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ORIGINAL ARTICLE

Motion correction and myocardial perfusion SPECT using manufacturer provided software. Does it affect image interpretation?

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Abstract

Purpose Myocardial perfusion SPECT is an excellent tool for the assessment of coronary artery disease (CAD); however, it is affected by several artifacts, such as patient motion during acquisition, which increases false-positive rates. Therefore, the purpose of this work is to analyze changes in perfusion scores after motion-correction software application.

Methods The population included 160 ^{99m}Tc-sestamibi CAD studies, divided into two groups: with and without perfusion defects, equally divided into subgroups according to movement during standard acquisition. A Siemens ECAM 180 was used for processing without correction and with automatic and manual e.soft 2.5 modalities. Visual interpretation as well as QPS software was compared using Pearson correlation and kappa agreement statistics.

Results Moderate agreement was observed between SPECT interpretations after motion correction versus the original report, according to the presence of perfusion defects. Manual correction using the software obtained the lowest agreements. Perfusion summed stress scores (SSS) correlation from different processing modalities versus non-corrected studies differed significantly independent of the degree of motion. Mean SSS in 40 patients with no motion was 3.9±3.9 when no correction was applied; with automatic correction was 8.8±10 (p=0.03) and with manual correction was 3.1±3.5 (p=ns versus non-corrected). Automatic correction was better when applied to patients with mild to moderate motion. In those with mild or no motion, software overestimated or created new perfusion defects.

Conclusion Motion-correction software must be used with caution when trying to optimize myocardial perfusion SPECT based on individual analysis. Acquisition should be always repeated in cases with severe motion and in no or mild motion it seems preferable to avoid correction.

Keywords Single-photon emission computed tomography (SPECT) · Myocardial imaging · Motion correction · Artifacts

Introduction

Artifacts in myocardial single-photon emission computed tomography (SPECT) could have a significant impact on specificity, mainly by the creation of false or inaccurate images [1–6]. Sudden or gradual body motions are frequently observed depending on the technique used and the particular patient status. Motion could be still present despite clear indications and comfortable positioning, mainly in longer acquisition. It is probably more common in centers with no multi-detector equipment, in patients unable to maintain arm overextension, or those with respiratory distress or chronic cough.

Subsequent artifacts may correspond to loss of contrast (seen as defects) or hot spots in the myocardial wall. Basal distortion, dislocation, tails and early septal drop-off as well as a hurricane-image has been also described with severe motion. The *upward creep* is a phenomenon observed early post-exercise stress (axial superior to inferior cardiac movement with the diaphragm returning to resting position); even though it is not present with delayed stress ^{99m}Tc imaging, motion correction methods are still required.

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Another common cause of motion not considered is normal respiratory movement. However most works in this setting are oriented to analyze new methods of motion detection and correction; their application has been evaluated with phantoms and experimental situations and some performed with clinical cases [7–16]. Image recovery in unsatisfactory myocardial SPECT studies due to patient motion is a challenge. It is not clear which amount of movement could be important; it appears to depend on several factors. Being discussed is the possible effect in sensitivity in some cases of motion correction using non-adequate quantitative polar maps bases and ^{201}Tl SPECT [8].

Re-acquiring the study in some cases is not possible or helpful; there is a high percentage of motion in second studies due to the basal patient's conditions. Even though prevention and positioning are the rule, support systems as well as several motion-correction techniques have been developed. These programs allow manual or semi-automated compensation of cardiac displacement and should be used when motion cannot be eliminated [3]. Detection and adequate motion correction should always be part of quality control. However, unnoticed over-correction could affect the interpretation worsening the accuracy of the study.

The goal of this work was to assess interpretation changes when using a widely available motion-correction program in routine CAD patients with a different degree of motion during standard acquisition.

Materials and methods

Population

A total of 160 sestamibi ^{99m}Tc-gated SPECT studies were selected retrospectively from our database. They corresponded to patients under evaluation for coronary artery disease (CAD) with a mean age of 64±13 year old, and 44% of them were female.

They were homogeneously distributed from patients consecutively acquired during the 3 years, according to the following inclusion criteria:

a) Presence of any motion in either stress or rest acquisitions based on two observers consensus from cinematic display of raw data graded as absence, mild, moderate or severe patient movement (40 patients each group).
b) Presence of any perfusion defect based in the original clinical report (84 with normal perfusion and 76 with abnormal perfusion).

