"Upward Creep" of the Heart: A Frequent Source of False-Positive Reversible Defects During Thallium-201 Stress-Redistribution SPECT

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A new cause of artifactual ^{201}Tl defects on single photon emission computed tomography (SPECT) termed "upward creep" of the heart is described. In 102 consecutive patients undergoing ^{201}Tl SPECT, 30 (29%) demonstrated upward creep defined by an upward movement of the heart of ≥ 2 pixels during acquisition. In 45 consecutive patients with a $<5\%$ likelihood of coronary artery disease, 17 (38%) had upward creep. Of these nine had reversible ^{201}Tl defects localized to the inferior and basal inferoseptal walls, while none of the 28 without upward creep had defects. The 17 low likelihood patients with upward creep had longer exercise duration and higher peak heart rate than those without upward creep. In five additional low likelihood patients with upward creep in whom imaging was immediately repeated, the upward creep pattern disappeared on the repeated images. After we changed our test protocol to begin imaging 15 min postexercise, only five (14%) of 36 low likelihood patients tested demonstrated upward creep. Upward creep is probably related to a transient increase in mean total lung volume early following exhaustive exercise, resulting in a mean lower position of the diaphragm (and thus the heart) at the beginning of imaging. The frequency of this source of false-positive ^{201}Tl studies can be reduced by delaying SPECT acquisition until 15 min postexercise.

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In our early experience with stress-redistribution thallium-201 (^{201}Tl) single photon emission computed tomography (SPECT) (1984–1986), we observed that many apparently normal patients demonstrated reversible inferior and basal inferoseptal myocardial perfusion defects. We detected a systematic cause for this high frequency of false-positive response—a phenomenon we have termed "upward creep of the heart." This phenomenon was discovered through review of a summated image of the 32-frame acquisition routinely obtained prior to image reconstruction (*1*). Normally the lower border of the summated heart image inscribes a horizontal line. In many patients without evidence of disease the bottom edge of the heart demonstrated gradual upward motion across the summated image. The position of the heart was lower (more inferior) in the beginning than at the end of acquisition. The purpose of this study was to determine the frequency and determinants of "upward creep" in normal patients, and the frequency with which this phenomenon is associated with artifactual defects on stress-redistribution ^{201}Tl SPECT imaging.

PATIENT POPULATION

The frequency of upward creep was assessed in four patient groups studied between 1984 and 1986 (group 1–4), and one studied in 1987 (group 5). All patients were referred for testing because of suspected or known coronary artery disease.

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Group 1 consisted of 102 consecutive (mean age 56.9 yr, range 35 to 84 yr, with 84% males) but unselected patients who underwent stress redistribution SPECT thallium imaging.

Group 2 consisted of 45 consecutive patients (mean age 51.2 yr, range 35 to 77 yr, with 67% males) with a <5% likelihood of coronary artery disease before ^{201}Tl testing based on serial Bayesian analysis of age, symptoms classification, risk factors and results of the stress electrocardiogram (*2*).

Group 3 consisted of 11 consecutive patients (mean age 52.2 yr, range 42 to 66 yr, 100% males) who underwent coronary angiography following an abnormal thallium scintigraphic study and were found to have normal coronary arteriograms.

Group 4 consisted of five additional patients (mean age 44.6 yr, range 29 to 54 yr, 100% males) with <5% likelihood of coronary disease and upward creep during thallium scintigraphy in whom the thallium study was repeated immediately following the initial post-stress acquisition.

Group 5 consisted of 36 low likelihood patients (mean age 51.6 yr, range 28 to 77 yr, with 59% males) in 1987 in whom initiation of thallium tomographic post-stress imaging was delayed an additional 5 min, thus starting 15 min postexercise.

METHODS

Exercise and imaging procedures

Patients were requested to withhold beta blocking medication for 48 hr and calcium blocking medication for 24 hr prior to testing. All patients underwent maximum-tolerated treadmill exercise testing using the Bruce protocol. One minute before termination of exercise, 3 mCi of ^{201}Tl was injected intravenously. Beginning five to ten minutes and then three to five hours after ^{201}Tl injection, tomograms were obtained by means of a large field-of-view camera (Siemens Orbiter, or GE 400AT) with an all-purpose, parallel hole collimator. A 20% energy window centered on the 80-keV x-ray peak and a second 10% energy window centered on the 167-keV x-ray peak on ^{201}Tl were employed. Thirty-two equidistant projections were obtained over 180°, from the 45-degree right anterior oblique (RAO) to the 45-degree left posterior oblique (LPO). Each of the 32 projections was acquired for 30 sec. All data were stored in a 64 × 64 × 16 bit computer matrix. The spatial resolution of the system was 18mm full width half maximum for ^{201}Tl. Prior to imaging, two point sources were placed on the chest wall, ~ 5cm to the right of the sternal border, one superior and the other inferior to the heart to monitor vertical patient motion during acquisition.

