Role of Quantitative Planar Thallium-201 Imaging for Determining Viability in Patients with Acute Myocardial Infarction and a Totally Occluded Infarct-Related Artery

Peter J. Sabia, Eric R. Powers, Michael Ragosta, William H. Smith, Denny D. Watson and Sanjiv Kaul

Division of Cardiology, Department of Medicine, University of Virginia School of Medicine, Charlottesville, Virginia

We studied 57 patients with a recent infarction and an occluded infarct-related artery to test the hypothesis that the amount of ^{201}Tl on *delayed* planar images correlates with the extent of viable myocardium after acute myocardial infarction. There was a significant ($p < 0.001$) correlation between mean ^{201}Tl activity in the infarct zone and regional wall motion score in that zone both at baseline ($r = -0.60$, $n = 57$) and 1 mo after attempted angioplasty ($r = -0.67$, $n = 48$), with better function being associated with greater ^{201}Tl uptake in the delayed images. There was no correlation between the number of segments showing redistribution and the wall motion score. We conclude that in patients with recent myocardial infarction and an occluded infarct-related artery, the average ^{201}Tl activity within the infarct zone on *delayed* planar imaging correlates well with the extent of viable myocardium in that zone. The presence or absence of redistribution does not influence these results.

J Nucl Med 1993; 34:728–736

In patients with acute myocardial infarction (AMI), the uptake of ^{201}Tl within the infarct zone may depend on the amount of blood flow to and the extent of viable myocardium within that zone. When the infarct-related artery (IRA) is totally occluded, flow to the infarct zone can emanate only from collateral vessels from other myocardial beds. Moreover, since patients with AMI have a mixture of normal, ischemic and necrotic tissue, the overall thallium kinetics will be determined by how much of the IRA bed consists of each of these types of tissues. Finally, because of possibility of redistribution, the relative thallium activity within a hypoperfused but viable zone may be maximal on the delayed image.

Based on these considerations, we hypothesized that the amount of thallium within an occluded bed on the *delayed* planar images would correlate with the extent of viable myocardium in patients with AMI. In this study, the relationship between the extent of viable myocardium and thallium uptake on the delayed images was established in three ways. First, average thallium activity within the occluded bed was correlated with regional wall motion in that bed at baseline. Second, the increase in thallium uptake within the occluded bed after attempted angioplasty of the IRA was correlated with improvement in regional function in that bed. Finally, pre-angioplasty thallium uptake in the occluded bed was correlated with wall motion score in that bed after attempted angioplasty.

METHODS

Patient Population and Study Protocol

Fifty-seven consecutive patients with recent AMI who were found to have a totally occluded IRA at cardiac catheterization were included in this study. Their characteristics are depicted in Table 1. The protocol was approved by the Human Investigation Committee at the University of Virginia and all patients gave informed consent. They underwent thallium imaging and two-dimensional echocardiography prior to and 1 mo after attempted angioplasty of the IRA.

Thallium Imaging

Baseline thallium imaging was performed after exercise in 23 patients (40%) and during rest in 34 (60%), whereas 1 mo post-angioplasty imaging was performed after exercise in all patients. Approximately 2.0 mCi of thallium (Dupont Medical Products, No. Billerica, MA) was injected 5 min prior to obtaining the initial images; the delayed images were obtained 2 hr later. Images were obtained in the anterior and 45° and 70° left anterior oblique projections and were analyzed using a previously described computer-assisted approach (*1*). After interpolative background subtraction, thallium activity in each of the previously described 11 segments in the three views was expressed as a percent of activity in the 9 × 9 pixel region with maximal activity in that view (*2*).

The IRA bed was defined in the pre-angioplasty initial images as the segments showing hypoperfusion. Thallium activity was measured in these same segments in the delayed images both prior to and after attempted angioplasty. The activity in all segments within the IRA bed shown on the delayed images were averaged and activity in the segment with the least thallium

Received Oct. 8, 1992; revision accepted Jan. 18, 1993.
For correspondence or reprints contact: Sanjiv Kaul, MD, Division of Cardiology, Box 158, University of Virginia, Charlottesville, VA 22908.

TABLE 1
Patient Characteristics

Number of patients: 57	
Gender: 40 men (70%), 17 women (30%)	
Age: 56 yr (range 36–77 yr)	
Period between infarction and baseline study: 2–36 days (mean = 12 ± 8 days)	
Q-wave infarction: 42 patients (74%)	
Peak creatine kinase levels: 1704 ± 1443 for Q-wave infarction versus 805 ± 482 for non-Q-wave infarction (p = 0.05)	
Infarct-related artery:	Left anterior descending in 19 (33%)
	Left circumflex in 6 (11%)
	Right coronary in 32 (56%)
Multivessel coronary artery disease: 20 patients (35%)	
Prior myocardial infarction: 11 patients (19%)	
Postinfarction ischemia (chest pain with EKG changes): 14 patients (25%)	

uptake was also noted. Improvement in thallium uptake after angioplasty was defined as an increase of at least 5% in average activity within the IRA bed. In addition, the presence or absence of redistribution was also noted in each segment in the pre-angioplasty images. If the ratio of thallium activity between hypoperfused and normal segments was greater in the delayed image compared to the initial one, redistribution was considered to be present (*1*). It was not required that this ratio be close to unity in the delayed image as long as it was higher than in the initial image.

Two-Dimensional Echocardiography

Two-dimensional echocardiography was performed using standard parasternal and apical views. The studies were reviewed by two blinded observers. Wall motion within the infarct zone was scored using a previously defined method where 1 = normal function; 2 = mild hypokinesia; 3 = severe hypokinesia; 4 = akinesia; and 5 = dyskinesia (*3*). The 1 mo postangioplasty images were compared with the pre-angioplasty images without knowledge of the results of either the angioplasty or thallium imaging. A change in wall motion score by at least one grade was considered to represent a change in regional function.

Statistical Methods

Data were analyzed using RS/1 (Bolt, Beranek and Newman, Cambridge, MA) (*4*). Continuous data were expressed as mean ± 1 s.d. and comparisons between groups were performed using either the unpaired Student's t-test or analysis of variance. Categorical data were expressed as proportions and comparisons between groups were performed using either the chi square or Fisher's exact test. Differences between groups were considered significant at $p < 0.05$ (two-sided). Correlations were performed using either linear regression (continuous data) or Spearman's rank (ordinal data) tests.