Exclusion criteria corresponded only to studies with extra cardiac activity that could make difficult the interpretation and also those with gated signal problems.

Equipment and acquisition protocol

A dual-head Siemens ECAM 180 camera was used for all cases. Low-energy, high-resolution collimators in 90° angle were used, 64 × 64 matrixes, auto contour, 180° orbit with 32 steps of 25–30 s each and 8 frames gated SPECT.

We used a 2-day sestamibi protocol with 740–925 MBq dose each day or a 1-day with 296–370 MBq at stress and 925 MBq at rest.

The motion-correction program applied is included in the Syngo system provided by the manufacturer. Motion is estimated using interframe correlation and curve fitting. First, the transverse (horizontal) disparity between a fitted sine function and interframe sinogram correlation shifts is assessed. Second, interframe linogram correlation disparity, estimated from the region containing the heart, determines the axial (vertical) motion. When the initial vertical motion estimate exceeds sub-pixel limits, raw projection frames are motion compensated and the horizontal (sinogram) motion is estimated again. Third, a sub-pixel refinement technique concludes motion estimation. Finally, data obtained from a dual or single detector camera are appropriately compensated.

Processing

Reconstruction was performed using filtered back projection with a Butterworth filter; motion correction was available in our e-soft 2.5 System (Syngo Software Siemens, Medical System, Inc.). All studies were reprocessed applying motion correction with automatic and manual modalities and without either of them. They were then interpreted with blind reading and using Quantitative Perfusion SPECT QPS automatic summed stress and rest score (SSS and SRS).

Statistical analysis

Pearson correlation and kappa coincidence were used in order to compare the variables (kappa provides a measure of the degree to which two judges concur in their respective sorting of N items into k mutually exclusive categories).

Analysis was performed in all cases in processed images with no motion correction, with automatic and also with semiautomatic (manual) correction. Automatic SSS values were used to compare groups, because most motion was observed on stress studies. Due to the fact that a clinical and realistic gold standard was not easy to obtain, the original interpretation performed by our nuclear medicine staff was employed to compare data.

The proportion of females was 60, 50, 37.5, and 27.5% in the groups with none, mild, moderate and severe motion, respectively. Males presented significantly more abnormal perfusion studies 63% versus females only 28% (Fisher exact test $p<0.0001$)

Results

The correlation value (r) in all 160 cases between visual analysis, according to two observers' agreement, and QPS automatic scores for stress and rest scores were:

a) No motion correction for SSS was 0.72 and for SRS 0.82
b) Automatic correction: for SSS was 0.49 and for SRS 0.60
c) Manual correction: for SSS was 0.71 and for SRS 0.70

I. The summed stress scores in patients with no motion during their acquisition are displayed in Table 1, as well as when using automatic and manual correction.
II. Perfusion scores correlation from both correction modalities vs. non-corrected studies differed significantly, independent of motion severity.

Automatic correction was better when applied in moderate motion. In mild or no motion cases, software may overestimate or create new perfusion defects.

Manual correction was inferior, globally (see Table 2).

III. Interpretation concordance of perfusion SPECT between original reports and newly processed data with or without motion correction software in the same study was lower for those initially normal than for those initially abnormal. This was also observed when using automatic and semiautomatic methods.

In the originally normal studies, concordance between automatic and no correction methods were compared and was 58.3% (kappa 0.19), between semiautomatic and no correction was 72.6% (kappa 0.44), and between automatic and semiautomatic was 50% (kappa 0.04). Those values for the initially abnormal reports were 92.1% (kappa 0.22); 94.7 % (kappa 0.31) and 89.5% (kappa 0.15), respectively. These findings show that the agreement was stronger when comparing semiautomatic with no correction in normal and abnormal perfusion studies (with moderate and low kappa values, respectively). See also Figs. 1 and 2.

Discussion

Currently performed ^{99m}Tc-based perfusion SPECT studies have different imaging characteristics that could enhance artifacts compared with ^{201}Tl, as well as electrocardiography gating or multi-detector systems use could difficult their correction. ^{201}Tl quantitative analysis demonstrated different degrees of abnormalities in normal studies when patient motion occurred; severity varied according to employed methodology.

