Myocardial Imaging with Thallium-201: An Experimental Model for Analysis of the True Myocardial and Background Image Components

Kenneth A. Narahara, Glen W. Hamilton, David L. Williams, and K. Lance Gould

University of Washington and Seattle Veterans Administration Hospital, Seattle, Washington

The true myocardial and background components of a resting thallium-201 myocardial image were determined in an experimental dog model. True background was determined by imaging after the heart had been removed and replaced with a water-filled balloon of equal size and shape. In all studies, the background estimated from the region surrounding the heart exceeded true background activity. Furthermore, the relationship between true myocardial background and that estimated from the pericardiac region was inconsistent. Background estimates based on the activity surrounding the heart were not accurate predictors of true background activity.

J Nucl Med 18: 781–786, 1977

Due to the inherently low myocardial-to-background ratios obtained in myocardial images with agents such as potassium-43, thallium-201, and cesium-129, various methods have been used to improve the resultant image display. Generally these attempts have used background subtraction, or alterations in the linearity of the display response (contrast enhancement), or both in combination. Initially, these maneuvers were preselected during scanner setup; for example, the 40% threshold used for rectilinear scans of K-43 (*1*). More recently, video display devices and computer systems have been used to enhance contrast and subtract background activity (*2*). The processed myocardial image is visually more pleasing and often appears to have a greater "information content" following these alterations.

Goris et al. (*3*) recently reported a method of interpolative background subtraction for Tl-201 myocardial images, basing the amount of background subtraction on the activity surrounding the myocardium. The images so processed have virtually no background activity and the implication was that lesion detection was improved.

We have developed an animal model to determine precisely the actual or true myocardial and background components of the resting Tl-201 image and how these components combine to form the gross scintillation image. Also reported is a comparison between experimentally determined true background subtraction and the interpolative subtraction technique reported by Goris et al. (*3*).

METHODS

Resting thallium-201 images were obtained from four mongrel dogs (weight = 17–26 kg) in the following manner. An 18-gage needle was inserted into a leg vein and 1–2 mCi of Tl-201 chloride injected. Thirty minutes later, the animal was killed with an injection of sodium pentobarbital, and the chest was opened. The aorta, pulmonary artery, pulmonary veins, and cavae were doubly ligated and cut. A cuffed endotracheal tube was inserted and the lungs expanded to one-third full inspiration. Myocardial imaging was immediately performed in the left lateral position. The scintillation camera had a high-resolution, parallel-hole collimator; the energy win-

Received Jan. 31, 1977; revision accepted March 14, 1977.

For reprints contact: Glen W. Hamilton, Nuclear Medicine Section (115), Veterans Administration Hospital, 4435 Beacon Ave. S., Seattle, WA 98108.

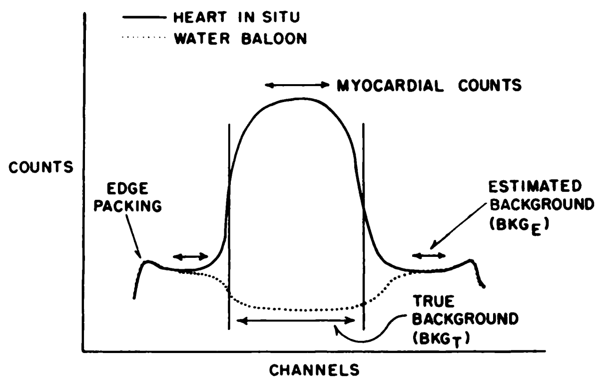

FIG. 1. Diagramatic representation of method used for analysis of profile curves of myocardial images. Myocardial counts were defined as means of profile's highest five points with heart in situ. Estimated background (BKG_E) was calculated as mean of five points overlying pericardiac region. True background (BKG_T) was calculated from profile with heart replaced by nonradioactive water balloon and was defined as mean of all points within FWHM limits of myocardial profile.

dow was centered over the 80-keV mercury x-ray peak. The camera's field uniformity was checked before each experiment. Images (400,000 counts) were obtained as Polaroid prints and were simultaneously stored in a computer system in a 64 × 64 matrix. After the initial image, the heart was removed and measured. A water-filled balloon with equal exterior dimensions was then substituted for the heart and imaging was repeated for the same time required for the initial image. The water balloon was then replaced with an air-filled balloon of the same size and a third image obtained. Care was taken to ensure that the animal was not moved relative to the camera between images. Finally, the excised heart was imaged for an identical time.