RESULTS

All Patients

There was a significant ($p < 0.001$) negative correlation between peak serum creatine kinase levels and thallium activity within the IRA bed. The correlation coefficient was −0.56 for mean thallium activity and −0.62 for the lowest thallium activity within the IRA bed (Fig. 1). There was also a significant ($p < 0.001$) inverse correlation (rho = −0.60) between mean and lowest thallium activity in the IRA bed and two-dimensional echocardiography assessed regional wall motion score at baseline. Figure 2 illustrates box plots depicting the relationship between mean thallium activity in the IRA bed and regional wall motion score. In the 16 patients with either normal motion or mild hypokinesia, the activity was 83% ± 11% compared to 75% ± 11% in the 22 patients with severe hypokinesia and 65% ± 9% in the 19 patients with either akinesia or dyskinesia ($p < 0.001$).

Mean thallium uptake in the IRA bed was significantly

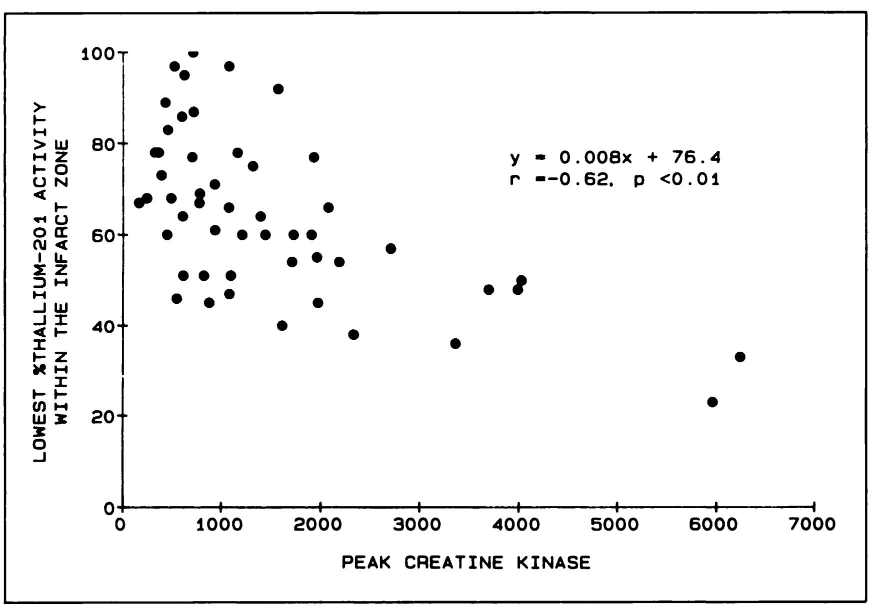

FIGURE 1. Relationship between thallium activity in the segment within the IRA bed showing the least perfusion (y-axis) and peak creatine kinase levels (x-axis) in patients with recent myocardial infarction.

lower ($p < 0.01$) in the 19 patients with an occluded left anterior descending artery (67 ± 12) when compared to the 6 with an occluded left circumflex (79 ± 11) and the 32 with an occluded right coronary artery (77 ± 20). There was a weak ($r = 0.40$) but significant ($p < 0.01$) relationship between wall motion score and the number of segments subtended by the IRA. When wall motion was normal or exhibited only mild hypokinesia, the number of segments subtended by the IRA was 3 ± 1 compared to 4 ± 2 and 5 ± 1 when severe hypokinesia or akinesia/dyskinesia, respectively, were present.

Twenty-seven of the 57 patients (47%) demonstrated redistribution; in three-fourths it was incomplete. Interestingly, the wall motion score was slightly worse in those showing redistribution (3.3 ± 0.9 versus 2.8 ± 0.9, $p = 0.06$). There was no correlation between the number of segments with redistribution and the wall motion score. When multivariate analysis was performed, the only significant correlate of wall motion score was the average thallium activity within the IRA bed in the delayed images. The presence or absence of Q-waves, prior infarction, multivessel coronary artery disease and redistribution and the number of segments subtended by the IRA on thallium imaging did not correlate with wall motion score.

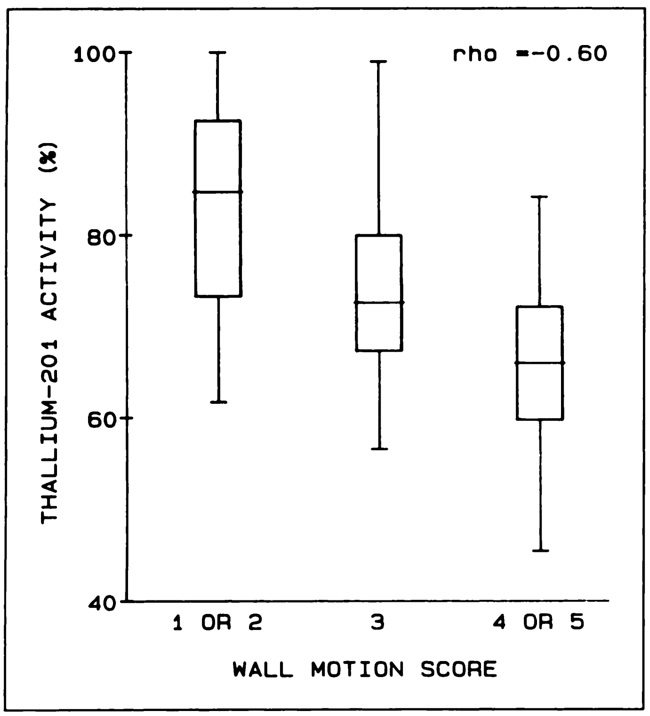

FIGURE 2. Relationship between regional wall motion score (x-axis) and average thallium activity within the IRA bed determined from all three views (y-axis) at baseline. Thallium activity in this and the next two figures is depicted as box plots where the central horizontal line in each box denotes the median; the upper and lower horizontal lines denote the upper and lower quartile (levels containing 25% of the data above and below the median, respectively); and the tails denote the high and low ranges of values. Wall motion scores are as follows: 1 = normal; 2 = mild hypokinesia; 3 = severe hypokinesia; 4 = akinesia; and 5 = dyskinesia.