Computer Processing and Analysis

Prior to reconstruction, the 32 frames were added together to form a "summated" image. If no vertical patient motion occurred during the acquisition period, the point sources inscribed a horizontal line across the field of view (*1*). The upper and lower borders of the heart should also inscribe a horizontal line across the summated image, parallel to that inscribed by the point sources. Upward creep of the heart is noted when the upper and/or lower borders of the heart shift superiorly (from right to left) so that the position of the heart appears more superior to the end of the acquisition than at the beginning of acquisition (Fig. 1). We assessed these borders visually and measured the amount of upward creep of the heart as the number of pixels that the heart shifted upward from the beginning to the end of acquisition.

After correction for nonuniformity and center of rotation, the unreconstructed images were smoothed using a three point algorithm (1-2-1). Images were then reconstructed using a commercially available program (MDS A3) employing a Butterworth filter with a cutoff of 0.2 Nyquist, order 5. The tomograms were reoriented into the short axis and vertical long axis views (*3*). Representative slices from the apical, midventricular and basal regions of the short axis views and the vertical long axis views were analyzed visually, as shown in Figure 2, by 2 experienced observers. A four-point scoring system was assigned to six segments for each short axis view and the two apical segments in the vertical long axis views: 0 = normal, 1 = mildly decreased, 2 = moderately decreased, and 3 = severely decreased thallium uptake. A segmental score ≥2, in ≥2 segments was considered abnormal (*4*).

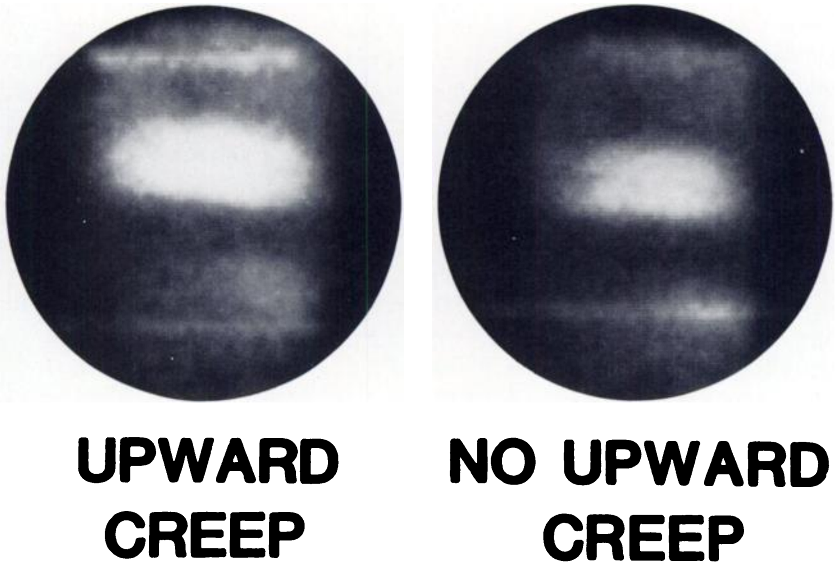

FIGURE 1
Summated images of a patient in group 4 demonstrating upward creep on the immediate post-stress acquisition (left), and no upward creep on repeat imaging immediately following the post-stress acquisition (right). The heart is in the middle of the field of view while the horizontal lines on the top and bottom of the image are the two summated point sources. The right hand edge of the heart represents the initial frame (image no. 1) while the left hand edge represents the last (image no. 32) acquired image.

