A Quantitative Assessment of Patient Motion and Its Effect on Myocardial Perfusion SPECT Images

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Patient motion during image acquisition is a frequent cause of SPECT perfusion image artifacts. We sought to determine the relationship between patient motion and the resultant image artifact. The effect of patient motion on ^{201}Tl SPECT scintigrams was assessed with computer simulation to create 66 new image sets with artifactual vertical, horizontal and combined patient motion introduced over a broad range in six normal studies. Visual analysis of regional radioactivity in these simulated images, as well as quantitative analysis of the resultant polar coordinate display was performed. The presence and extent of "motion" artifacts varied with the number and location of the projection images affected, as well as the extent of their displacement. Although the extent of the defect varied with the frames affected, they were not necessarily more extensive when related to vertical displacement in the center of the orbit. The location of induced defects varied with direction of displacement and the location of frames affected. Vertical and horizontal motion created additive defects. Defect size grew with incremental vertical displacement but subsequently decreased with yet increasing displacement. Both the irregular, "lumpy" distribution of radioactivity, often with opposing "defects", as well as curvilinear extraventricular radioactivity, were visual clues suggesting SPECT defects related to motion artifact. A clinical case review revealed that approximately 25% of studies demonstrate such motion during acquisition but only 5% contribute to visible image deterioration. While detection is important, postacquisition attempts to correct such artifacts are incomplete and optimally, they must be prevented.

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Stress and redistribution ^{201}Tl myocardial perfusion scintigraphy has been widely applied to the diagnosis and evaluation of patients with known or suspected coronary artery disease. Recently, the application of single-photon emission computed tomography (SPECT) has proliferated widely owing to its apparent advantages beyond those of the planar imaging method. While SPECT provides greater image contrast, anatomic detail and the potential for greater diagnostic accuracy (*1,2*) the method is not without difficulties. SPECT may actually be viewed as an image enhancement technique and computer enhancement methods have been shown to bring increased diagnostic sensitivity, often in association with reduced specificity (*3*). The latter may simply relate to the enhancement of unimportant intensity differences, or may be due to method related technical factors which lead to the production of artifactual image defects.

Patient motion during SPECT image acquisition is well recognized as an important factor which may adversely effect the accuracy of ^{201}Tl SPECT myocardial perfusion imaging (*4,5*). SPECT myocardial perfusion imaging may present a greater frequency of patient motion and related image artifact than other SPECT imaging protocols since cardiac SPECT acquisition using ^{201}Tl and ^{99m}Tc sestamibi requires 20–30 min and is often performed in elderly and ill patients who may have difficulty lying still. Imaging is frequently done twice in a single day and is often performed soon after vigorous dynamic or pharmacologic stress. Yet, such motion-related image artifacts have been evaluated to only a limited extent. DePuey and Garcia (*5*) note that "... it is unknown what type and degree of motion will routinely cause scan artifacts."

In a preliminary screening of clinical studies, the variation in location of a radioactive marker dot in a dynamic display of projection images supported the presence of artifactual vertical patient motion of some evident degree, in approximately one of ten clinical studies. Friedman et al. (*4*) have highlighted the problem of patient motion and suggest its importance for quality control of SPECT studies. They have also noted the occurrence of upward creep (*6*), a gradual change in intrathoracic cardiac orientation, likely due to variability in respiratory motion soon after exercise. This variable brings a dissociation of cardiac from chest wall related marker motion. Eisner and coworkers (*7,8*) have previously reported the effects of motion in both patient and phantom studies of SPECT myocardial perfusion image acquisition. They applied a sophisticated, cross-correlation computer method to identify and quantitate sudden "nonreturning" vertical patient motion and to attempt correction for motion postacquisition. Nonre-

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turning patient motion was applied in normal studies to assess the incidence and characteristics of false-positive studies. Prigent and coworkers (*9*) also intentionally displaced the SPECT table or manipulated the display of projection images to determine the effects of patient motion on image findings.

We sought to identify in greater detail the specific effects of regional, incremental patient motion on SPECT myocardial perfusion imaging with ^{201}Tl. We applied a simple computer simulation method to create specific patterns of artifactual patient motion varying in location, duration, magnitude and direction, in order to assess the effects on the distribution, extent and density of resultant image defects and the interpretation of SPECT myocardial perfusion scintigrams. Like some prior studies (*6,7*) we assessed the effects of coordinate motion of the chest wall and heart. We developed software to create, measure and conversely, correct, motion in a vertical orientation in reference to a low thoracic or upper abdominal radioactive marker dot and the cardiac silhouette. Computer software was also developed to implement horizontal rotational artifacts and analyze the resultant image defects.

