IMAGING

Incidence and Characterization of Patient Motion in Myocardial Perfusion SPECT: Part 1

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Despite advances in ^{99m}Tc-based radiopharmaceuticals and multiple-detector gantries, patient motion in myocardial perfusion SPECT acquisitions is still problematic and may produce artifacts that mimic coronary artery disease. ***Methods:*** A prospective cross-sectional study of 800 myocardial perfusion SPECT studies performed with ^{99m}Tc-based radiopharmaceuticals at 3 private nuclear medicine sites was used to determine the incidence, type, and location of visually detectable motion. The rotating cinematic display and sinograms of the ungated datasets were visually assessed by 2 experienced technologists unaware of the other observer's responses and the clinical outcome. ***Results:*** Among the 800 studies analyzed, 36% contained visually detectable motion. Motion was seen on 31.5% of rest studies, compared with 40.5% of stress studies ($P = 0.004$). The most common type of motion detected was multiple bounce, which represented 47.6% of motion. Left anterior oblique and anterior were the most common specific locations in which patient motion was detected in the raw data. ***Conclusion:*** This investigation established the significant incidence of patient motion during ^{99m}Tc-based myocardial perfusion SPECT studies that, fully realized, has the potential to introduce artifacts leading to false-positive findings. Further investigation of the impact of various types and degrees of patient motion is recommended.

Key Words: patient motion; incidence; myocardial perfusion SPECT; motion artifacts

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Recent years have seen numerous advances in the technology, science, and methodology used to perform myocardial perfusion studies in nuclear medicine. Despite advances in radiopharmaceuticals (^{99m}Tc-based) and instrumentation (gated SPECT on multiple-detector gantries), patient comfort is still problematic.

Patient motion often occurs because of patient discomfort. The patient may have difficulty with hyperextension of the arms because of arthritis, weakness, fatigue after a stress test, previous surgery to the shoulders, or a general lack of fitness, flexibility, or cooperation. Anxiety about the procedure and the possible outcome can also cause the patient to move (*1–4*). A review of the literature reveals that patient motion has been reported in 10%–26% of clinical SPECT myocardial perfusion studies (*1,4,5*). The artifacts produced by patient motion in myocardial SPECT acquisitions commonly mimic coronary artery disease (CAD) and may be interpreted as ischemia both qualitatively and quantitatively, leading to a false-positive finding of CAD (*6*).

The purpose of this research was to evaluate and characterize patient motion commonly seen during ^{99m}Tc-based myocardial perfusion studies. The aim of this study was to evaluate the proportion of clinical myocardial perfusion studies that demonstrate motion in the image dataset and to characterize the types of movement that occur.

MATERIALS AND METHODS

Study Design and Subjects

This was a prospective, cross-sectional study of consecutive patients undergoing myocardial perfusion SPECT using ^{99m}Tc-based radiopharmaceuticals at 3 nuclear medicine departments. All data were acquired using 1 of 3 protocols: 1-d rest/stress, 2-d rest/stress, or 2-d stress/rest. An MS3 scanner (Siemens Medical Systems) was used in department 1, a Prism 3000 (Philips Medical Systems) in department 2, and a Prism 2000 (Philips Medical Systems) in department 3 (Table 1).

Evaluation of the Presence of Motion

The raw SPECT dataset for each study (rest and stress) was converted from an 8-interval gated study to an ungated SPECT dataset by summation of the 8 intervals for each projection. The rotating cinematic display and sinograms for the ungated datasets were viewed independently by 2 experienced technologists who were unaware of the other observer's responses and the clinical outcome of the study. Each study was assessed for the presence of visually detectable motion, the type of motion, and the location of the motion. These data were recorded along with the patient identification number, nuclear medicine site, type of study

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TABLE 1
Acquisition Parameters for Myocardial Perfusion SPECT

Parameter	Department 1	Department 2	Department 3
Configuration	Triple detector	Triple detector	Dual detector
Collimator	LEHR	LEHR	LEHR
Mode	Step and shoot	Step and shoot	Step and shoot
Orbit	Noncircular	Noncircular	Noncircular
Matrix	64 × 64	64 × 64	64 × 64
Magnification	1.23	1.23	1.488
Angular range	120°	120°	180°
Angular step	4°	3°	6°
Number of steps	30	40	30
Time/step (s)	25	20	25
Gate bins	8	8	8
Rotation	Clockwise	Counter-clockwise	Clockwise
Orientation	Supine/ head out	Supine/ head out	Supine/ head in

(rest or stress), study protocol, gantry configuration, and patient age.