The digitized images were analyzed as follows. Profile curves were generated by placing a 10-channel-wide cursor (4 cm) over the center of the heart in a horizontal (ventral to dorsal) and vertical plane. The measurements made from the profile curves are shown graphically in Fig. 1. Myocardial counts were arbitrarily defined as the mean of the five highest matrix points centered over the heart. Background estimated from the pericardiac area (BKG_E) was defined as the mean of five matrix points overlying the region surrounding the heart, chosen carefully to avoid edge-packing. Both these measurements were made from the image with the heart in situ. True background (BKG_T) was obtained from the curve generated from the image with the water balloon in place. The BKG_T was defined as the mean count in the cardiac area limited by the full-width-half-maximum (FWHM) of the myocardial profile in the image with the heart in situ (see Fig. 1). Finally, for each dog, background subtraction was performed (A) on the initial image with the heart in situ by subtracting the true background image (image with the heart replaced by a water balloon) and (B) by using the interpolative background-subtraction method described by Goris (*3*). In the latter method, background for each matrix point (x,y) in the cardiac area is calculated by linear interpolation from orthogonal coordinates overlying preselected regions in the pericardiac area. The resultant background-subtracted images were then subjected to profile analysis, as previously described, to determine the number of remaining myocardial counts.

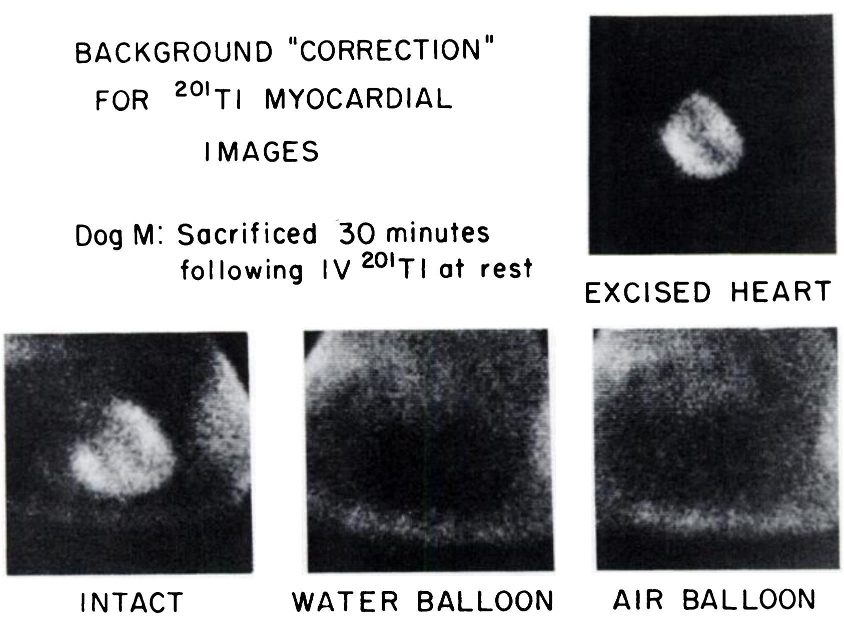

FIG. 2. Images from dog killed 30 min following resting injection of Tl-201. Image labeled *intact* was obtained after ligation of major vessels. *Water-balloon* and *air-balloon* images were obtained after heart was replaced by equal-sized water- or air-filled balloon. Note that area formerly occupied by heart has less activity than surrounding area.

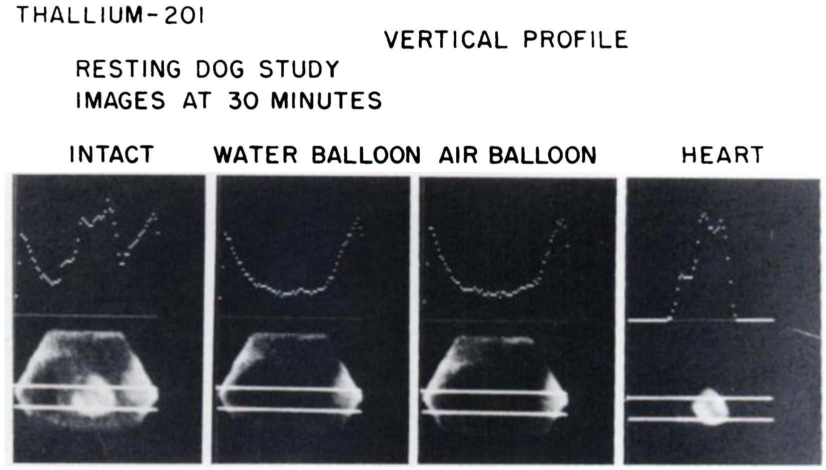

FIG. 3. Vertical profiles (the head is to left) through images shown in Fig. 2. When heart was replaced with water- or air-filled balloon, true background was lower than that predicted from region surrounding heart.