MATERIALS AND METHODS

Baseline SPECT Images

Six normal ^{201}Tl SPECT myocardial perfusion scintigrams were selected from male patients with a low pretest likelihood of coronary disease, according to the criteria of Diamond et al. (*10*). To assess the effects of vertical motion on image findings, we applied our standard method. Here, 32 projection images, or frames, were acquired for 40 sec each, employing the step and shoot technique, applying a circular orbit from the 45° RAO to the 45° LPO projection, using a leap collimator applied to a Siemens Orbitor (Des Plaines, IL) scintillation camera. A single study, specifically acquired over 360° in 64 frames employed a selected 32 frames in processing in order to provide data to test the effects of horizontal patient motion. In all cases, processing employed a Butterworth filter with a 0.4 Nyquist cutoff frequency and fifth order roll off. Images were displayed on a 64 × 64 matrix in short as well as vertical and horizontal long axis projections. Given the field and matrix size, each pixel represented approximately 0.4 cm in each direction. All images were technically optimal without evidence of localized soft tissue attenuation.

Each study was acquired in association with a normal maximal treadmill exercise test taken to over 85% of maximum predicted heart rate for age. Initial images were read as normal by both visual agreement of two experienced readers, and their objective analysis and comparison with a large population of normal males applied by the polar coordinate display and analysis program developed by Garcia and coworkers (*1,2,11*). A ^{201}Tl marker dot placed on the skin below the heart and viewed in summed and dynamic displays of the projection images and the image sinogram served to confirm initial patient immobility and subsequent artifactual vertical and horizontal motion introduced by altering the relative position and relationship of projection images in these normal studies.

Intervention: Artifactual Vertical Motion

Specific software was employed to produce apparent artifactual vertical patient motion by shifting 1 to 8 consecutive frames, from 1 to 20 pixels up or down (Fig. 1). Specifically, the software permits vertical translation of projection images in increments of 0.5 pixels. Each shifted projection image was produced by relocating the original unshifted image. The operator shifts a particular projection as many pixels as desired and then views the resultant cine display of projection images.

Displacement artifacts were produced over a wide range in order to sample intervals thought by previous investigators (*5–9*) to produce SPECT artifacts and to test the characteristics and relationships of such artifacts in individual patients. Chosen were diminutive displacements, designed to test the sensitivity of the SPECT method to motion artifact and large deviations, likely surpassing those generally observed clinically, in order to gain an appreciation of the effects of varying magnitude of motion on processed SPECT images. The number and location of altered frames was also varied to determine the magnitude and characteristics of resultant SPECT image artifacts. A large selection of displacements were made both superiorly and inferiorly.

In the initial patient study, 38 altered image sets were analyzed spanning a 0.5 to 20-pixel vertical displacement over 1 to 8 frames. A concentration of sampling was placed at the level of 3-pixel displacement in 8 frames since this was thought to yield an impressive motion artifact well suited for characterization. In order to confirm the original findings in the initial intensely evaluated patient study and further characterize resultant motion artifacts, additional altered image sets, each with 3-pixel displacement in 8 different and widely varying frames, were analyzed in each of 5 additional normal studies. This latter analysis tested the effects of position or timing of motion displacement on the location and magnitude of resulting artifactual defects. Overall, 56 new SPECT image data sets were generated and analyzed. Specific image alterations were performed and related findings are enumerated in Tables 1–3 and Figure 1.

Artifactual Horizontal Motion

Horizontal patient motion in the rotational orbit was simulated by replacing a projection frame and all subsequent frames with

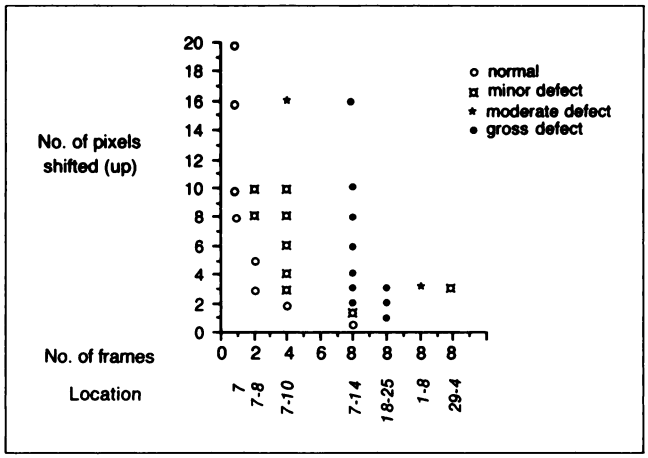

FIGURE 1. Defect size. Shown is the relationship between the visual extent and intensity of the defect generated and the extent (number of pixels), duration (number of frames), and timing (specific frames) of upward image displacement. Defect size and intensity increased with increased extent and duration of motion.