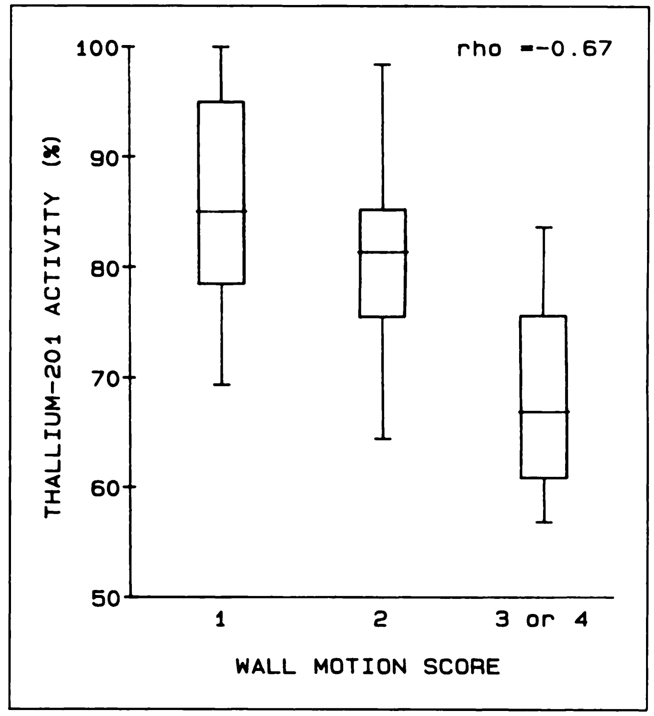

FIGURE 3. Relationship between regional wall motion score (x-axis) and average thallium activity within the IRA bed determined from all three views (y-axis) 1 mo after attempted angioplasty. The wall motion scores are the same as in Figure 2.

These results were not influenced by the imaging protocol used. Thallium activity within the IRA bed in the delayed images was similar in the 23 patients undergoing exercise and the 34 undergoing rest imaging (73% ± 12% versus 75% ± 13%, $p = 0.50$). The occurrence of redistribution was greater in patients undergoing exercise compared to rest imaging (61% versus 38%, $p = 0.10$). In those imaged at rest, the average thallium activity was only marginally greater (mean of 2.9 ± 3.9, $p = 0.01$) in the delayed images compared to the initial ones.

All Patients with Follow-Up

Of the 57 patients, 7 did not undergo repeat 1 mo two-dimensional echocardiography and thallium imaging; 1 died; 1 had bypass surgery within 2 wk of angioplasty; and 5 failed to return for the repeat studies. In addition, two had normal wall motion at baseline which could not have improved any further after angioplasty. Therefore, 48 patients were analyzed for changes in wall motion score and thallium uptake 1 mo after attempted angioplasty. A significant ($p < 0.001$) correlation (rho = −0.67) was noted between wall motion score and mean thallium activity within the IRA bed in the delayed image 1 mo after attempted angioplasty (Fig. 3). A close correlation (rho = 57, $p = 0.001$) was also noted between change in wall motion score and change in mean thallium activity

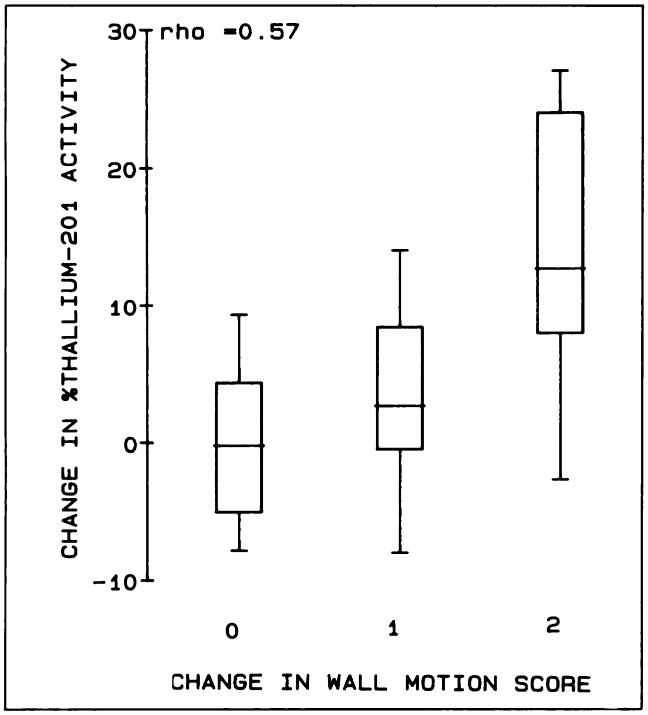

FIGURE 4. Relationship between change in regional wall motion score (x-axis) and change in average thallium activity within the IRA bed (y-axis) 1 mo after attempted angioplasty.

within the IRA bed, with greater improvement in thallium activity being associated with greater improvement in wall motion score (Fig. 4).

Of these 48 patients, 38 had successful angioplasty with sustained reperfusion, whereas 10 did not, 7 had initial unsuccessful angioplasty and 3 had reocclusion. Table 2 shows that there were no significant differences in the

TABLE 2
Comparison of Baseline Characteristics Between Patients With and Without Successful Angioplasty

Variables analyzed	Successful angioplasty (n = 38)	Unsuccessful angioplasty (n = 10)	p value
Age (yr)	57 ± 10	52 ± 9	0.12
Males (%)	63	70	0.99
Days after infarction	12 ± 9	10 ± 4	0.80
Prior infarction (%)	16	40	0.18
Q-wave infarction (%)	71	100	0.09
Peak creatine kinase	1232 ± 1151	1997 ± 1203	0.08
Multivessel disease (%)	26	50	0.25
Occluded LAD (%)	42	20	0.72
Collateral grade	1.8 ± 0.9	1.6 ± 0.9	0.54
Wall motion score	3.1 ± 0.9	3.3 ± 0.7	0.43
Mean thallium activity	75 ± 12	69 ± 8	0.19
Seg. with hypoperfusion	3.9 ± 1.6	4.9 ± 2.0	0.10
Redistribution (%)	58	50	0.73

LAD = left anterior descending artery and Seg. = number of segments (total of 11).

