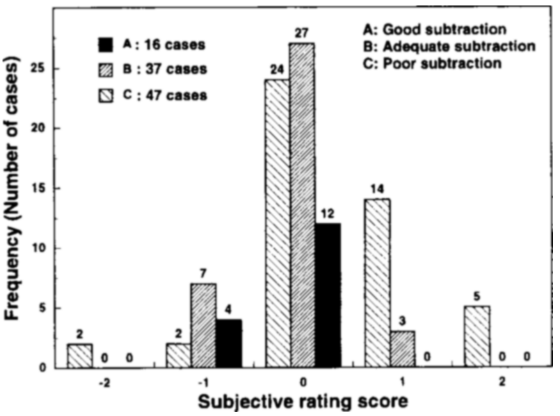

Fig 8. Result of the subjective ratings for subtraction images obtained by the improved temporal subtraction scheme relative to those for the previous scheme.

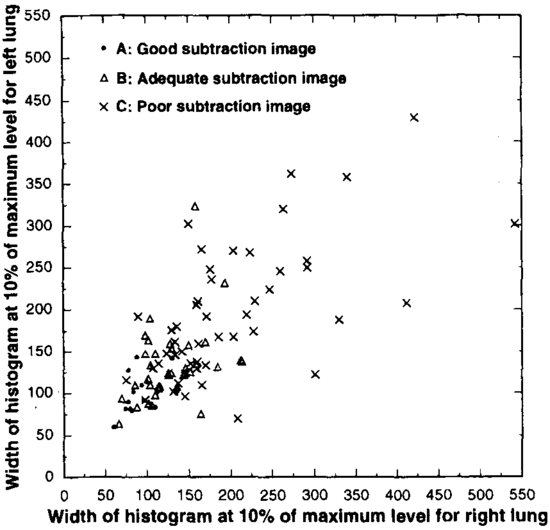

Fig 10. Distribution of the widths of the histograms at 10% of maximum frequency level between right and left lung.

includes automated initial image matching, with the quality of the manual "ideal" subtraction images. Figures 12A and 12B are subtraction images obtained by manual initial image matching without and with warping (respectively) for one of the seven cases. The quality of the subtraction images obtained with the manual initial image matching scheme without warping is slightly better than that of the subtraction image obtained by *automated* initial image matching without warping, as shown in Figs 12A and 7C. However, Figs 12B and 7D show that the quality of the subtraction images obtained by automated initial image matching with warping is comparable to that of the "ideal" subtraction images obtained by the manual initial matching with warping. For the other six cases, the results were similar.

In the initial image matching scheme, we employed a Gaussian filter with a 9 × 9 matrix size to blur the low-resolution chest images. To investigate the effect of the filter size, we changed the mask size to 5 × 5 and 13 × 13. The temporal subtraction image obtained with the 13 × 13 Gaussian filter was comparable to that obtained with the 9 × 9 size. However, the quality of the temporal subtraction image was degraded slightly when a 5 × 5 Gaussian filter was used. This may be because cross-correlation values become unreliable owing to fine anatomic structures included in these blurred images.

In addition, we attempted to use a smaller matrix size for the low-resolution image for automated initial image matching. Blurred low-resolution im-

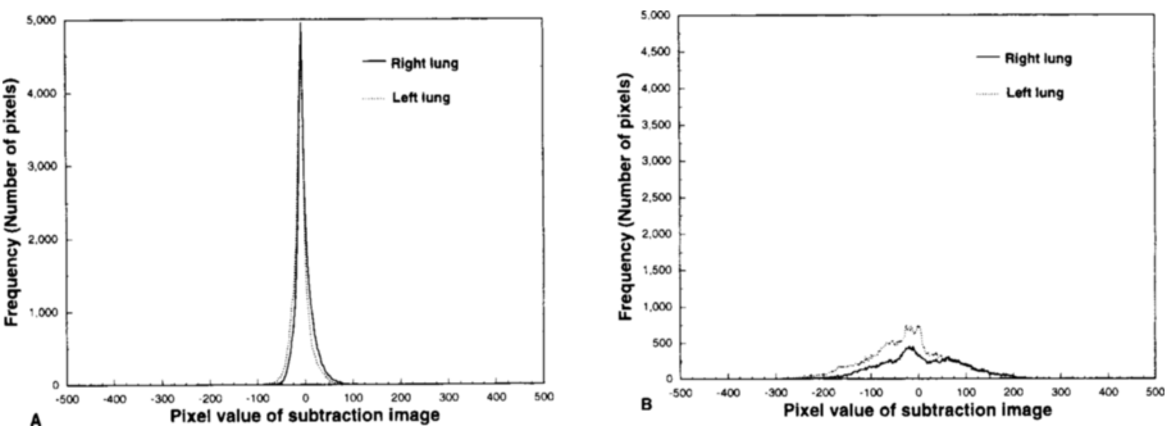

Fig 9. (A) Histogram of pixel values for each lung area of a good temporal subtraction image. (B) Histogram of pixel values for each lung area of a poor temporal subtraction image.