For Eisner et al. [9] motion as small as 0.5–1.0 pixels (3–6 mm) in the vertical axis caused defects with false-positives up to 40% for a +1.0 pixel shift. Patient motion was greater than 0.5 pixels (considered the threshold for artifact-production) at a rate of 10%. Cooper et al. [10] showed that vertical motion produced more artifacts than lateral motion, reporting that 6.5 mm motion is visually detectable but infrequently clinically important; 13 mm or greater movement frequently caused quantitative abnormalities.

External markers have been advocated, mainly to correct *upward creep* with ^{201}Tl [6]. Matsumoto et al. [11] reported that the simulated motion corrected with their algorithm produced more defects with dual than single head camera.

Germano et al. [12] described a method designed for three head cameras and multi-rotation SPECT cardiac studies using visual patient motion detection.

Leslie et al. [13] used an image-quality method to compare several procedures simultaneously. Visual assessment of a cinematic display of the corrected projection data did not appear to be enough quality control. Prigent et al. [5] also applied a similar cutoff value in order to verify quantitatively a pixel shift score. Kiat et al. [14], as well, published that mild and severe motion occurred in 12 and 4% of the supine studies and in only 3.5% and none of the prone studies, respectively. However, prone imaging is an additional acquisition, requiring longer camera time; ideally,

Table 1 Summed stress scores (SSS from QPS program) in patients with normal perfusion and diverse degree of motion using both correction modalities compared with non-corrected studies

Normal perfusion	*n*	Type of correction	Automatic SSS mean ± SD	*p* vs. Non-corrected
No motion	23	Non-corrected	3.87±3.93	
		Automatic correction	8.78±10.15	0.03
		Manual correction	3.13±3.51	ns
Slight motion	21	Non-corrected	4.76±5.83	
		Automatic correction	5.71±5.71	ns
		Manual correction	3.48±4.39	ns
Moderate motion	19	Non-corrected	2.79±2.80	
		Automatic correction	7.11±7.88	ns
		Manual correction	4.16±6.50	ns
Severe motion	21	Non-corrected	3.95±3.85	
		Automatic correction	5.05±6.39	ns
		Manual correction	3.43±4.84	ns

Table 2 Summed stress scores in patients with any kind of motion with normal and abnormal perfusion SPECT using both correction modalities compared with non-corrected studies

Any motion	n	Type of correction	Automatic SSS Mean ± SD	*p* vs. Non-corrected
Normal perfusion	61	Non-corrected	3.87±4.39	
		Automatic correction	5.92±7.37	ns
		Semiautomatic correction	3.67±5.20	ns
Abnormal perfusion	59	Non-corrected	10.78±9.05	
		Automatic correction	12.85±9.54	ns
		Semiautomatic correction	10.37±8.76	ns

to have multidetectors and also a special table and that is not a widespread accepted protocol.

Multiple and combined corrections appear able to improve accuracy in cardiac SPECT compared with single motion correction [15]. It has been compared, on the other hand, to four different motion-correction algorithms in ^{201}Tl SPECT studies (controlled motion cases) reporting different results among them; patient motion produced some loss of resolution with any magnitude and type of movement [13].

Botvinick et al. [4] using quantitative assessment, published that 25% of their 165 ^{201}Tl SPECT studies presented motion, however, only 5% contribute to image deterioration, being post-acquisition attempts to correct incomplete and ideally should be avoided. Not using motion correction could be a good decision. Prigent et al. [5] also did not correct one pixel motion or those movements produced in the last frames in a work performed with ^{201}Tl.

Bai et al. [16] recently published the development and evaluation of a new motion-correction technique for cardiac studies that claims to be more effective than the current industrial software. Matsumoto et al. [17] reported that specificity significantly increased after motion correction in a group of 38 patients with simulated vertical and horizontal motion. In another work, performed with 130 clinical patients (non-simulated motion) using a dual-isotope technique, they observed that using automatic QPS scores before and after motion correction, only 1.3% of segments considered normal changed to abnormal, whereas 27% of abnormal were reclassified as normal after using the correction program [11].

Tout et al. [18], as well, presented a report in a group of 60 patients from their clinical population, visually classified into three categories between 0 and 2 pixel motion. Their correction algorithm does not significantly interfere with the interpretation of an experimented observer. Gated SPECT parameters also could be affected by motion. Uchiyama et al. [19] in a work with phantoms and a ^{99m}Tc source could correct ejection fraction (EF) and volume errors with their program.