TABLE 1
Effects of Incremental Vertical Displacement in Frames 7–14 on Motion Artifact in a Single Patient

Displacement magnitude (pixels)	% Polar Defect					
	Up			Down		
	L	R	X	L	R	X
0	3	0	0	3	0	0
2	7	0	3	25*	12*	2
4	14*	8	19*	33*	25*	24*
6	23*	27*	23*	42*	0	28*
8	21*	2	45*	25*	0	0
10	20*	0	21*	9	0	4
16	16*	0	4	11	0	6

L = left anterior descending coronary region, R = right coronary region and X = left circumflex coronary region.
* Beyond normal limits, $p < 0.05$ compared to baseline.

TABLE 3
Effects of Horizontal, Rotational Displacement, in (+) or Counter to (–), the Direction of Orbit on Motion Artifact, Beginning with Frame 16 in Patient 6

No. frames shifted	% Polar defect					
	+			–		
	L	R	X	L	R	X
0	0	0	0	0	0	0
1	1	0	0	1	0	0
3	1	0	0	8	0	0
5	3	0	0	23*	3	8

+ = horizontal rotation in direction of orbit, – = horizontal rotation counter to direction of orbit, L = left anterior descending coronary region, R = right coronary region and X = left circumflex coronary region.
* Beyond normal limits, $p < 0.05$ compared to baseline.

another, imaged earlier or later in the acquisition sequence by a given interval. Such artifactual horizontal rotational patient motion could be simulated in 5.9° increments in, or counter to, the orbital direction. Thus, the frame sequence evaluating the effects of horizontal motion of 29.5° in the direction of rotation beginning at frame n would be 1, 2...n, n + 5, n + 6...37. To accommodate this sequence, 64 projection frames were acquired over 360° in a single subject and the appropriate 32 frames were chosen in sequence and used for reconstruction. This same, specifically acquired normal study was utilized as well to evaluate horizontal motion artifact counter to the orbital direction where a 29.5° shift beginning in frame n would be represented by projection frames 1, 2...n, n − 5, n − 4...n, n + 1....27. Here, developed software permitted frame selection so that certain specific frames were used twice at specific locations in the simulated acquisition sequence, while others were shifted from their appropriate location, and yet others at the end of the cycle were omitted. Artifactual horizontal motion of 1-, 3-, and 5- were omitted. Artifactual horizontal motion of 1-, 3-, and 5-frame displacement in and counter to the direction of the orbit were evaluated. In four examples vertical displacement was combined in varying increments with horizontal motion.

Image Analysis

Following introduction of the desired motion artifact in projection images, each set was reprocessed as was the original unaltered postexercise clinical images and again displayed in the three standard SPECT axes. They were then read blindly by the same two readers as normal or abnormal, where defects were graded as follows: mild—if demonstrating a slight, subtle defect involving only a part of a single coronary vascular area; moderate—if demonstrating an obvious defect involving all or most of a single coronary vascular region or severe—if demonstrating a dense defect and involving multiple vascular areas. Again, objective quantitative analysis of the perfusion abnormality compared to a normal population was performed utilizing a polar coordinate display. Here, regional defects were related to coronary vascular areas and abnormalities were present when exceeding 12% in the left anterior descending (LAD) vascular area, 9% in the right coronary artery (RCA) area according to established

TABLE 2
Effects of Frame Location on Motion Artifact

Frames vascular area	% Defect on Polar Display														
	Baseline			3 pixels upward displacement											
				1–8			7–14			13–20			18–25		
	L	R	X	L	R	X	L	R	X	L	R	X	L	R	X
1	3	0	0	7	0	0	5	1	7	24*	2	8	23*	27*	2
2	4	8	0	10	13*	2	6	18*	4		—		15*	45*	0
3	1	0	0	7	13*	0	8	6	0		—		25*	54*	9
4	2	0	0	10	15*	9	6	29*	2		—		20*	49*	1
5	6	3	0	11	13*	10	6	5	14*	18*	21*	9	23*	25*	3
6		—								15*	5	15*			

L = left anterior descending coronary region, R = right coronary region and X = left circumflex coronary region.
* Beyond normal limits, $p < 0.05$ compared to baseline.

criteria and 12% in the left circumflex (LCX) area. Following this evaluation of the effects of projection image displacement on normal SPECT studies, we reviewed 165 consecutive clinical SPECT studies for the frequency and severity of patient motion and related artifact.

Reproducibility

Ten SPECT image data sets derived from altered projection images spanning a wide range of vertical displacement, from 1 to 6 frames, were each processed 3 times by the same observer. This permitted the evaluation of the reproducibility of defect grade, extent and location assessed both visually and with reference to the polar coordinate display of regional radioactivity.