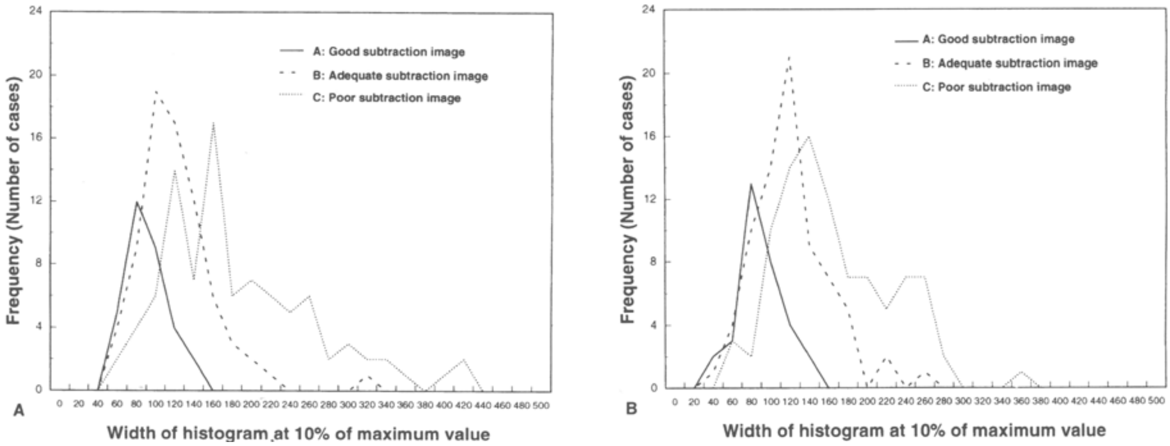

Fig 11. (A) Distribution of histogram widths for three groups of subtraction images obtained with the previous scheme. (B) Distribution of histogram widths for three groups of subtraction images obtained with the improved temporal subtraction scheme.

ages with a 64 × 64 matrix size were used instead of a 128 × 128 size. A 5 × 5 Gaussian filter was used for blurring because the matrix size of the image is smaller. The quality of the subtraction image became inferior to that obtained by the scheme with 128 × 128 images for automated initial image matching. The shape of the lung was visibly distorted on the 64 × 64 images, thus resulting in an erroneous global shift value.

CONCLUSION

We have developed a new initial image matching technique based on a cross-correlation method using low-resolution images. By incorporating this technique, the overall performance of the temporal subtraction improved substantially. It is anticipated that detection of subtle changes in chest radiographs will be enhanced with the improved temporal subtraction scheme.

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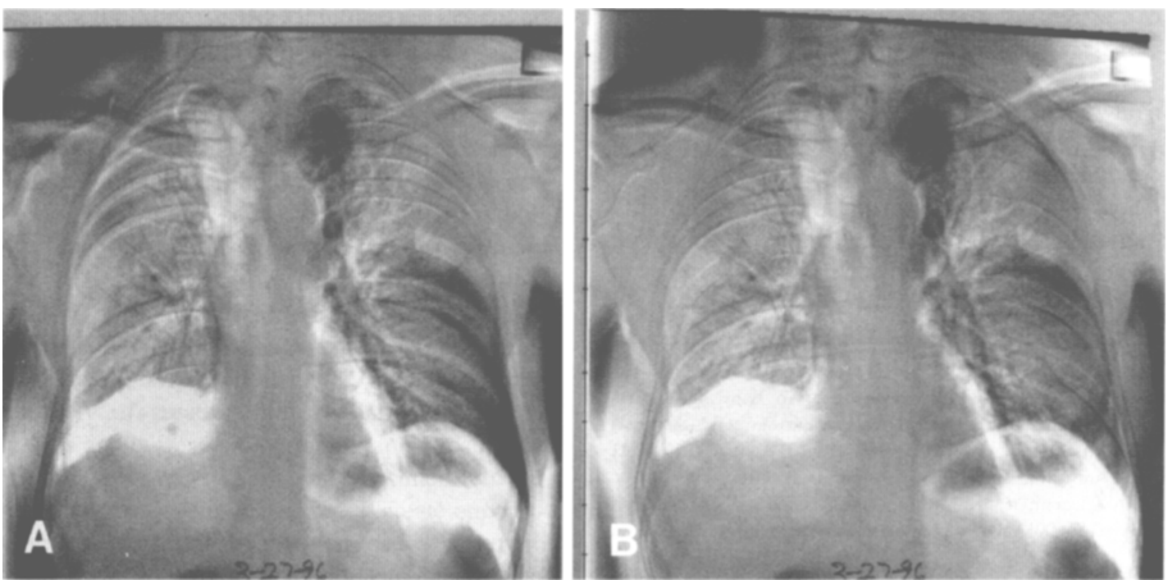

Fig 12. (A) Subtraction image without warping obtained by use of manual initial image matching. (B) Subtraction image with warping obtained by use of manual initial image matching.

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