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Performance of the automated motion correction program for the calculation of left ventricular volume and ejection fraction using quantitative gated SPECT software

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The effectiveness of the automated motion correction software (INSTILL, Philips Medical Systems Co. Ltd., Andover, USA) proposed by Matsumoto et al. to prevent motion artifact in quantitative gated SPECT, was tested with a technetium-99m point source and cardiac phantom. INSTILL well corrected the error due to point source movement during acquisition up to a distance of 5 pixels (32.8 mm) in the right and caudal directions, as well as with a distance of up to 7 pixels (45.9 mm) of oblique (caudal-right 45 degree) movement inside the coronal plane. End-diastolic volume (EDV), end-systolic volume (ESV) and ejection fraction (EF) were also well adjusted with INSTILL, for up to 3 pixels (19.7 mm) movement of the dynamic cardiac phantom during acquisition in the right, caudal and oblique directions. The respective maximum error with one, two and three pixel movement was 9, 24 and 23 m*l* in EDV, and 8, 22 and 21 m*l* in ESV. The maximum error of EF was 3% in all conditions without INSTILL. After using INSTILL, the maximum residual errors of both EDV and ESV were 7 m*l* and that of EF was 3% in all conditions. Quantitative gated SPECT software with INSTILL will calculate EDV, ESV and EF against movement of patients in the coronal plane. INSTILL is therefore concluded to be a reliable software for motion correction in clinical use.

Key words: quantitative gated SPECT, automatic motion correction, EDV, ESV, EF

INTRODUCTION

THE QUANTITATIVE GATED SPECT software (QGS) proposed by Germano et al. in 1995[1] is a useful method for estimation of left ventricular function and myocardial perfusion and viability. The accuracy of end-diastolic volume (EDV), end-systolic volume (ESV) and ejection fraction (EF) measured with QGS was confirmed by previous reports.[2,3] It is well known that the motion of a patient and/or heart itself modifies the results of myocardial SPECT.[4–6] To avoid these motion artifacts, Matsumoto et al. developed the automatic motion correction software (INSTILL, Philips Medical Systems Co. Ltd., Andover, USA).[7] This program is widely used and is built into the Auto SPECT software package. The effectiveness of this software to avoid false-positive perfusion defects was well demonstrated.[7] However, the correction effect against errors of EDV, ESV and EF, which are caused by patient motion, has not been reported in detail. In this article, basic patterns of movement were produced with a technetium-99m (Tc-99m) point source and dynamic cardiac phantom during acquisition, in order to examine the effectiveness of INSTILL for the correction of EDV, ES and EF.

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MATERIALS AND METHODS

Tc-99m point source and a dynamic cardiac phantom (type HD, Kyoto Kagaku Co. Ltd., Kyoto, Japan), proposed by Kubo et al.,[8] were imaged with a 2-head gamma camera (Vertex Plus, Philips Medical Systems Co. Ltd., Andover, USA) and data set was processed with PEGASYS workstation (Philips Medical Systems

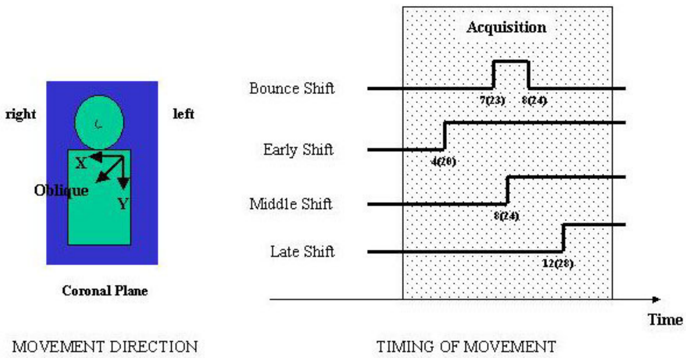


Fig. 1 The left and right columns show the direction and timing of phantom movement. The movement was produced within the "coronal plane." The bounce shift is a transient movement during acquisition. The early, middle and late shifts are permanent movements which begin in the early, middle and late periods during acquisition. The number on the right column represents the step number. The number in parentheses represents the step number of the second detector. *X*; right direction, *Y*; caudal direction.