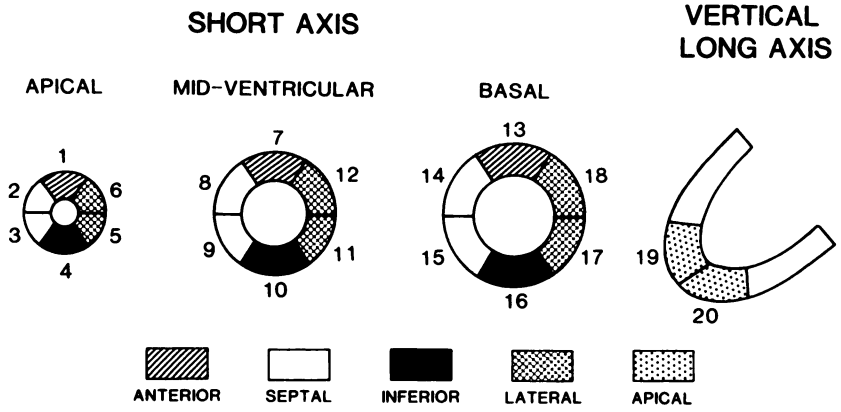

FIGURE 2
Diagrammatic ^{201}Tl SPECT images illustrating the anatomic assignment of left ventricular segments.

Statistical Analysis

The exercise test variables were compared using the unpaired t-test. The results are expressed as a mean ±s.d. P values <0.05 were considered significant.

RESULTS

Among the unselected 102 patients (group 1), 30 (29%) demonstrated upward creep ≥2 pixels, 22 had upward creep of 1 pixel, and 50 had no upward creep. Among the initially selected 45 low likelihood patients (group 2), 5 (11%) had upward creep ≥3 pixels, 12 (27%) had upward creep of 2 pixels, and 9 (20%) had upward creep of one pixel, on the immediate post-stress images. None of the patients had upward creep on the 4-hr images. The relationship between the magnitude of upward creep and the frequency and location of thallium perfusion defects is shown in Table 1. The frequency of thallium defects increased with increasing magnitude of upward creep. We compared the age, sex, and exercise duration, and peak heart rate achieved in the patients having "definite" upward creep defined as ≥2 pixel compared to those without upward creep (upward creep ≤1 pixel) (Table 2). The patients with upward creep had significantly higher means for exercise duration, peak exercise heart rate and percent maximal predicted heart rate achieved. Age and sex were not significantly different.

Among the 11 patients with normal coronary arteriograms (group 3), seven had definite upward creep; all seven had reversible inferior and/or inferoseptal wall defects. One of the four patients with normal coronary arteriograms but without upward creep also had a reversible inferior defect. In the remaining three patients reversible defects were present in other walls.

In the five low likelihood patients who were immediately re-imaged following the detection of significant upward creep (group 4), the thallium results differed in the two studies. All five had reversible inferior and/or inferoseptal defects on the immediate post-stress images. On the repeat study, neither upward creep nor thallium defects were present in any of the five patients. Figures 1 and 3 illustrate the summated images and representative short axis slices of a patient in group 4, illustrating the disappearance of upward creep and its associated perfusion defects in the immediately repeated post-stress images.

In the low likelihood patients in whom SPECT imaging was performed by our current routine involving a 15-min delay to initial SPECT imaging (group 5), a lower frequency of upward creep was noted. Five of these 36 patients (14%) demonstrated definite upward creep, of whom 4/5 (90%) demonstrated defects.

DISCUSSION

Our study describes an important potential cause for false positive thallium scans in patients undergoing SPECT imaging: upward creep of the heart. In our initial experience between 1984–1986, upward creep occurred relatively frequently among 102 unselected patients. Twenty-nine percent of these patients were noted to have upward creep of the heart on immediate post-stress thallium scintigrams. Moreover, a similarly high occurrence of this phenomenon was noted in a consecutively evaluated sample of patients with a very low likelihood of coronary artery disease. When upward creep was considered "definite" (≥2 pixels), there was a high frequency of reversible inferior and inferoseptal

TABLE 1
Relationship Between Degree of Upward Creep and Frequency of Defects in Patients with Low Likelihood of CAD (group 2)

No. of pixels of upward creep	No. of patients	Frequency of defects
0	20	0 (0%)
1	9	1 (11%)
2	11	3 (27%)
≥3	5	5 (100%)

TABLE 2
Comparison of the Clinical Parameters in the Group 2 Patients With and Without Upward Creep

	Without upward creep	With upward creep	
Exercise duration	9.0 ± 3.4	11.5 ± 3.4	p = 0.04
Peak heart rate	143.9 ± 12.3	164.4 ± 12.4	p = 0.023
% Maximum predicted heart rate	92.3 ± 5.8	97.3 ± 5.8	p = 0.027
Age	53.0 ± 11	50.4 ± 7.7	p = 0.41
Sex (% males)	71%	59%	p = 0.32

defects, occurring in 27% of the low likelihood patients with 2 pixel upward creep and all patients with ≥3 pixel upward creep. Before we learned to recognize this phenomenon, the abnormalities resulting from upward creep were an important source of false-positive responses among the patients who were referred for coronary arteriography.