TABLE 3
Comparison of Wall Motion Score and Thallium Activity Within the Infarct Bed at Baseline and 1 Month After Attempted Angioplasty

Variable	Pre-angioplasty	Post-angioplasty	p value
Patients with unsuccessful angioplasty (n = 10)			
Wall motion score	3.3 ± 0.8	3.3 ± 0.8	0.99
Mean thallium activity	69 ± 8	67 ± 8	0.14
Patients with successful angioplasty (n = 38)			
Wall motion score	3.1 ± 0.9	1.9 ± 0.9	0.0001
Mean thallium activity	75 ± 12	81 ± 11	0.001

With lower wall motion scores, there is better regional function.

baseline characteristics between these two groups of patients. Importantly, wall motion score and mean thallium activity were similar between the two groups.

Patients with Unsuccessful Angioplasty

There was no change in mean wall motion score 1 mo later in the 10 patients with unsuccessful angioplasty (Table 3). In six patients, wall motion score did not change, while in two it improved by one grade and in two it worsened by one grade. Similarly, there was no overall change in mean thallium activity within the IRA bed (Table 3). It remained unchanged in five patients, improved by > 5% in one and worsened by > 5% in four.

Patients with Successful Angioplasty

Unlike those with unsuccessful angioplasty, the 38 patients with successful angioplasty showed significant improvement in wall motion score 1 mo later (Table 3). Figure 5 illustrates wall motion score in each of these patients before and 1 mo after successful angioplasty. Compared to 27 patients (71%) with severe wall motion

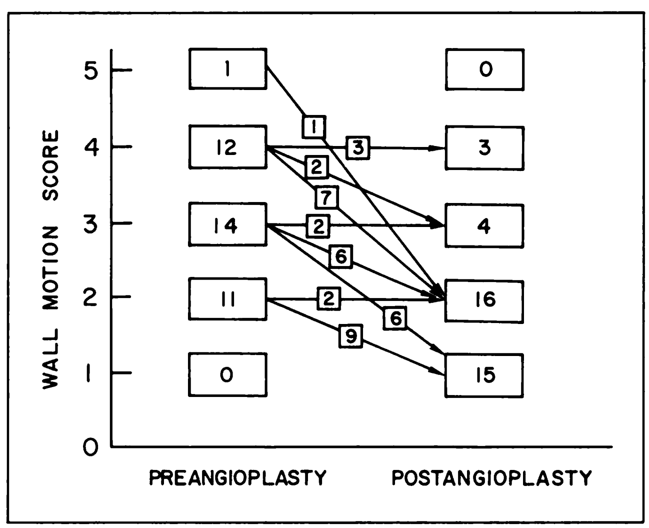

FIGURE 5. Wall motion scores in 38 patients before and 1 mo after successful angioplasty.

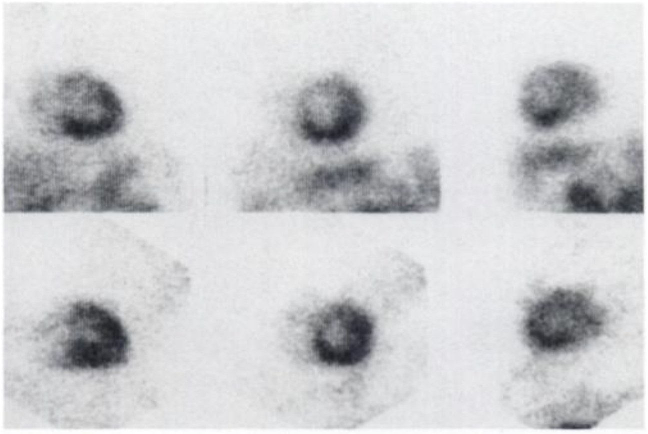

FIGURE 6. Delayed thallium images before (upper panel) and 1 mo after (lower panel) successful angioplasty of the left anterior descending artery in a patient with anterior AMI. The left panel depicts the anterior projection, while the middle and right panels depict the 45° and 70° left anterior oblique projections, respectively.

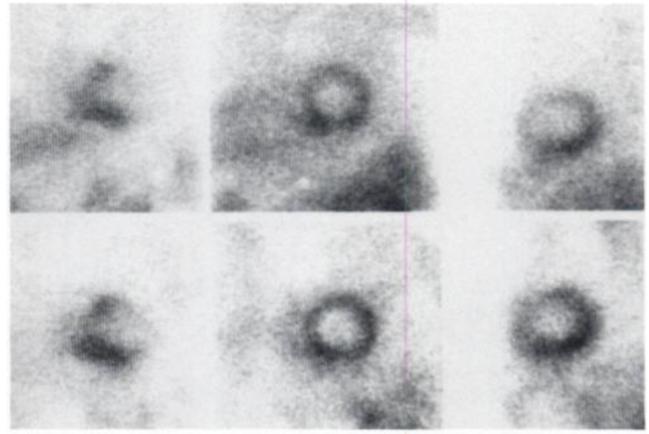

FIGURE 7. Delayed thallium images before (upper panel) and 1 mo after (lower panel) successful angioplasty of the left anterior descending artery in a patient with anterior AMI. The left panel depicts the anterior projection, while the middle and right panels depict the 45° and 70° left anterior oblique projections, respectively.

abnormality prior to angioplasty (severe hypokinesia to dyskinesia), only 7 (18%) had severe wall motion abnormality 1 mo after successful angioplasty ($p < 0.001$). Seventeen patients improved their wall motion score by 1 grade and 14 patients improved it by more than 1 grade; in 7 patients there was no change in the wall motion score.

The patients with successful angioplasty also showed improvement in mean thallium activity 1 mo later (Table 3): 22 showed an increase in activity by > 5%; 4 exhibited a decrease in activity by > 5%; whereas in 12 patients the activity remained unchanged. There was a fair but significant ($p = 0.01$) correlation between pre-angioplasty mean thallium activity within the IRA bed and postangioplasty wall motion score (rho = −0.50) as well as between change in mean thallium activity and change in wall motion score (rho = −0.51). There was no association between the presence of redistribution before angioplasty and change in wall motion score after angioplasty. Wall motion score improved by 1.3 ± 0.8 in patients with redistribution compared with 1.0 ± 0.6 in those without redistribution ($p = 0.30$).