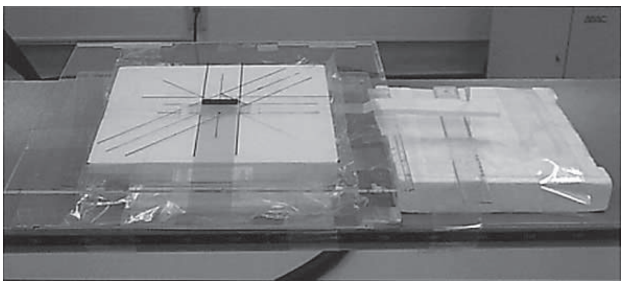


Fig. 2 Figure 2 shows the moving tray. The movement distance and direction were determined precisely using the measure fixed on the tray. A cardiac phantom was put on the tray attached to the table of a scinticamera.

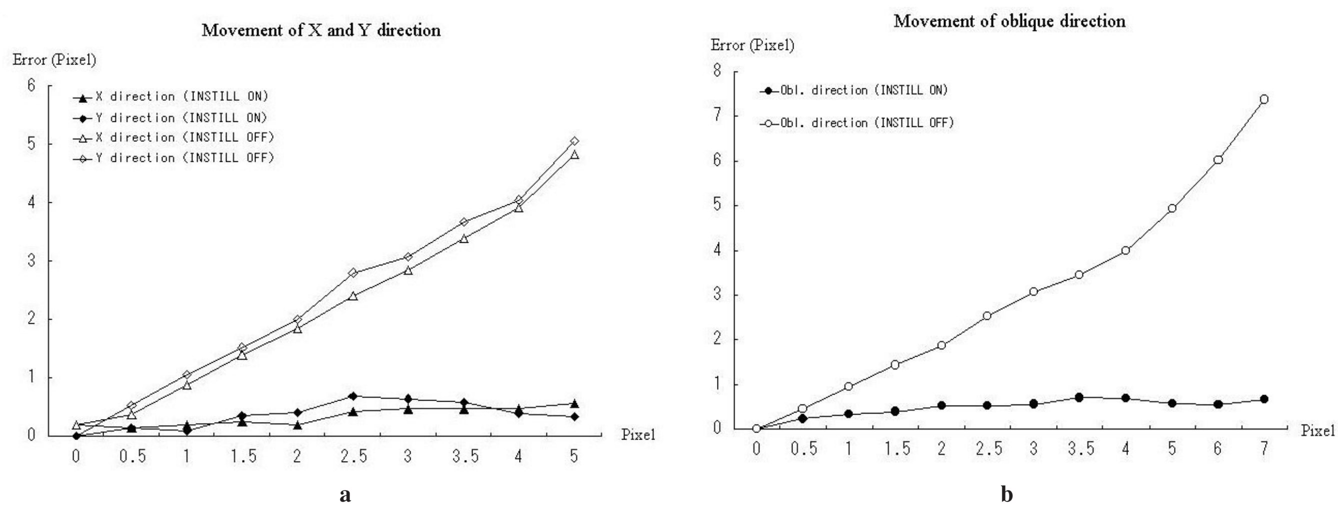
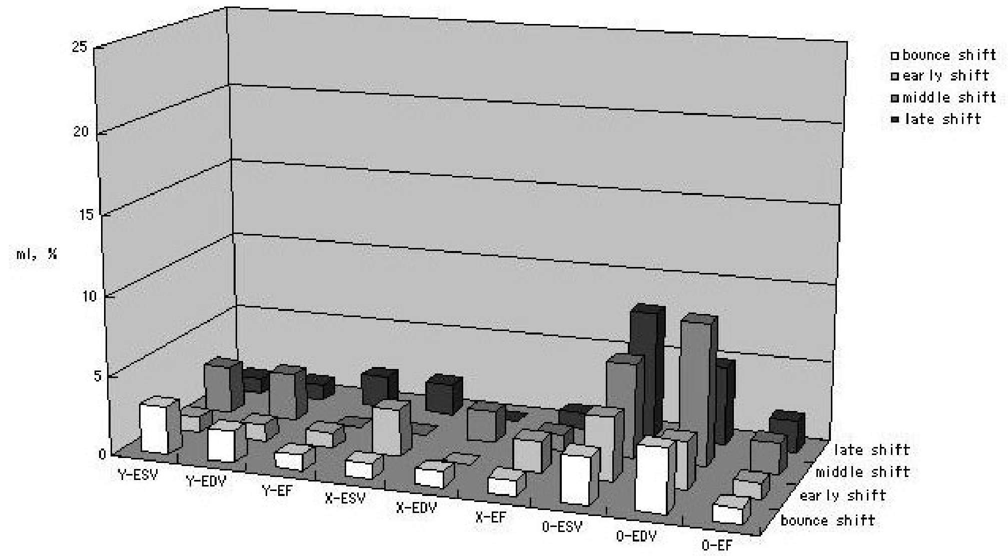
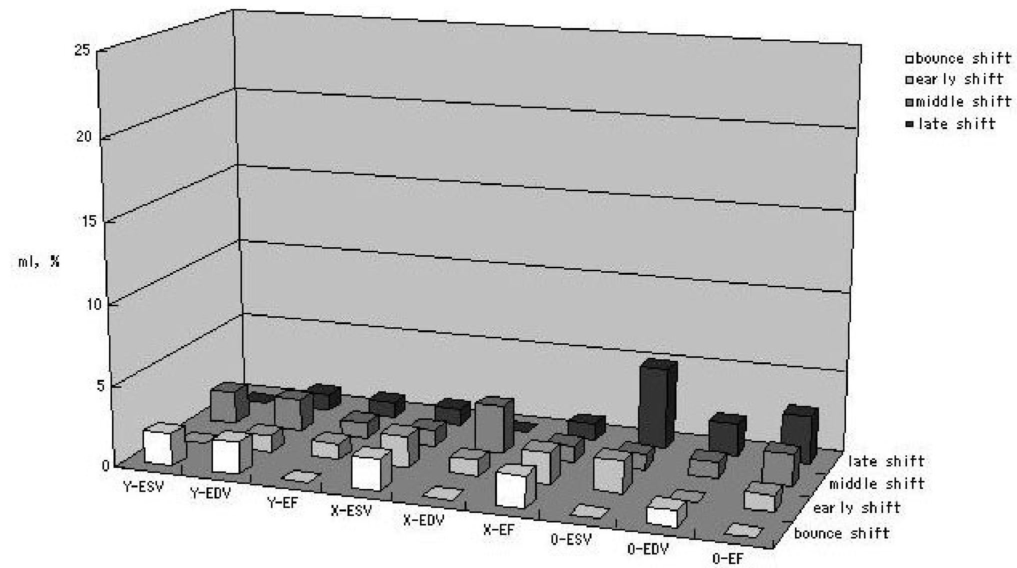