Statistics

Reproducibility and differences in quantitative polar map defect size were analyzed with the Student's t-test. A p value < 0.05 was significant.

RESULTS

Initial Studies and Reproducibility

Both visual and objective polar coordinate analysis were normal in each of the six initial baseline SPECT patient studies. Reproducibility was excellent and there was no significant difference in defect grade, size or distribution with repeated analysis of ten selected SPECT data sets, each altered with a varying magnitude of vertical displacement. Similarly, the findings described in depth for analysis of a single data set paralleled those seen among more limited samples in five other normal studies.

Effects of Vertical Motion

Defects identified visually were always confirmed on objective analysis of polar coordinate maps. The minimum magnitude of vertical displacement that was required to produce an evident visual abnormality varied inversely with the number of frames affected (Fig. 1). A mild motion related defect was evident in association with 8-pixel upward motion affecting only two frames (7 and 8). However, displacement of only 3 pixels produced an image artifact when affecting four frames (7–10), and only 2-pixel motion produced a similar artifact when eight frames (7–14) were involved. Displacement of a single frame, (7) even over 20 pixels, brought no evident significant image artifact.

Direction and Location (Timing) of Motion

Similar effects were noted with vertical displacement inferiorly and superiorly (Fig. 2 and Table 1). However, in the same patient, defect location varied with direction of displacement (Fig. 3 and Table 1), and defects due to inferior displacement generally projected to ventricular regions opposite in location to those related to defects produced by superior displacement or upward vertical motion. Sensitivity to motion, as well as the location of artifacts of motion, appeared to depend on the location of frames affected (Figs. 3 and 4 and Table 2). A mild defect was evident in a different location with only 1 pixel of upward vertical displacement over eight frames when those frames were 18–25 (Fig. 1). Sensitivity to vertical motion appeared similar when central frames 13–20 were affected (Table 2).

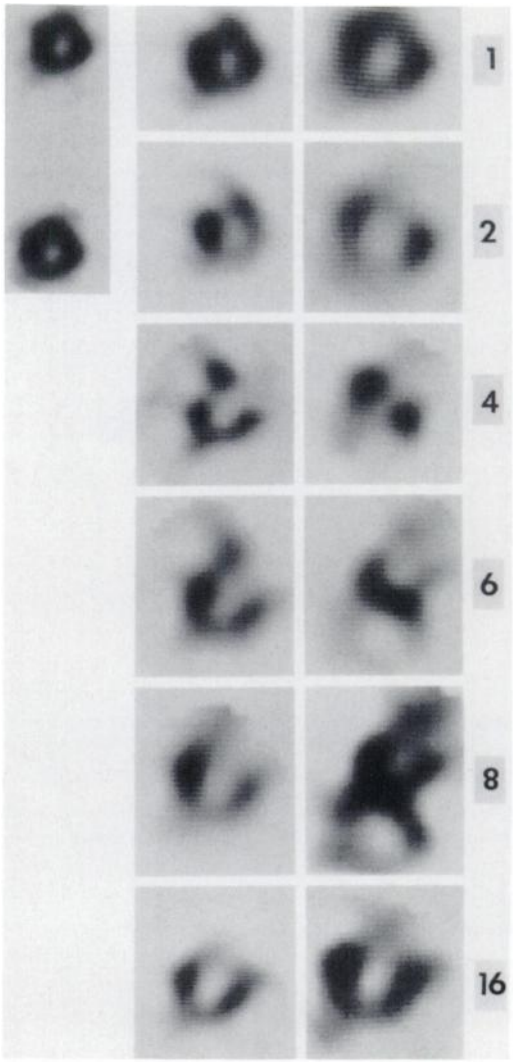

FIGURE 2. Effects of motion. Shown are midventricular short-axis slices derived from incremental displacement of Frames 7–14. At left are the initial normal poststress (above) and delayed images. The effect of upward displacement is shown in the center column, while the effect of downward displacement is shown with a slightly greater magnification, in the right column. The number of pixels displaced is indicated at right. Note the extent, location and configuration of artifactual defects and the apparent reduction in defect extent with increased displacement.

The extent of the artifactual abnormality produced initially appeared to vary with the amount of frame displacement, when the number and location of frames affected was held constant (Fig. 1). There was an observed biphasic effect where defect size increased initially, but then appeared to decrease with yet increasing displacement, either superiorly or inferiorly (Fig. 5 and Table 1). When inferior and superior motion exceeded the vertical ventricular dimension, the resultant defects appeared to decrease in