After the interpretation guidelines for the study had been established, the 2 observers performed a masked evaluation of a 50-study sample to establish interobserver agreement. Cohen's κ-coefficient was calculated as 0.85 for interobserver reliability, demonstrating excellent agreement beyond chance for the 2 observers. The raw, ungated data for each of the 800 studies (400 rest and 400 stress) were individually displayed and were evaluated by observation of both the rotating cinematic display and the sinogram.

The cinematic display and the sinogram were examined for the presence of an obvious disruption to their smooth progression (Fig. 1). Motion was deemed to be present only when the observer was certain of its existence. Motion on the patient's *y*-axis (vertical) was best detected using the rotating cinematic display, although larger vertical motions were also apparent on the sinogram. Motion on the patient's *x*-axis (lateral) was best detected using the sinogram, although lateral motions were also apparent on the cinematic display.

Types of Motion

Motion observed on the myocardial perfusion SPECT studies was categorized as one or more of the following:

Bounce Up or Down. The position of the heart altered superiorly or inferiorly on the *y*-axis as a single event. The alteration was followed by a return to (or nearly to) the original *y*-ordinate within a frame interval that indicated a single motion visually.

Abrupt Up or Down. The position of the heart altered superiorly or inferiorly on the *y*-axis as a single event without a subsequent return to the original *y*-ordinate.

Multiple Bounce. The position of the heart altered in either or both directions on the *y*-axis on multiple occasions during the acquisition. Care was taken to ensure that a single event of bounce or abrupt motion was not interpreted as a multiple bounce when the single event was simultaneously detected by multiple detectors.

Lateral. The position of the heart altered on the *x*-axis, and the alteration included left and right translocations and clockwise and counterclockwise rotations.

Creep. The position of the heart gradually altered on the *y*-axis throughout the acquisition.

The rotating cinematic display was used to identify the anatomic projection in which motion was seen to originate. The anatomic projection was recorded to the nearest 45° through the 180° of interest, and the projections therefore included right anterior oblique, anterior, left anterior oblique (LAO), left lateral, and left posterior oblique.

In cases of multiple bounce, the location was recorded as "all" to reflect motion throughout the dataset. In cases of more than one event being seen, the location of each event was recorded.

Statistical Analysis

Interobserver correlation was evaluated with χ^2 analysis, and interobserver reliability was measured using the Cohen κ-coefficient. Differences between independent means and proportions were calculated as a 95% confidence interval (CI). Statistical significance was calculated using χ^2 analysis for nominal data and the Student *t* test for continuous data. A Welch ANOVA F test was used for continuous data with unequal variances. A *P* value less than 0.05 was considered significant. CIs that had no overlap or did not include zero were considered to support a statistically significant difference, whereas CIs that had an overlap or included zero represented differences for which chance could not be excluded as the cause.

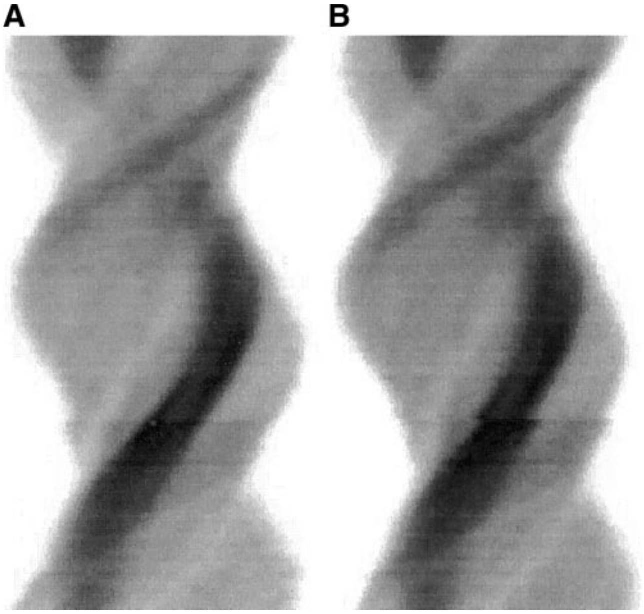

FIGURE 1. Interruption of the normal smooth sinusoid appearance (A) by patient motion (B).