Fig. 3 Figure 3 shows correction of point source movement in *X* and *Y* (a) and oblique (b) directions. The vertical axis represents position error in the reconstructed image, and horizontal axis represents the amount of movement in each direction. The closed symbol represents reconstruction with INSTILL and open symbol that without INSTILL. The simple correlation coefficients between error of each condition and the amount of movement were calculated as 0.99 ($p < 0.0001$; *X* and *Y* direction without INSTILL), 0.94 ($p < 0.0001$; *X* direction with INSTILL) and 0.61 ($0.05 < p < 0.1$; *Y* direction with INSTILL).



a 1 pixel movement without INSTILL

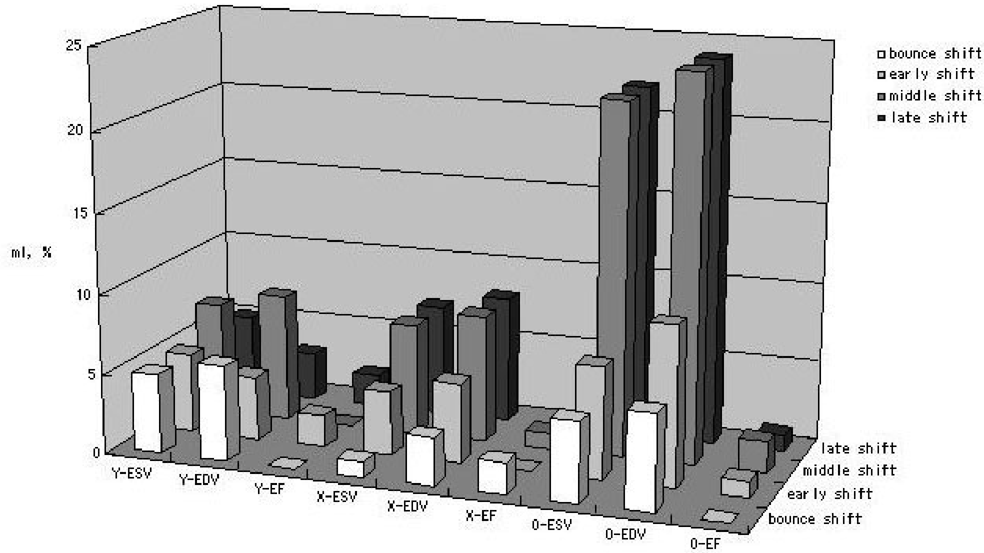


b 1 pixel movement after correction with INSTILL

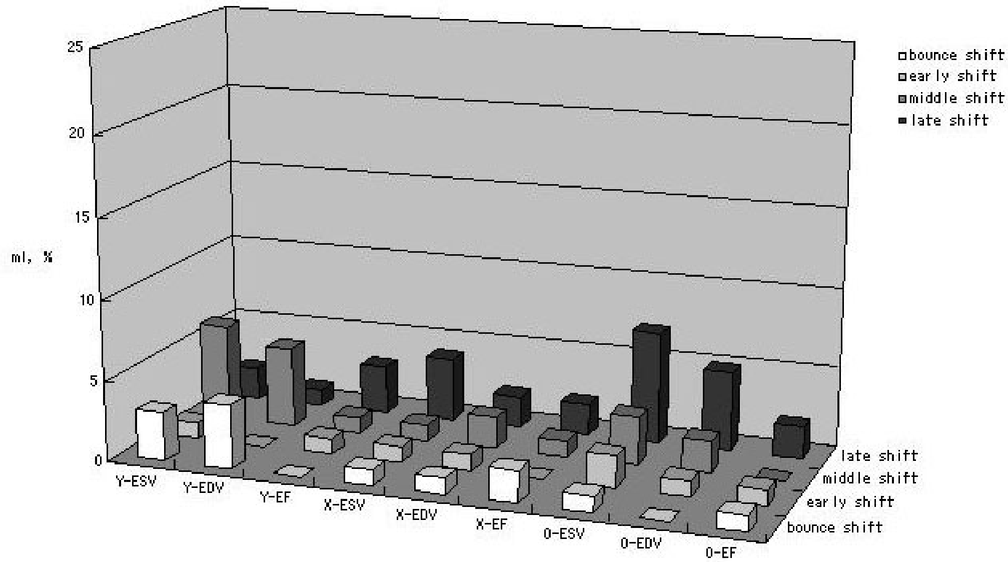
Fig. 4 Figure 4-a shows the error of EDV, ESV, and EF produced by movement in each direction (*X*, *Y*, and Oblique, as represented in Fig. 1) and each pattern without INSTILL. The amount moved is 1 pixel (6.56 mm/pixel). Figure 4-b shows the residual errors after adapting INSTILL. O: Oblique direction

Co. Ltd., Andover, USA) to examine the effectiveness of INSTILL. The data acquisition was performed under the following conditions: arrangement of detector; vertical position, total rotation; 180 degree/32 step, start position; 315 degrees (right anterior oblique), field of view; 38 cm × 38 cm, matrix; 64 × 64, acquisition time; 40 sec/step, collimator; low-energy general purpose (VXGP, Philips Medical Systems Co. Ltd., Andover, USA), photopeak 140 keV ± 14 keV. Butterworth (cutoff 0.38 cycle/cm, power factor 10) and Ramp filters were used as processing filters. The acquisition was performed with ECG gating, and R-R interval was divided into 16 intervals.