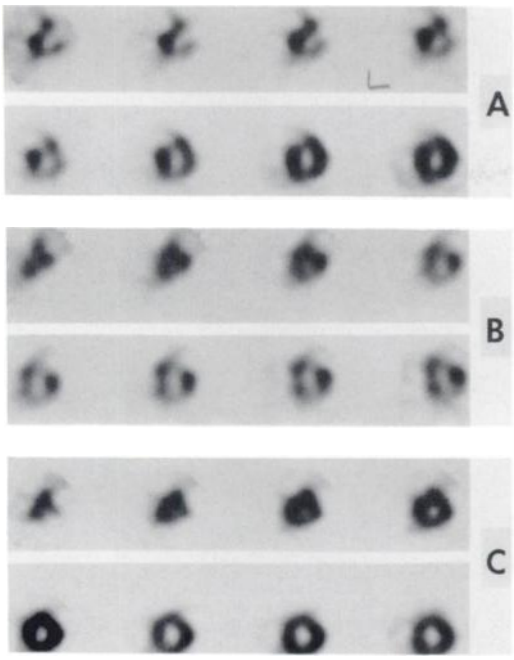

FIGURE 3. Effects of motion timing. Shown are the resultant contiguous short axis slices from apex (upper left) to base (lower right) after upward displacement of two pixels in eight frames. Panel A illustrates short axis slices when Frames 7–14 were affected while panel B shows slices resultant when Frames 18–25 were affected. The normal undisturbed image set is shown in C. Note the difference in defect size and location.

magnitude. Displacement of the same frames in the same direction and to the same magnitude brought similar defect size in the same or adjacent locations in different subjects.

Image Pattern

A simple visual review of SPECT images derived from altered projection images in multiple projections revealed typical artifacts of patient motion (Figs. 2 and 3). These included an irregular or lumpy distribution of radioactivity with often opposing defects between the lumps. This was most exaggerated as defect size peaked and overlap of initial and displaced ventricles maximized. Also evident was a curvilinear extraventricular region of radioactivity, likely related to the projection of aspects of the displaced ventricle adjacent to the nondisplaced ventricle. However, artifactual defects appeared to triangulate in the multiple SPECT projections and otherwise suggested that they were truly myocardial in origin.

Effect of Horizontal Motion

Limited sampling of horizontal motion artifact revealed greater sensitivity to patient motion counter to the direction of rotation. Here, defects on the polar map were only appreciated in association with displacement of five projection frames. Limited defects were produced in anterior-septal and lateral areas. However, displacement of five frames in the direction of rotation brought no discernible objective defects (Fig. 6 and Table 3). When five-frame counter rotational displacement was combined with three-pixel upward displacement in central frames 13–20, an extensive defect was noted involving all vascular territories (Fig. 6).

Internal Clues

The summed display of all projection images could not provide consistent, sensitive evidence of the presence and extent of motion artifact. However, careful review of the dynamic display of projection images was diagnostic in all cases. Also, review of the image sinogram provided objective identification of the presence and location of horizontal motion artifact.

Clinical Review and Efforts at Correction

The subsequent review of 165 serial clinical SPECT perfusion scintigrams revealed evident motion in approximately 25% (41/165) of cases. However, motion was sufficient to produce evident artifacts on resultant SPECT images in only 8 (5%) studies. Reversal of the displacement process which produced the artifacts forming the main body of this study permitted a degree of realignment of displaced clinical projection images and the reduction of the subsequent defect on SPECT reconstruction (Fig. 7). Only rarely, however, could the artifact be fully corrected if associated with pure vertical motion. Here, with vertical displacement, defects were most evident in anterior and inferior walls as projected in short- and vertical long-axis projections. One patient in our series demonstrated an identifiable horizontal shifting motion during imaging resulting in displacement limited to the horizontal axis of rotation (Fig. 8). Here, the SPECT "defect" was most evident in septal and lateral walls as displayed in the short- and horizontal long-axis projections. Application of the software correction algorithm was of no help in reducing the defect which disappeared completely on repeat study performed successfully without patient motion.

DISCUSSION

The data presented here were generated from extensive analysis of limited SPECT data sets. Only general conclusions should be drawn in applying the results to other cases. However, observations made and trends demonstrated suggest principles which are worth extrapolating with care and may serve as the basis for future work. Studies chosen for analysis excluded confusion with defects created by soft tissue attenuation or other extracardiac artifacts. The observations should apply as well to perfusion images made using the new technetium-based agents.