Figures 6 and 7 illustrate examples of delayed thallium images obtained before and after successful angioplasty of the left anterior descending coronary artery in two patients who showed improvement in wall motion score within the IRA bed. Several important points are illustrated. First, neither of these patients exhibited redistribution. Second, the value of measuring activity within the IRA bed from all views is illustrated from these examples. In Figure 6, whereas the interventricular septum shows the least activity (47%), the average activity in all hypoperfused segments (the anterolateral and anterior walls and 70° left anterior oblique projections, respectively) is higher (60%). This patient had akinesia in the infarct bed which improved to mild hypokinesia after angioplasty. The mean thallium activity within the IRA bed increased to 84%, with the activity in the interventricular septum increasing to 59%.

Figure 7 is an example of a patient with a large anterior AMI who also had akinesia of the IRA bed. Whereas the thallium activity in the most abnormal segment (the anterolateral wall in the anterior view) is 36%, the average thallium activity within the IRA bed, including the interventricular septum and anterior wall in the 45° and 70° left anterior oblique projections, respectively, is higher (55%). One month after successful angioplasty, wall motion improved to mild hypokinesia and mean thallium activity within the IRA bed improved to 66%. Wall motion within the segment with the most severe defect also improved with thallium activity within that region, increasing to 45%. Finally, the value of quantitation of images is apparent from this illustration. Although on visual inspection no thallium activity was noted within the most abnormal segment in the anterior view, the measured activity within that region was 36% of normal activity.

DISCUSSION

Thallium Activity and Myocardial Viability

Thallium is a K^+ analog (*5*) and in a viable cell, the intracellular concentration of K^+ is approximately 40-fold higher than its extracellular concentration. Like K^+, thallium requires an active Na^+-K^+ pump to enter a cell (*5*). A viable cell will extract thallium on every pass through the coronary circulation in order to achieve a 40-fold transmembrane gradient. As the extracellular concentration of thallium decreases, the intracellular concentration will also decrease while maintaining a 40-fold transmembrane gradient. In contrast, loss of membrane integrity will preclude thallium from accumulating within a necrotic cell (*7*). This simple principle forms the theo-

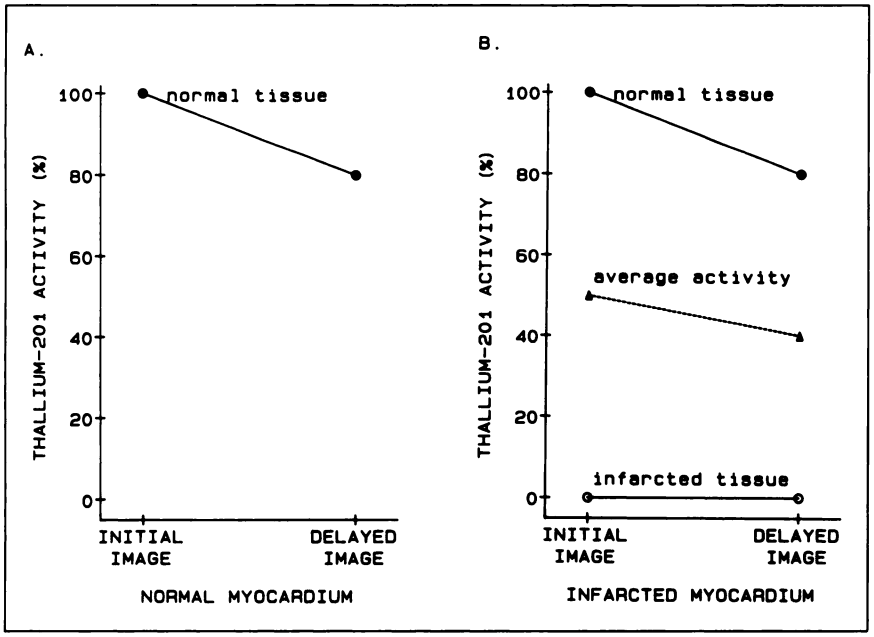

FIGURE 8. Thallium activity curves after injection at rest from normal noninfarcted myocardium (A) and from myocardium within the IRA perfusion bed which contains 50% of normal tissue and 50% of necrosed tissue (B). Compared to the normal bed, the infarcted bed appears to have a "fixed" 50% defect both on initial and delayed images.

retical basis for using thallium as a marker of myocardial viability.

For a cell to be viable, it must receive blood flow. Most myocardial cells will remain viable at blood flows as low as 20% of normal (*8,9*). Following coronary occlusion, the endocardium usually undergoes necrosis because of lower blood flows (< 20% of normal), while the epicardial and lateral zones survive because of the presence of collateral flow (*9*). Because of its limited spatial resolution, thallium imaging cannot differentiate between endocardial and epicardial regions. Consequently, counts on thallium imaging represent an average transmural thallium uptake. Unless the entire thickness of the myocardium has been infarcted, some thallium uptake will be noted in the IRA bed as long as there is flow to that bed. As demonstrated in the present study, the more thallium present in the IRA bed, the smaller the infarct (as measured by peak serum creatine kinase levels) and greater is the amount of viable myocardium.

We found a significant correlation between mean thallium activity within the IRA bed and regional function both before and after attempted angioplasty. We also found a significant relationship between the increase in thallium activity within an IRA bed following attempted angioplasty and improvement in regional function in that bed. The increase in thallium counts within the IRA bed after successful angioplasty indicates that some cells were viable and able to extract more thallium due to the restoration of higher anterograde flow. The positive correlation between the increase in activity within the IRA bed and the improvement in regional function after successful angioplasty further suggests that thallium uptake within the IRA bed indicates myocardial viability.

Redistribution and Myocardial Viability

The accumulation of thallium within an ischemic but non-necrotic myocardial bed over time has been termed "redistribution" (*10–12*). The presence of redistribution has, therefore, been used as an indicator of myocardial viability (*10,13–15*). Unfortunately, the absence of redistribution has been construed as the absence of myocardial viability. In patients with AMI, the IRA bed consists of a mixture of necrotic, ischemic and normal tissue. As such, each type of tissue handles thallium differently and the mean activity will depend on the overall composition of the IRA bed.