RESULTS

Study Population Demographics

Of the 402 consecutive patients, 2 were excluded because their raw data were prematurely deleted from the computer. The study population consisted of 800 myocardial perfusion studies (400 rest and 400 stress) acquired at 1 of 3 nuclear medicine sites: 155 (38.75%) at department 1, 177 (44.25%) at department 2, and 68 (17%) at department 3. The mean age of the study population was 64.7 y, and the age range was 18–87 y.

Statistically significant differences in age distribution were found between patients examined in department 3 and patients examined in department 2 ($P = 0.0245$) and between patients examined in department 3 and patients examined in department 1 ($P = 0.0098$). No statistically significant difference in age distribution was found between patients examined in department 2 and patients examined in department 1 ($P = 0.5384$) (Table 2).

Patient Motion

Interobserver correlation—at 90%—was excellent for the presence of visually detectable motion in the 800 studies acquired. The Cohen κ-coefficient was 0.799, indicating excellent interobserver reliability, and no statistically significant difference was identified between observer responses ($P = 0.1018$).

Among the 800 studies analyzed, motion was seen in 36% (288/800; 95% CI, 32.7%–39.3%), of which 126 were rest studies and 162 were stress studies. In 55% (220/400) of patients, motion was seen in at least one of their studies (95% CI, 50%–60%). In 14.5% (58/400) of patients, motion was seen in the rest study only; in 23.5% (94/400), in the stress study only; and in 17% (68/400), in both the rest and the stress studies.

The age distribution for patients with no visually detectable motion was compared with that for patients with visually detectable motion (Table 3). No statistically significant difference in mean age was found between patients with motion and patients without motion ($P = 0.3451$). Furthermore, no statistically significant difference in mean age was found between patients with motion in both their studies and patients without motion ($P = 0.1126$).

A statistically significant difference ($P = 0.004$) was found between the proportion of rest studies with visually detectable motion (31.5%; 126/400) and the proportion of stress studies with visually detectable motion (40.5%; 162/400).

TABLE 3
Patient Age vs. Patient Motion

Parameter	No motion	Any motion	Motion in both studies
Mean age (y)	64.1	65.2	66.8
Number	180	220	68
SD	11.6	11.7	12.5
Interquartile range (y)	55–73	57–74	57–74

A 1-d rest/stress protocol was performed on 8% (32/400) of patients; a 2-d rest/stress protocol, on 52.75% (211/400) of patients; and a 2-d stress/rest protocol, on 39.25% (157/400) of patients. Visually detectable motion was found in 37.25% (149/400) of the studies that were performed first in the sequence and 34.75% (139/400) of the studies that were performed second ($P = 0.231$).

Table 4 provides some insight into the relationship between the presence of visually detectable motion, the type of study (stress or rest), and the study sequence (protocol). No statistically significant difference ($P = 0.468$) in the proportion of rest studies with visually detectable motion was found when those performed first in the protocol sequence (31.3%) were compared with those performed second (31.8%). However, a statistically significant difference ($P = 0.001$) in the proportion of stress studies with visually detectable motion was found when those performed first in the protocol sequence (46.5%) were compared with those performed second (36.6%).

Of the studies performed in department 1, 36.5% (113/310) contained motion. Of the studies performed in department 2, 43.8% (155/354) contained motion. Of the studies performed in department 3, 14.7% (20/136) contained motion. Statistically significant differences in the proportion of studies demonstrating motion were found between department 2 and department 1 ($P = 0.028$), between department 3 and department 2 ($P < 0.01$), and between department 3 and department 1 ($P < 0.01$).

Types of Motion

The most common type of motion detected was multiple bounce, which represented 47.6% (150/315) of motion (Table 5). Of the patients who demonstrated motion in both

TABLE 2
Age Distribution for Each of the 3 Nuclear Medicine Sites

Parameter	Department 1	Department 2	Department 3	Total
Mean age (y)	63.6	64.4	68.0	64.7
Age range (y)	18–86	35–86	36–87	18–87
SD	12	11.4	11	11.7
Number	155	177	68	400

TABLE 4
Study Sequence vs. Presence of Motion

Sequence	Type of test	No motion	Motion	% with motion
Performed first	Stress	84	73	46.5
	Rest	167	76	31.3
Performed second	Stress	154	89	36.6
	Rest	107	50	31.8

stress and rest studies, 54.4% (37/68) exhibited the same type of motion in each of their studies.

The most common location recorded for motion was “all” (50.7%; 150/296). These instances corresponded to the 150 reports of multiple-bounce motion. The most common specific locations of patient motion detected in the raw data were LAO and anterior, at 21.3% (63/296) and 17.2% (51/296), respectively (Table 6).