Motion artifacts are among the most frequent as well as the most destructive of technical artifacts related to SPECT myocardial perfusion imaging (*4,5*). These are intrinsic to the method and influenced only by patient cooperation and the ability of technologist and physician to optimize them. Prior studies have identified the problem in clinical

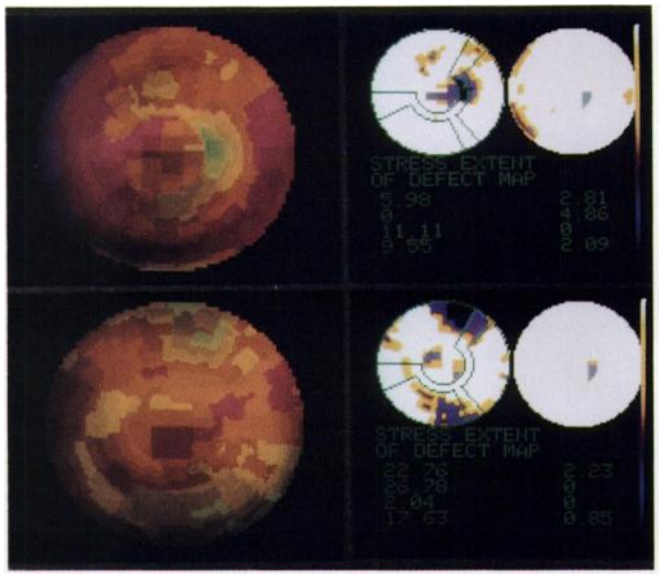

FIGURE 4. Effects of motion timing—polar coordinate display. Shown are resultant polar displays for the studies illustrated here where the effect of "motion" in Frames 7–14 is shown above and the effect due to alterations in Frames 18–25 is shown below. Here differences in defect size and location are apparent. The color polar displays at left represent the relative difference in count distribution between altered stress and delayed SPECT image sets. Here red or dark grey represents peak activity. Those at right indicate regional abnormalities in altered poststress and delayed images compared to a normal population.

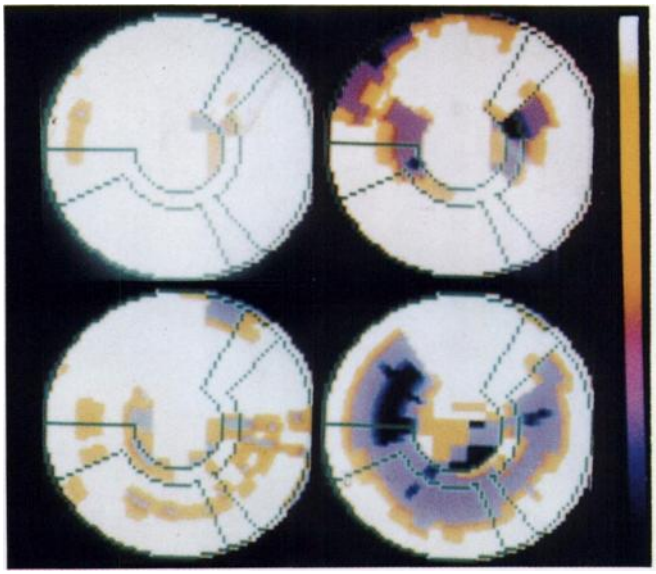

FIGURE 6. Combined effects of vertical and horizontal displacement. Shown are polar displays of resultant SPECT images following computer simulation of horizontal rotational motion of 5-frame magnitude, beginning with Frame 16, in the direction of orbital rotation, upper left and counter to the direction of orbital rotation, upper right in Patient 6 (see Table 3). A significant defect shown in violet, blue or black, here in the left anterior descending distribution, was only evident with artifact opposite to the direction of orbital rotation. Shown below are polar coordinate displays of resultant SPECT images following computer simulation of 3-pixel vertical upward motion in Frames 13–20 in the same Patient 6 (Table 2), lower left, and with added horizontal rotational motion of 5-frame magnitude beginning with Frame 16, counter to the direction of orbital rotation, lower right. Note the dramatic increase in defect size when vertical and horizontal motion artifacts were combined.

evaluations of the relationship between motion displacement and resultant SPECT artifacts (*7,8*). Others performed limited analysis of artifacts produced by motion intentionally introduced during acquisition or processing (*7,9*). Eisner et al. (*7*) used a complex cross-correlation function to characterize and quantitate continuous or "nonreturning" vertical patient motion initiated at Frame 16. However, they did not fully determine the sensitivity of the method to vertical displacement, nor did they fully evaluate the relationship between motion direction, magnitude or timing, and resultant defect size and location. This could only be done by applying a computer simulation of "returning" patient motion in designated locations and directions through the data set.