Considering the processing and the reconstruction method selected, Zakavi et al. [20] studied a small group of patients with and without different degrees of motion. They demonstrated that the incidence of abnormal findings and the location of defects were not different between filtered backprojection and iterative reconstructions; but the severity of defects increased with the latter, showing a

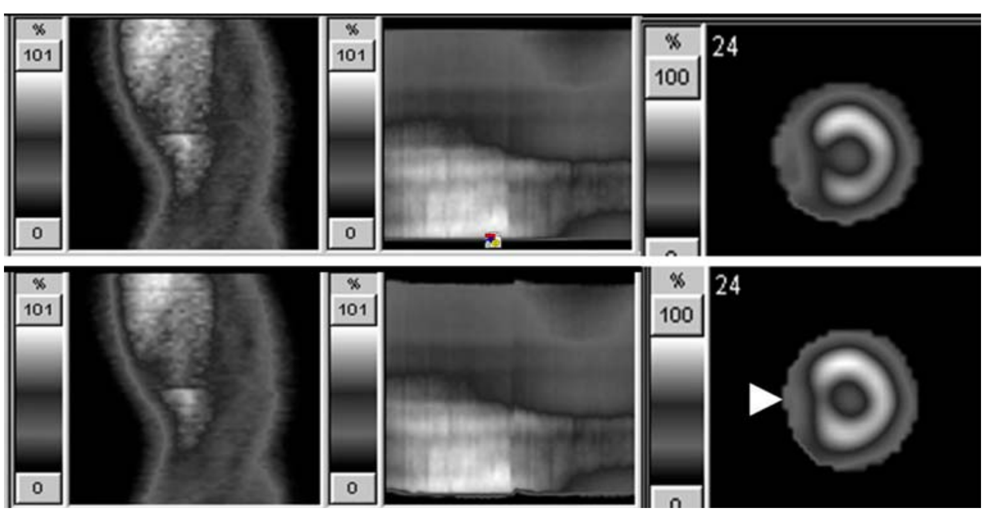

Fig. 1 Improvement of an artifact-induced septal perfusion defect with automatic motion correction. *Upper row*: moderate patient motion, without motion correction, showing quality-control sinogram and linogram and short axis reconstructed image. *Lower row*: same patient, with adequate automatic correction