DISCUSSION

This clinical study determined a 36% incidence of visually detectable motion in the 800 myocardial perfusion SPECT studies evaluated. This figure is substantially greater than the 25% reported by Botvinick et al. (*1*) and the 26% reported by Prigent et al. (*5*) and is most likely the result of an absence of interventions to prevent or minimize patient motion in the 3 nuclear medicine departments. The 3 departments are busy private clinics where the time and tendency to ensure patient comfort physically and mentally may be limited. Botvinick et al. and Cooper et al. (*2*) reported patient discomfort and anxiety as factors in patient motion during myocardial perfusion SPECT studies. Furthermore, no devices were routinely used to support the hyperextended arms of the patients, a technique found by Cooper et al. to decrease patient motion.

Eisner et al. (*6*) and Gerson (*3*) reported that patient motion is often the result of arthritis, weakness, fatigue, or general lack of fitness. These factors are also associated with increasing age, and one might expect to see a positive correlation between patient age and likelihood of motion. In this study, however, we observed no correlation between patient age and the presence of visually detectable motion. This observation may be related to patient compliance. General compliance of the patient has been reported as an important factor in reducing patient motion (*6*). It could be suggested that the increased compliance of patients with increasing age nullifies the impact of age-related factors reported to increase patient motion.

Fatigue after stress testing has been reported to increase patient motion during myocardial perfusion SPECT acquisitions (*1*). This study demonstrated a 9% difference between the incidence of patient motion during stress studies and the incidence of patient motion during rest studies ($P =$ 0.004). Upward creep motion is a common cause of artifacts in myocardial perfusion stress studies if the time between the stress test and the stress acquisition is inadequate for cardiac and lung volumes to return to normal; however, this difference in the incidence of motion between stress and rest cannot be attributed to upward creep because only 2 studies with creep were identified. Although the acquisition began at a sufficient interval after the stress test to eliminate upward creep, these results suggest that the practice of starting the acquisition as early as 20 min after stress testing is clearly inadequate to allow full recovery from the stress test. Fatigue, anxiety, and discomfort are elevated after stress, and stress accentuates other factors that contribute to patient motion (e.g., arthritis, weakness, lack of fitness, and general ill health). Moreover, stress testing (particularly pharmacologic stress) may leave the patient with a headache and nausea.

TABLE 5
Types of Motion Detected vs. Number of Studies with Motion

Type of motion	Number	Percentage
Multiple bounce	150	47.6
Bounce up	18	5.7
Bounce down	79	25.1
Abrupt up	17	5.4
Abrupt down	20	6.4
Lateral	29	9.2
Creep	2	0.6

TABLE 6
Acquisition Location Where Motion Was Detected

Location	Number	Percentage
Left posterior oblique	2	0.7
Left lateral	23	7.8
Left anterior oblique	63	21.3
Anterior	51	17.2
Right anterior oblique	7	2.4
All of study	150	50.7

In the 2-d protocol, the incidence of patient motion in the rest studies that were performed first did not differ from the incidence in stress studies or in the rest studies that were performed second. However, the incidence of patient motion in the stress studies that were performed first was significantly higher than the incidence in rest studies or in the stress studies that were performed second. This finding suggests that the causal relationship between the type of study performed first and the presence of motion represents effect modification for stress studies. This relationship most likely results from compounding of factors known to contribute to patient motion when the stress study is performed first in the sequence (i.e., anxiety of not knowing what to expect, combined with the rigors of stress testing).

No differences were anticipated between the 3 nuclear medicine departments with respect to the proportion of studies showing patient motion; however, department 3 (14.7%; 20/136) demonstrated a significantly lower incidence of patient motion than did department 2 (43.8%; 155/354) or department 1 (36.5%; 113/310). Because all nuclear medicine technologists were rotated through all 3 sites, the bias associated with the individual abilities and practices of technologists can be eliminated as the cause of these differences. The differences may be explained by the structure of the 3 departments. Department 3 is a 1-camera, 1-technologist department in which the technologist must take responsibility for all work being performed. The departmental structure facilitates proactive participation of the technologist in both the patient-care and the technical aspects of the study. Department 3 provides patients with greater privacy and may reduce anxiety because they have the undivided attention of the technologist. Because department 3 operates a dual-head gantry with head-in positioning, resulting in a fractionally longer and more claustrophobic procedure, one might expect more patient motion than in departments 1 and 2, but this was not the case.