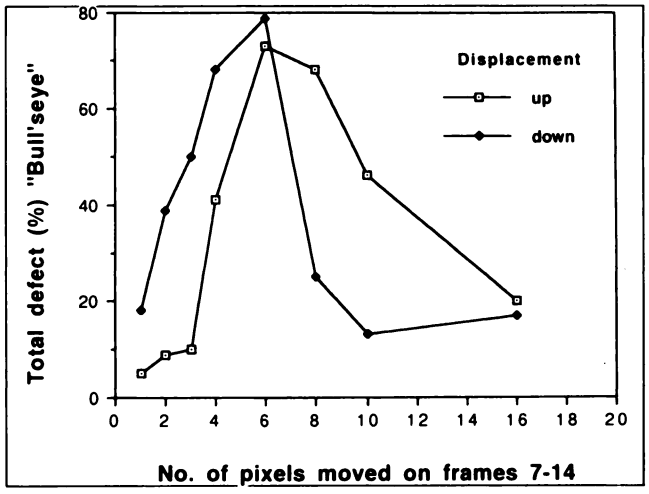

FIGURE 5. Extent of displacement. Shown is the relationship between the extent of displacement (abscissa) and resultant defect size (ordinate) quantitated on polar display, for upward and downward displacement in the same projection images (Frames 7–14). Note the similar patterns and defect size, and the reduction in defect size with increased "motion".

Further, although such returning motion would appear uncommon, both clinical experience and the recent literature (*7–9*) support the variable nature and timing of patient motion during SPECT acquisition. Eisner et al. (*7*) note that multiple episodes of patient motion rather than a square wave nonreturning motion is the "more general case." Additionally, incomplete application of the described computer algorithm to correct apparent nonreturning vertical motion displacement could result in remnant returning motion. Similarly, the effects of horizontal motion artifact on resultant SPECT perfusion images have not been previously analyzed.

This study applied a simple, specially designed computer algorithm to introduce apparent motion during processing

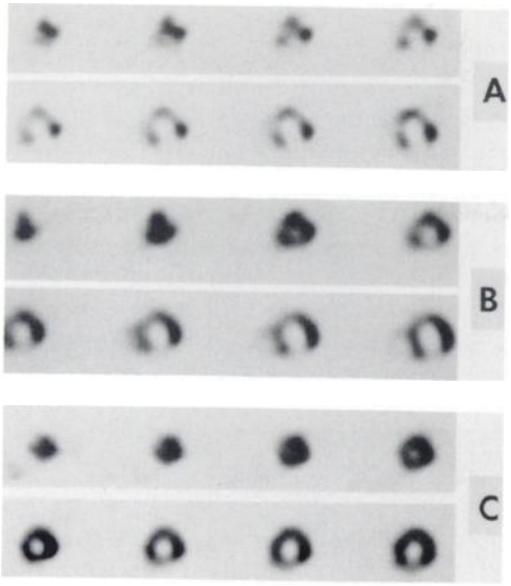

FIGURE 7. Clinical study—vertical motion postexercise. Shown according to the format of Figure 3, are immediate poststress (A) and 4-hr delay (C) contiguous short-axis SPECT slices from apex (upper left) to base (lower right) acquired in a clinical study with gross vertical patient motion during the immediate poststress acquisition. Here, obvious defects were improved after applying the motion correction algorithm on the same immediate poststress data. This partially corrected version of images shown in (A) is shown in (B). Postprocessing could not correct motion artifacts in most cases.

in otherwise normal SPECT studies in order to determine the specific effects of vertical patient motion along a single axis on resultant SPECT images. In the course of this analysis, tolerance of the SPECT method to patient motion was assessed and the influence of the extent, direction, duration and location of motion, which determine such tolerance, were identified and quantitated. While the findings here will not prevent artifacts, they will make us more alert to their occurrence and help us understand the limits and effects of motion. This could aid image interpretation.

Previous workers suggested that motion as little as a centimeter could cause a significant image artifact (*7*). While this may be the case when many frames are affected, the situation is clearly more complex.

The presence and extent of SPECT vertical motion artifacts vary with number and location of the projection images affected as well as the direction and extent of their displacement. Specific artifactual effects of motion on SPECT imaging were related to the extent of displacement, the duration of displacement, the number of frames and the specific frames affected (Figs. 1–4 and Tables 1 and 2). While the SPECT method seemed quite sensitive to displacement toward the center of the orbit, a unique sensitivity of the central region could not be demonstrated.

The extent and duration of vertical displacement appeared additive in their influence on image artifacts. This supports the preliminary findings of Prigent and coworkers (*9*) who noted that the product of extent and duration of motion, the pixel-frame "area," determines the presence and extent of resulting image artifact. However, SPECT perfusion images are relatively tolerant to isolated motion affecting few frames. While even extensive motion brought little change when affecting one or two frames, minor displacement brought obvious defects when affecting eight frames. These findings agree generally with observations of others (*7–9*) and carry them further. The location of SPECT motion artifacts relates to the direction of displacement as well as the location of frames affected.