Upward creep is seen only on the immediate postinjection images and represents gradual movement of the heart within the chest during data acquisition. Because the heart does not stay in the same position throughout imaging in these patients, there is misrepresentation of the spatial data during computer reconstruction resulting in an apparent defect. What led us to discover this artifact was the observation that an unduly high proportion of our patients undergoing ^{201}Tl tomography were found to have normal coronary arteriograms. Review of these cases revealed frequent inferior and inferoseptal reversible ^{201}Tl defects. These patients were in all other respects normal by noninvasive testing. We simultaneously noted from routine summed projection images, obtained for assessment of patient motion (*1*), that these patients demonstrated the upward creep pattern on the post-stress images but not on the four hour studies, with the pattern unassociated with apparent patient motion. Hence, we began to look for the occurrence of upward creep, both in a prospective and retrospective fashion. After finding that the pattern disappeared on repeat imaging, we instituted our current routine of delaying initial image acquisition until 15 min post-stress.

Upward creep appears to be associated with exercise to exhaustive levels. Although the mechanism is presently ill-defined, we postulate that the mechanism involves an increase in mean total lung volume persisting postexercise in period, with a consequent depression of the diaphragm and lowered cardiac position. As the patients gradually diminish their depth of ventilation postexercise, the mean lung volume decreases and the diaphragm and heart assume their normal baseline positions. Waiting until 15 min postexercise to begin imaging reduces the frequency of upward creep; however, 14% of patients still manifested upward creep. We therefore, recommend that each patient be evaluated prior to beginning tomographic imaging, by observing the depth and frequency of breathing, and occasionally delaying imaging an additional 5 min in those patients who do not appear to be at baseline after the standard 15-min delay. Due to the problem of potential early redistribution of ^{201}Tl (*5*), which could result in decreased sensitivity for initial defect detection, this additional delay is not routinely used. In the interval between exercise and imaging, we routinely acquire a 5-min planar anterior view. The benefit of this anterior planar view, in addition to reducing the frequency of upward creep, is to assess processes not well detected by tomographic imaging, such as the degree of pulmonary thallium uptake (*6*) and the presence of transient ischemic dilatation of the left ventricle (*7*). With the technetium-99m isonitriles, which are routinely imaged 1 hour after injection, and which do not appear to redistribute significantly (*8*), the problem of upward creep is not likely to occur.

Knowledge of the phenomenon of upward creep, use of summated images to detect it, and delay of the initial post-stress imaging to at least 15 min, should reduce the frequency of false-positive responses when ^{201}Tl SPECT myocardial scintigraphy is performed.

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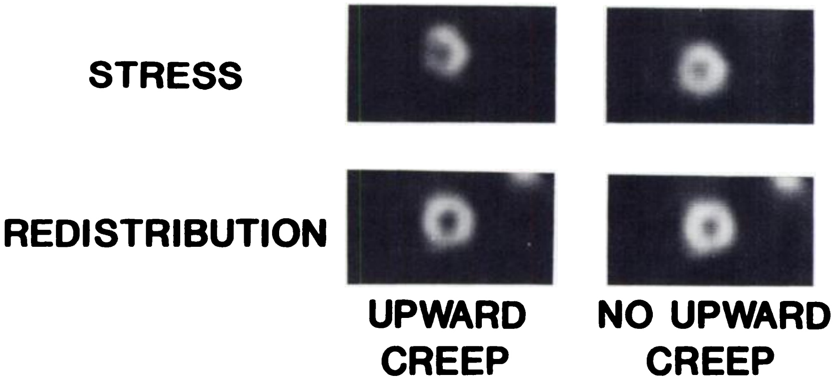

FIGURE 3
Midventricular short axis slices of the initial (left) and immediately repeated (right) post-stress acquisition in the same patient as shown in Figure 1. The images with upward creep show the typical pattern of an inferior and septal perfusion defect. The repeat images without upward creep show resolution of the defects.

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