The difference between department 1 and department 2 may be explained by the greater impact of the factors outlined above. Department 2 has an additional technologist on the roster, a higher workload per technologist, and a floor plan that could provide for greater distractions to patients on the cardiac camera. Furthermore, all 1-d protocols performed during this evaluation were performed at department 2.

Of interest is that the most common specific locations for patient motion were anterior and LAO 45°, since these angles correspond to the traditional middle of the acquisition. Multiple-detector gantries, however, may result in acquisition of these projections toward the beginning or end of the acquisition. The reason for the prominence of the anterior and LAO 45° angles as sites of patient motion is that these angles have both the least distance and the least attenuation between the heart and the detector and thus contain the highest count densities in myocardial perfusion SPECT imaging. In short, patient motion is easier to detect at these angles.

Several limitations were identified in this study; however, it is our impression that neither the internal nor the external validity of the study was threatened by these limitations. Although the proportion of myocardial perfusion SPECT studies that were identified as having motion in this clinical study may not be representative of that in nuclear medicine departments in general, the proportions reported for types and locations of motion are externally valid. Moreover, the correlation between the incidence of patient motion and variables suspected of contributing to it (e.g., age, protocol, and gantry) is also generally applicable across nuclear medicine departments.

Perhaps the most significant limitation of this clinical study was the ability to correctly identify the presence of patient motion when it was present in the clinical study. Although study design ensured that the rate of false-positive findings of the presence of patient motion were negligible, false-negative findings were suspected to be significant. Physiologic or technical artifacts may have prevented detection of patient motion in some studies. Furthermore, count-deficient and low-contrast projections (outside anterior to LAO 45°) may have prevented detection of patient motion in these projections. Although projections with poor myocardial counts may have a higher incidence of patient motion than the incidence identified in this study, the resulting impact of such motions on dataset integrity has been demonstrated to be less significant. This clinical study may, however, have underestimated the proportion of studies with visually detectable motion.

Difficulties in identifying multiple motions in a single patient study may have contributed to the proportion of multiple-bounce motions identified. Several single events of bounce or combinations of bounce and abrupt motion would generally have been interpreted as multiple bounce by the observers. A single event of patient motion may also have been reported as multiple bounce by the observers when seen on multiple detectors. The low incidence of creep motion in this study may have resulted from misalignment at the start or ending projections, creating the appearance of an abrupt motion. Although limiting the study, all these interpretation difficulties were identified as such in the methodology and the observers were conscious of their influence.

Reviewing retrospectively, we can see that the study design might have been strengthened by incorporating a way to quantitate patient motion, correlate motion with clinical findings, and qualify differences between the 3 departments. Implementing interventions to prevent patient motion and assessing their success would provide a valuable postscript to this clinical study.

Some recommendations arise from the study observations. One recommendation is that preventative measures be implemented to minimize the incidence of patient motion, including lengthening the time between the end of the stress test and the beginning of the acquisition to ensure adequate recovery. As further measures, the staff should review their approach to giving explanations to patients and their skill in recognizing and dealing with anxiety in patients, students should be more closely supervised in this area, and the distraction of staff or patient movements and conversation in and around the γ-camera should be minimized. In addition, evaluation of the SPECT data for patient motion should be an integral step in the acquisition: Technologists should be familiar with techniques for recognition and correction of patient motion, and physicians should routinely examine cinematic displays and sinograms during reporting to identify studies in which motion may be problematic. Another preventative measure to minimize the incidence of patient motion is the use of devices to support the hyperextended arms of patients. These devices should support the arm at the shoulders and elbows and not just be something for the patient to grasp. Finally, the starting angle of 360° acquisitions (180° reconstruction) should be changed to anterior, ensuring that high myocardial count projections are acquired early in the dataset, when the patient finds it easier to remain still.

The most important recommendation arising from this study is that the impact of motion on the diagnostic integrity of the data needs to be investigated. The characteristics of patient motion identified in this study should be used to examine the actual impact of motion type, degree, duration, and position on the introduction of artifacts. From this information, the potential impact of patient motion on false-positive findings of CAD can be determined.

CONCLUSION

This investigation established that the incidence of patient motion during ^{99m}Tc-based myocardial perfusion SPECT studies is significant and has the potential to introduce artifacts leading to false-positive findings. Further investigation of the impact of various types and degrees of patient motion is recommended.

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