Let us take a simple example of a patient with AMI in whom 50% of the IRA bed is necrotic, while the other 50% receives normal blood flow at rest from collateral vessels (Fig. 8). Because 50% of the IRA bed is composed of necrotic tissue showing no thallium uptake and 50% of normal tissue showing normal thallium uptake, the average activity within the IRA bed on the initial image (Panel B) will be 50% of that in the normal bed (Panel A). If 20% of the thallium washes out from the normal myocardium by the time the delayed images are obtained, then the normally perfused tissue within the IRA bed will also lose 20% of its thallium, while the necrotic tissue will continue to demonstrate no activity. Consequently, the average activity within the IRA bed in the delayed image (Panel B) will still be 50% of that in the normal myocardium in the same image (Panel A) making the IRA bed appear to have a severe persistent defect despite 50% of that bed being normally perfused.

If this same patient exercises, collateral blood flow within the IRA bed would not increase by the same magnitude as flow to the normally perfused myocardium. Theoretically, this relative hypoperfusion induced by exercise should reverse on the delayed image. The apparent reversal, however, depends on several factors. The degree of disparity in thallium activity in the initial images will influence whether redistribution can be detected in the delayed images. Therefore, the greater the degree of disparity in the initial images, the greater the likelihood of seeing this disparity decrease in the delayed images. It is for this reason that we noted redistribution twice as frequently during exercise than during rest. The timing of the initial image can also be crucial. If the initial images are obtained relatively late after thallium injection, significant redistribution may already have occurred. Finally, the noise inherent in thallium images can be a source of substantial error in determining whether a change has indeed occurred in the thallium activity ratio between normal and hypoperfused images over time.

Quantitative Versus Visual Assessment of Thallium Images

When only visual assessment of images is performed, not only can redistribution be missed, but the amount of thallium within an IRA bed can be grossly underestimated (*16*). Therefore, it is not surprising to visually determine myocardial segments as "dead" on thallium imaging (dense defect and no redistribution), while demonstrating myocardial metabolism on positron emission tomography (PET) (*17*). Myocardial cells cannot, however, be viable without blood flow and "absence" of thallium on delayed images may merely indicate that its uptake is being underestimated by visual inspection.

One reason for the underestimation of thallium activity by visual inspection may be due to the use of high-contrast x-ray film used for processing images. Figure 9 illustrates the characteristic curve of a widely used single-emulsion film where the log relative exposure on the x-axis can be translated to thallium activity. Consequently, if a region of the myocardium receives maximal counts so as to produce a log relative exposure of 24 units and an x-ray film density of close to 4 units, half the counts (equal to a log relative exposure of 12) will hardly produce any density on the x-ray film. Furthermore, depending on which part of the curve is examined, the same difference in the log relative exposure can result in variable differences in x-ray density. For instance, log relative exposures of 16 and 20 (difference of 4) will appear as distinctly different densities on the film while those of 8 and 12 (also a difference of 4) will look similar. Other factors, such as film exposure time, will also affect the relative densities on the x-ray film. It is only by quantitation of the digital background-subtracted data that actual counts within a myocardial bed can be determined. Even viewing images on computer screens is not adequate because of the inherent limitations of the human eye in discerning grey shades.

Comparison with Previous Studies

It has been previously demonstrated that patients with "fixed" defects can improve regional function after undergoing revascularization (*18,19*). Such patients have been shown to have viable myocardium within regions with "fixed defects" on the basis of ^{18}F-fluorodeoxyglucose uptake during PET (*17*). Based on this "flow/metabolism mismatch," it has been erroneously construed and popularized that markers of blood flow, such as thallium, are poor indicators of viability and that demonstration of metabolic activity on PET is required to define the presence of viable myocardium (*17*).

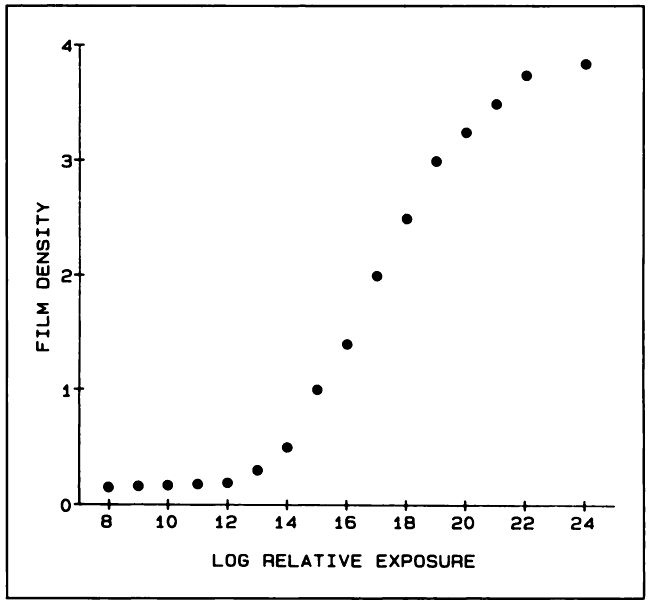

FIGURE 9. Relationship between log relative exposure (x-axis) and x-ray density (y-axis) on high-contrast, single emulsion x-ray film results in "severe defects" even when thallium activity is 30%–50% of normal.

Because thallium cannot accumulate within nonviable cells, different imaging algorithms have been suggested to enhance the discrimination between nonviable and viable myocardium using thallium. One such algorithm recommends that if redistribution is not noted on the conventional delayed image (2–4 hr postinjection), then 24-hr imaging should be performed to give enough time for redistribution to occur (*20*). Using such an approach, regions that do not show fill-in on the routine delayed images may sometimes show better fill-in on the 24 hr images (*20*). We have found that redistribution occurs almost immediately after thallium injection and can be quantitatively determined 2 hr postinjection even if visual fill-in has not occurred (*21*). These same segments show visual fill-in later (*21*).