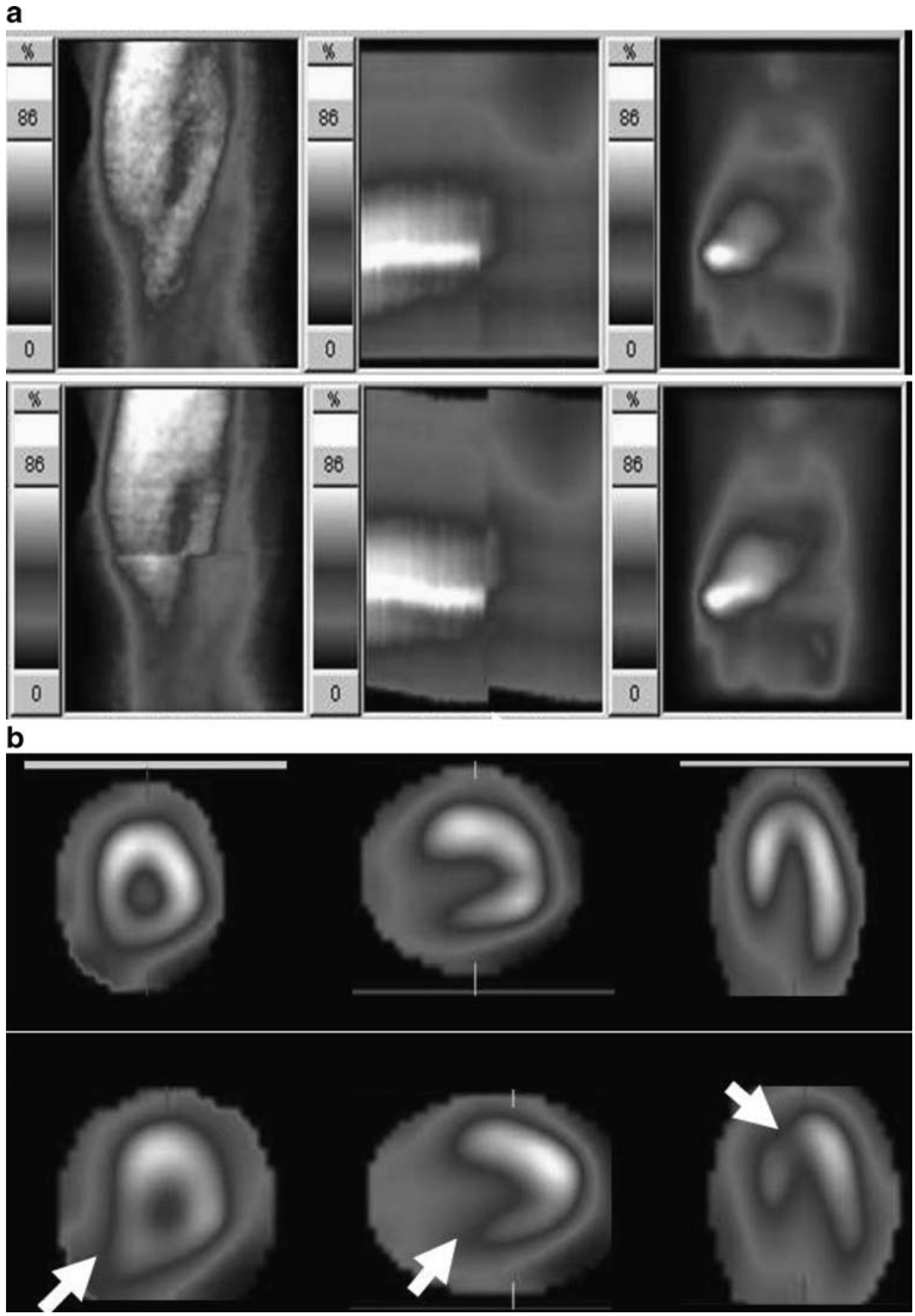

Fig. 2 Overcorrection artifact in a patient without motion during acquisition. *Upper rows*: original sinograms (**a**) and reconstructed images in short and long axis (**b**). *Lower rows*: same patient, unnecessary automatic correction sinograms (**a**) with confusing reconstructed images (**b** *arrows*)

lower tolerance to patient motion regarding reconstruction artifacts.

Even though functional parameters such as ventricular volumes or EF were not analyzed in this study, there is some evidence regarding different EF values obtained from the same patient when no or small motion is present during the acquisition (one to three pixel movement) [21]. We think that more variables involved could have interfered with the gated analysis, due to automatic border selection difficulties. Using simulated motion in 15 SPECT studies, Matsumoto et al. [22] found with QGS: left ventricular volume underestimation but predominantly unchanged ejection fraction in larger end diastolic volumes (but overestimated in smaller ones) and also affected wall motion particularly in larger cavities.

In our data, performed with backprojection, overcorrection was a problem that made us aware of possible artifacts due to routinely performed correction in patients with motion regardless of its severity. In the group with no motion or only mild motion, the automatic program produced a change in the interpretation of the studies overestimating or creating new perfusion defects. Hence, patients with no motion during acquisition should never be submitted to motion correction.

Using quantitative analysis, the observed correlation between corrected and non-corrected studies differed significantly, independent of their degree of motion. Automatic motion correction was better than semiautomatic (manual) when it was applied to patients with a moderate degree of motion.

It is interesting that we observed a trend in women to have less severe motion than males, without a clear explanation, because there was no bias for selection in any group. Gender was balanced without a significant difference in the ratio of male to female. However, males presented significantly more abnormal perfusion studies, perhaps being more enable to maintain their position due to their condition.

As a limitation in our study, it could be mentioned that we did not measure quantitatively the degree of motion present during acquisition; our analysis was based on clinical experience the same way as routinely performed. Another limitation was that we did not analyze left ventricular EF in order to appreciate the influence of motion correction application.

Finally, we agree with Burrell and MacDonald [23] in the following: the technologist has a role in recognizing patient motion and, where appropriate, to use the motion correction capabilities of the equipment to minimize its effect on the study.

Conclusions

Motion-correction software must be used cautiously to optimize myocardial perfusion SPECT specificity in CAD patients. Routine motion correction should be avoided; its use should be decided on an individual basis, due to variable correction results. These results confirm that quality-control supervision is necessary before image interpretation. Mild motion probably does not need correction. In moderate cases, if the corrected data is adequate it could be used for interpretation instead of the original, preferring automatic correction. On the other hand, all cases with severe motion should be always repeated, especially if they correspond to an abnormal perfusion study. Eventually, it could be repeated under sedation or using a shorter acquisition protocol. Correction could be used mainly in moderate motion cases.

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