Thirty-three MBq of Tc-99m point source and a dynamic cardiac phantom filled with 12.7 MBq of Tc-99m solution were moved toward three directions, right (*X*), caudal (*Y*) and caudal-right 45 degrees (oblique), during acquisition (Fig. 1). Four different patterns of movement were defined on the basis of movement timing (Fig. 1). Bounce shift is a temporary movement during the 7th and 8th (23rd and 24th) steps. Early, middle and late shift is a permanent shift at the beginning of the 4th, 8th and 12th (20th, 24th and 28th) steps. The number in parentheses means the step number with the second detector. Twelve different combinations of movement direction and timing were tested with a cardiac phantom. Only middle shift of three directions was applied with point source. This



a 2 pixel movement without INSTILL



b 2 pixel movement after correction with INSTILL

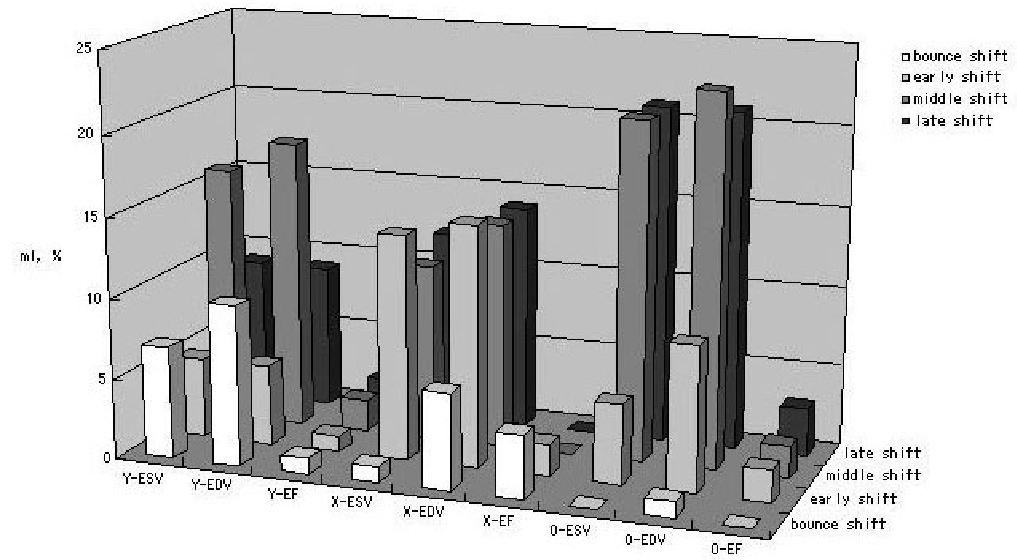
Fig. 5 Figure 5-a and 5-b shows the error of EDV, ESV, and EF produced by movement in each direction (*X*, *Y*, and Oblique, as represented in Fig. 1) and each pattern, before and after adapting INSTILL. The amount moved is 2 pixels (6.56 mm/pixel). O: Oblique direction

phantom and point source were put on a moving tray made by ourselves during the examination in order to quantify movement distance and increase reproducibility (Fig. 2). The amount of point source movement produced was from one to five pixels in 0.5 pixel steps (6.56 mm/pixel) in the *X* and *Y* directions, and from one to seven pixels in the oblique direction. The phantom was moved up to three pixels in one-pixel steps in each direction.