Another recommended approach involves reinjection of thallium if redistribution is not noted on the postexercise delayed images (*22,23*). Reinjection at rest allows more thallium to enter myocardial tissue that may be viable but which shows a fixed defect 2–4 hr after exercise. Moreover, the problem with reduced count statistics inherent in 24 hr imaging is minimized. Once again, however, we have demonstrated that this method does not improve upon the detection of redistribution using quantitative techniques (*24*). Although fill-in is visually more apparent after reinjection, it invariably occurs within regions that quantitatively demonstrate redistribution.

Limitations of the Study

We did not have many patients with severe reduction (< 35%) in average thallium activity. If such patients had been present in our study, we could have conceivably established the "threshold" of thallium activity below which the myocardium may not show recovery in function despite restoration of anterograde flow. On the other hand, finding such a threshold may be elusive because the gamma camera's sensitivity may be too low to detect thallium in regions where blood flow is so low as to cause transmural necrosis. Therefore, it could be argued that evidence of *any* thallium uptake within an IRA bed may represent viable tissue. As has been demonstrated in our study, the presence of greater amounts of thallium indicate the presence of more viable myocardium.

Because it is not possible to register exactly myocardial segments on planar imaging and those on two-dimensional echocardiography, we believe that averaging activity within an IRA bed from all views is reasonable. It is possible, however, that "shine through" from normal overlying or underlying tissue could have affected our results. Thallium activity within the most hypoperfused segment in any single view, however, also correlated well with regional function.

Finally, in some patients we used rest images and in others we used exercise images for the pre-angioplasty data analysis. However, since we analyzed only the delayed images, the results from both subsets of patients were comparable. Similarly, we compared rest images pre-angioplasty with exercise images postangioplasty in some patients. Since we only compared the relative thallium activity in the delayed images, the different imaging protocols would not have influenced our results.

Clinical Implications

Our results indicate that in patients with recent AMI and a totally occluded IRA, the amount of thallium activity within the IRA bed on delayed planar thallium imaging correlates with the extent of viable myocardium within that bed. Greater amounts of thallium present in these images indicate greater extents of viable myocardium. The presence or absence of redistribution does not influence these results. Further studies are required to define the usefulness of this approach in the day-to-day management of unselected patients with AMI.

ACKNOWLEDGMENTS

Supported in part by grants (R29-HL38345 and R01-HL48890) from the National Institutes of Health, Bethesda, Maryland to Dr. Kaul. Dr. Ragosta was the recipient of a fellowship training grant from the Virginia Affiliate of the American Heart Association, Glen Allen, Virginia. Dr. Kaul is an Established Investigator of the American Heart Association (National Center), Dallas, Texas. Presented in part at the 65th Annual Scientific Session of the American Heart Association, November 1992, New Orleans, LA.

REFERENCES

1. Berger BB, Watson DD, Taylor GJ, et al. Quantitative thallium-201 exercise scintigraphy for detection of coronary disease. *J Nucl Med* 1981; 22:585–593.
2. Villanueva FS, Kaul S, Smith WH, Watson DD, Varma D, Beller GA. Prevalence and correlates of increased lung/heart ratio of thallium-201 during dipyridamole stress imaging. *Am J Cardiol* 1990;66:1324–1328.
3. Touchstone DA, Beller GA, Nygaard T, Tedesco C, Kaul S. Effects of successful intravenous reperfusion therapy on regional myocardial function and geometry in humans: a tomographic assessment using two-dimensional echocardiography. *J Am Coll Cardiol* 1989;13:1506–1513.
4. BBN Software Products Corp. *RS/1 user's guide book 2*. Cambridge, MA: 1987:1–37.
5. Weast RC. *Handbook of chemistry and physics*. Boca Raton, FL: CRC Press; 1986–1987:3–38.
6. Beller GA. Nuclear cardiology: current indications and clinical usefulness. *Curr Probl Cardiol* 1985;10:1–76.
7. Goldhaber SZ, Newell JB, Ingwall JS, Pohost GM, Alpert NM, Fossel ET. Effects of reduced coronary flow on thallium-201 accumulation and release in an in vitro rat heart preparation. *Am J Cardiol* 1983;51:891–896.
8. Reimer KA, Jennings RB. The "wavefront phenomenon" of myocardial ischemic cell death. II. Transmural progression of necrosis within the framework of ischemic bed size (myocardium at risk) and collateral flow. *Lab Invest* 1979;40:633–644.
9. Jugdutt BI, Hutchins GM, Bulkley BM, Becker LC. Myocardial infarction in the conscious dog: three-dimensional mapping of infarct, collateral flow and region at risk. *Circulation* 1979;60:1141–1150.
10. Pohost GM, Zir LM, Moore RH, McKusick KA, Guiney TE, Beller GA. Differentiation of transiently ischemic from infarcted myocardium by serial imaging after a single dose of thallium-201. *Circulation* 1977;55:294–302.
11. Beller GA, Watson DD, Ackell P, Pohost GM. Time course of thallium-201 redistribution after transient myocardial ischemia. *Circulation* 1980; 61:791–797.
12. Gerry JL, Becker LC, Flaherty JT, Weisfeldt ML. Evidence for a flow-independent contribution to the phenomenon of thallium redistribution. *Am J Cardiol* 1980;45:58–62.
13. Pohost GM, Okada RD, O'Keefe DB, et al. Thallium redistribution in dogs with severe coronary artery stenosis of fixed caliber. *Circ Res* 1981;48:439–446.
14. Leppo J, Rosenkrantz J, Rosenthal R, Bontemps R, Yipintsoi T. Quantitative thallium-201 redistribution with a fixed coronary stenosis in dogs. *Circulation* 1981;63:632–639.
15. Okada RD, Leppo JA, Strauss HW, Boucher CA, Pohost GM. Mechanisms and time course for the disappearance of thallium-201 defects at rest in dogs: relation of time to peak activity of myocardial blood flow. *Am J Cardiol* 1982;49:699–706.
16. Kaul S, Chesler DA, Okada RD, Boucher CA. Computer versus visual analysis of exercise thallium-201 images: a critical appraisal in 325 patients with chest pain. *Am Heart J* 1987;114:1129–1137.
17. Brunken RC, Kottori S, Nienaber CA, et al. PET detection of viable tissue in myocardial segments with persistent defects at ^{201}Tl SPECT. *Radiology* 1989;172:65–73.
18. Gibson RS, Watson DD, Taylor GJ, et al. Prospective assessment of regional myocardial perfusion after coronary revascularization surgery by quantitative thallium-201 scintigraphy. *J Am Coll Cardiol* 1983;1:804–815.
19. Liu P, Kiess MC, Okada RD, Block PC, Strauss HW, Pohost GM. The persistent defect on exercise thallium imaging and its fate after myocardial revascularization: does it represent scar or ischemia? *Am Heart J* 1985; 110:996–1001.
20. Kiat H, Berman DS, Maddahi J, et al. Late reversibility of tomographic myocardial thallium-201 defects: an accurate marker of myocardial viability. *J Am Coll Cardiol* 1988;12:1456–1463.