Some of the effects of patient motion on SPECT images appear obvious, while others, such as the biphasic relationship between motion displacement and SPECT defect size, were surprising (Figs. 3 and 6, Table 1). These findings suggest an effect of the backprojection technique on the analysis of displaced and nondisplaced projection images; these may overlap as displacement approaches the ventric-

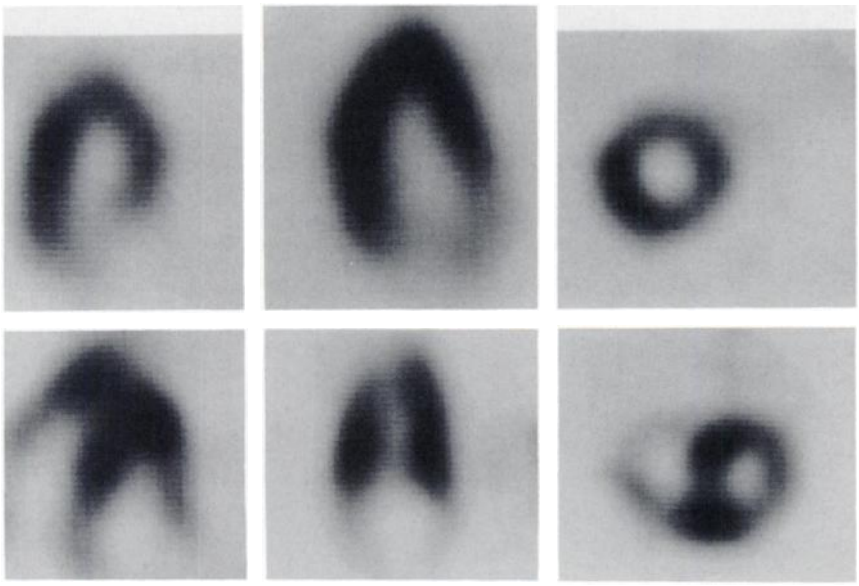

FIGURE 8. Clinical study—horizontal motion. Shown are examples of SPECT short-axis (left column) vertical long axis (center column) and horizontal long-axis (right column) slices acquired postexercise in a clinical study associated with obvious horizontal displacement (above). Gross artifactual duplication of shifted ventricular walls is apparent in short-axis and horizontal long-axis slices. These could not be software corrected but were no longer evident on subsequent re-study (below). Rotation in or counter to the orbital direction was evaluated in computer studies. However, in this clinical case there was evident horizontal motion in addition to rotation.

ular dimension. Here, projected myocardial walls initially move apart, then overlap with reinforcement of radioactivity in superimposed structures, maximizing the resulting SPECT defect, and then move apart again to minimize the defect. Incremental displacement brought first increasing, then decreasing SPECT defects related to the degree of image overlap and the varying reinforcement of regional ray sums. The nature of image motion artifacts relates to the interaction of image data in ray sums and can be less severe and more limited in relation to greater displacement. While of unlikely practical clinical significance, the analysis of the effects of such extensive motion provides insight into the method.

Identified were visual cues suggesting artifactual motion-related SPECT defects. The irregular, lumpy nature of defects, the often opposing distribution of motion-related artifacts and the presence of curvilinear extraventricular radioactivity likely relate to the relationship of backprojection ray sums of displaced and nondisplaced ventricular radioactivity (Fig. 3). These should be carefully sought on SPECT interpretation. However, only a review of projection images can reliably provide supporting evidence of patient motion.

While horizontal motion was less intensely analyzed, it appeared as though the SPECT method was more sensitive to motion counter to the rotational axis and that defects related to vertical and horizontal motion were additive.

Some have suggested the possibility of correcting for patient motion during SPECT processing (*7,12*). The algorithms applied here to test the effects of patient motion artifacts could be applied to correct such artifacts by the proper adjustment and alignment of affected projection images. Of course, such correction could only succeed if the artifact was produced by a pure vertical or horizontal motion in specific identified frames. As we noted in our clinical subgroup, this occurs rarely and our ability to fully correct motion artifacts is limited (Figs. 7 and 8). Further, this method can do nothing to correct for artifact due to motion in other planes. The clinical patient example of horizontal motion artifact (Fig. 8) was further complicated by evident horizontal displacement. In addition to probable horizontal rotation, the latter alone could likely be analyzed and corrected with the algorithm presented here. The double cardiac image presented in the clinical study likely results from this horizontal displacement but was not evident in association with simulated horizontal, rotational motion created here by the computer algorithm.

On the other hand, application of the method, seeking correction of apparent motion artifact with partial but obvious improvement in resulting SPECT defects, may provide tangible support to the origin of SPECT image defects in patient motion. As noted by DePuey and Garcia (*5*), motion is best detected by observation of the dynamic display of the projection images. It is obviously important to recognize the presence of motion and the observations here help to relate this observation to SPECT image findings. However, it is clear from this study and a wealth of clinical material that the best way to minimize a SPECT motion artifact is to prevent its occurrence.

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