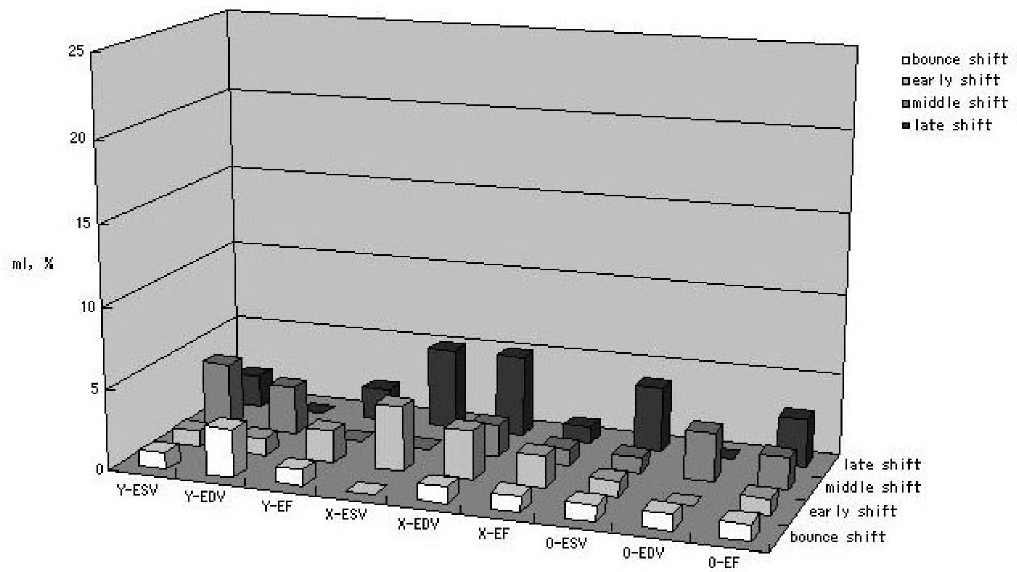
To estimate shift of the point source, the ideal position of the non-moved point source and real acquired position of the moved point source were compared at each of the 32 views of all steps. The error was defined as the difference between the maximum and minimum distances of these two positions. Post data processing was performed in two ways, with and without INSTILL. As for the phantom study, post data processing was also performed using QGS software with and without INSTILL, and EDV, ESV and EF were calculated. These results were evaluated by paired t-test for every movement distance in each of EDV, ESV, and EF to determine the effectiveness of INSTILL.

RESULTS

Figures 3-a and 3-b represent the error originating from movement of the point source and correction effect of



a 3 pixel movement without INSTILL



b 3 pixel movement after correction with INSTILL

Fig. 6 Figure 6-a and 6-b shows the error of EDV, ESV, and EF produced by movement in each direction (*X*, *Y*, and Oblique, as represented in Fig. 1) and each pattern, before and after adapting INSTILL. The amount moved is 3 pixels (6.56 mm/pixel). O: Oblique direction

INSTILL. The maximum error in each direction was 4.8 pixels in 5-pixel shift of *X* and 5.1 pixels in 5-pixel shift of *Y* and 7.4 pixels in 7-pixel shift of oblique direction. The maximum error after correction in each direction was 0.56 pixels in *X*, 0.68 in *Y* and 0.70 in the oblique direction.

Figures 4-a, 5-a and 6-a show the error between calculated EDV, ESV and EF without INSTILL and settled EDV, ESV and EF of cardiac phantom in each direction and pattern of phantom movement. Figures 4-b, 5-b and 6-b illustrate the respective values after adoption of INSTILL. Figures 4, 5 and 6 show one, two and three-pixel movement, respectively. All calculated values of EDV and ESV in every movement condition in Figures 4-a, 4-b, 5-a, 5-b, 6-a and 6-b were smaller than those of the real values. The error in EDV and ESV increased with the amount of movement. The largest error was produced by an oblique direction in Figure 4-a, 5-a and 6-a. The maximum error with two and three pixel movement was 24 and 23 m*l* in EDV, and 22 and 21 m*l* in ESV respectively. The error in EF was much smaller than that in EDV and ESV, and the maximum error was 3% in all movement conditions without INSTILL.

Bounce and middle shift produced larger error in EDV and ESV than early and late shift in *Y* direction movement (Figs. 4-a, 5-a, 6-a). Middle and late shift produced larger error in EDV and ESV than bounce and early shift in 2-pixel *X* direction movement (Fig. 5-a). The error produced by 3-pixel movement of early shift in *X* direction was also as large as those of middle and late shift (Fig. 6-a). Middle and late shift produced larger error in EDV and ESV than bounce and early shift in oblique direction movement (Figs. 4-a, 5-a, 6-a).

The errors of EDV and ESV were decreased using INSTILL as shown in Figures 4-b, 5-b and 6-b. The p-value of each case was as follows: EDV and 1-pixel movement $p = 0.08$, EDV and 2-pixel movement $p = 0.004$, EDV and 3-pixel movement $p = 0.0001$, ESV and 1-pixel movement $p = 0.01$, ESV and 2-pixel movement $p = 0.007$, ESV and 3-pixel movement $p = 0.0008$. Residual errors of EDV and ESV did not exceed 7 m*l* after adaptation of INSTILL in any condition. As for the error in EF, there was no significant difference between with and without INSTILL in any movement distance. The maximum residual error of EF was 3%.