21. Watson DD, Smith WH, Lillywhite RC, Beller GA. Quantitative analysis of ^{201}Tl redistribution at 24 hours compared to 2 and 4 hours postinjection [Abstract]. *J Nucl Med* 1990;31:763.
22. Dilsizian V, Rocco TP, Freedman NMT, Leon MB, Bonow RO. Enhanced detection of ischemic but viable myocardium by the reinjection of thallium after stress redistribution. *N Engl J Med* 1990;323:141–146.
23. Dilsizian V, Smeltzer WR, Freedman NMT, Dextras R, Bonow RO. Thallium reinjection after stress-redistribution imaging: does 24-hour delayed imaging following reinjection enhance detection of viable myocardium? *Circulation* 1991;83:1247–1255.
24. Watson DD, Thallium-201 reinjection: truth or artifact? *J Nucl Biol Med* 1992;36:15–21.

SELF-STUDY TEST

Skeletal Nuclear Medicine

Questions are taken from the *Nuclear Medicine Self-Study Program 1*, published by The Society of Nuclear Medicine

DIRECTIONS

Items 1-3 consist of a question or incomplete statement followed by five lettered answers or completions. Select the *one* lettered answer or completion option that is *best* in each case. Answers may be found on page 814.

1. The "flare" phenomenon in bone scintigraphy refers to which *one* of the following?

- **A.** An increase in uptake in healing metastases following therapy.
- **B.** The extended pattern seen with primary bone tumors.
- **C.** The flame-like edge seen in long-bone lesions of Paget's disease.
- **D.** The persisting minimal uptake seen in regressing metastases.
- **E.** The calvarial flame seen in the skull on oblique views.

2. Which *one* of the following mechanisms is most important in causing locally increased uptake of a bone-seeking radiopharmaceutical in an osseous lesion?

- **A.** Increased blood flow.
- **B.** Increased compact bone mass.
- **C.** The presence of excessive organic matrix.
- **D.** Increased local alkaline phosphatase activity.
- **E.** Increased surface area of hydroxyapatite crystals per unit volume of bone.

3. A 65-year-old man with newly diagnosed carcinoma of the prostate is referred for skeletal scintigraphy. Figure 1 is a posterior image of the pelvis. Based on the scintigraphic findings, the most appropriate next step is which *one* of the following?

- **A.** Obtain a plain radiograph of the pelvis.
- **B.** Repeat the pelvic scintigram after administration of furosemide.
- **C.** Perform SPECT of the pelvis.
- **D.** Perform ^{67}Ga scintigraphy.
- **E.** Obtain a caudal scintigram of the pelvis.

True statements regarding radionuclide imaging of fractures include which of the following?

4. Tibial stress fractures and shin splints are generally indistinguishable by ^{99m}Tc scintigraphy.

5. Infected and noninfected hypertrophic pseudoarthroses can be distinguished reliably by the finding of a high concentration of ^{67}Ga at the fracture site.

6. The ^{99m}Tc MDP scintigraphic abnormalities in a fracture often develop more slowly in patients over 70 years of age than in younger patients.

7. The finding of normal or minimally increased ^{99m}Tc MDP uptake at a site of delayed union indicates a high likelihood of healing with piezoelectric stimulation.

8. Vertebral compression fractures usually have returned to a normal scintigraphic appearance by 6 months after injury.

Three-phase bone scintigraphy reliably distinguishes

9. cellulitis from osteomyelitis.

10. periarticular cellulitis from septic arthritis.

11. acute osteomyelitis from recent fracture.

12. osteomyelitis from osteoid osteoma.

13. active Paget's disease from acute osteomyelitis.

True statements concerning the scintigraphic diagnosis of osteomyelitis include which of the following?

14. Intense focal concentration of ^{67}Ga in a known region of chronic osteomyelitis is highly suggestive of active infection.

15. Imaging with ^{111}In-labeled leukocytes is less sensitive for detecting chronic than acute osteomyelitis.

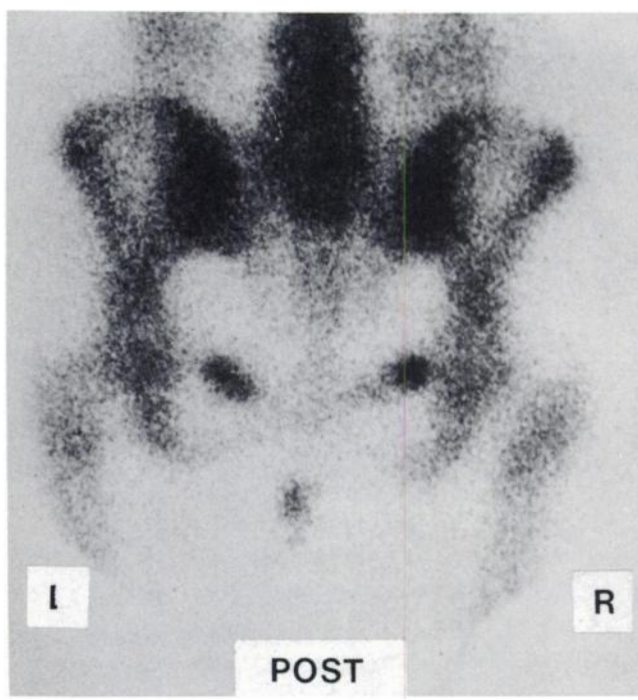

Figure 1

(continued on page 814)