DISCUSSION

The ability to correct for point source movement is considered to be the most basic test for INSTILL. In our experience, INSTILL has well corrected up to 5-pixel (32.8 mm) point source movement in *X* and *Y* direction. The maximum residual error after adaptation of INSTILL is 0.56 pixels (3.7 mm) and 0.68 pixels (4.5 mm) in *X* and *Y* direction movement. It also corrected within 7-pixel of oblique point source movement (45.9 mm). The maximum residual error after adaptation of INSTILL was 0.70 pixels (4.6 mm) in the oblique direction. The residual error tended to increase along with movement amount. There is no obvious difference in residual error between any direction. These basic data suggest the usefulness of INSTILL in clinical use. It is rare for a patient to move more than 32.8 mm during acquisition.

Patient motion is well known to affect the size and degree of myocardial distribution defects. Thus, patient motion is also thought to affect quantified cardiac index with QGS. On the other hand, it is reported that about a quarter of patients experience motion during acquisition.[4,9] Previous reports focused mainly on abnormalities such as false-positive defects originating from patient movement.[4,5,7,9] However, the effect of patient motion on quantitative cardiac indexes (EDV, ESV and EF) which are calculated with QGS, is also important. Few papers, however, have estimated the errors in these indexes caused by patient motion.

In the movement of *Y* direction, bounce and middle shift produced larger errors of EDV and ESV than early and late shift. It is considered that a view with higher counts affects the reconstruction of SPECT more markedly than other views.[7] In our acquisition, starting degree is 315 degrees, and step interval of the detectors is 5.6 degrees (90 degrees/16 steps). The data of complete anterior view, that has the highest count, were acquired at step 8. (The ratio of anterior view count against the averaged count of all other views is calculated as 1.1.) Thus, any movement around step 8 produces a greater error than at other times in the movement of *Y* direction.

In *X* direction, middle and late shift produced larger errors. Artifactual defects of myocardium were reported to be most marked when movement was produced at the late period of acquisition time in dual head scinticamera.[7] This is because steps in the late period of acquisition (left side views of patient) have greater counts than those in the early period. Late shift together with middle shift also created greater errors in our study. The movement of *X* direction is towards the right side of patients in our study, which increases the count of views in the early period of acquisition (right anterior oblique view for first detector). Thus, the error of early shift became more significant in 3-pixel shift. The artifactual effect of the movement inside the axial plane is complex, since it changes the count distribution of each view and the amount of movement effect varies with its direction.

The errors of EDV and ESV tended to increase more with movement in the oblique direction than in *X* and *Y* direction, and accordingly special notice must be taken of this kind of movement in the clinical context. Direction, amount and the timing of the start of the movement influence the errors of EDV and ESV. It was also reported that the significance of the motion artifact depends on the direction, amount and timing of the start of the movement.[4,7]

The movement-induced error of EDV and ESV did not originate from false positive defects of myocardium, but from the bend of the detected myocardial border. Up to 3-pixel shift, the false positive defect does not significantly influence the calculated values of EDV, ESV or EF.

In our experience, the movement, regardless of direction, of a phantom mainly changes the values of EDV and ESV, whereas the value of EF is minimally affected. This is because the effect of phantom movement on EDV cancels that of EDV. Thus, it is conjectured that the EF value calculated with QGS is more reliable despite patient motion compared to that of EDV and ESV. The errors of EDV and ESV increased with increasing movement distance. As for the direction of movement, oblique shift created the largest error.

The values of EDV and ESV were remarkably well corrected using INSTILL up to 3-pixel movement. The maximum residual error of EDV and ESV was 7 m*l*, which is not considerable in clinical measurements of either value, since such small changes in EDV and/or ESV rarely modify clinical decision-making in adult patients. The maximum error of EF was 3% in every condition, which is also not significant in clinical use. In the situation of within 19.7 mm (3-pixel) of patient movement, EDV, ESV and EF will be calculated accurately enough with QGS using INSTILL.

In conclusion, INSTILL was effective in correcting the tested point source and dynamic cardiac phantom movements of up to 7 and 3-pixel distance respectively, and thus is useful in clinical practice.

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