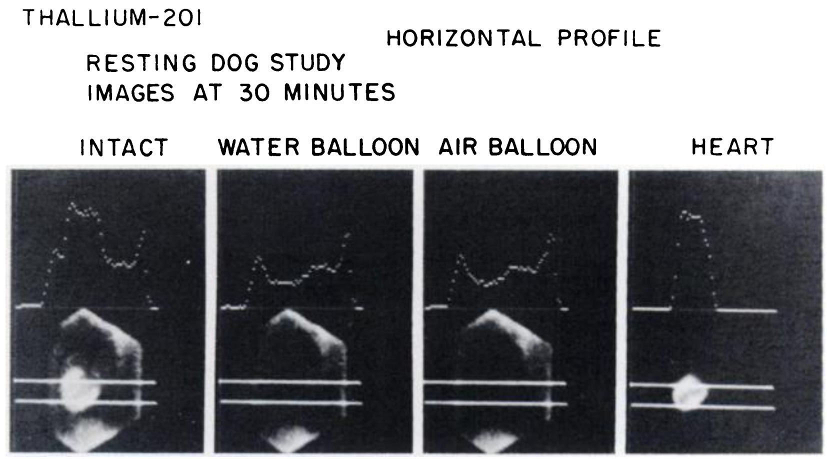

FIG. 4. Horizontal profiles through images shown in Fig. 2. Overestimation of background from area surrounding heart was apparent.

RESULTS

The images obtained from all animals were similar. Figure 2 presents those obtained from Dog 1. Visually, the heart did not appear to be superimposed on a uniform or monotone plane of background activity. In fact, with both the water balloon and the air balloon, the area normally occupied by the heart contains considerably less activity than the surrounding area. This is confirmed by the orthogonal profile curves, which show that activity surrounding the heart exceeds the activity in the heart area (Figs. 3 and 4). The curves obtained with the water-filled and air-filled balloons were similar in all dogs (Fig. 2). In Fig. 5, the profile curves from the images with the heart in situ and then removed are superimposed. They demonstrate not only greater activity surrounding than underlying the heart, but significant scatter from the heart into the pericardiac region.

Table 1 shows summary data calculated from the horizontal profiles (activity profile from ventral to

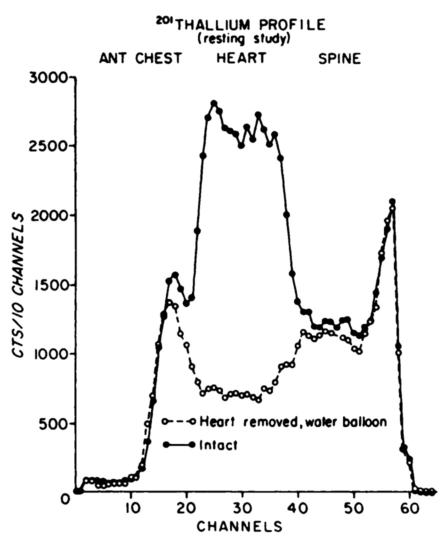

FIG. 5. Direct comparison of horizontal profiles with heart intact and with heart replaced with water balloon. Activity surrounding heart greatly exceeds true background activity. Effect of scatter from heart into surrounding region can be appreciated.

TABLE 1. COMPARISON OF TRUE AND ESTIMATED BACKGROUND

	Heart in situ		Water balloon	% overestimation	% of myoc cts	
Dog No.	Myoc cts	BKG_E cts	BKG_T cts	of BKG_T by BKG_F	BKG_T	BKG_E
1	4449	1707	680	151	15	38
2	2865	1136	686	66	24	40
3	4404	1565	765	104	17	36
4	4119	1401	1108	26	27	34
				Mean 87	21	37

Myoc cts = myocardial counts; BKG_E = estimated background counts; and BKG_T = true background counts.

dorsal through the heart) in the four dogs. Vertical profile analysis resulted in virtually identical numerical values for each dog.

In each animal, the estimated background (BKG_E) overestimated true myocardial background (BKG_T) by an amount varying from 26 to 151% (mean overestimation = 87%). No consistent relationship between BKG_T and BKG_E was found. The true background component constituted from 15 to 27% of the gross counts recorded as "myocardium" in the image with the heart in situ (Table 1). Estimated background was nearly twice as high (37%) as the true background.

Figure 6 compares the initial myocardial image (heart in situ) with the true background image (heart removed). The lower left image represents the true net myocardial image (i.e., the image with heart in situ minus image with the heart removed and replaced by the water balloon). The lower right image shows the background-subtracted image using the Goris interpolative technique. Due to the overestimation of background by the interpolative method, some of the true myocardial counts are subtracted by this method, resulting in considerably fewer myocardial counts in the resultant image (profile graph, Fig. 6). Residual myocardial activity following interpolative background subtraction was 62–75% (mean = 70%) of the true myocardial activity in the four dogs studied. Figure 7 compares true background (heart removed) with the background determined by the interpolative technique. Clearly this technique fails to predict the true background accurately.

DISCUSSION

This study clearly shows that the background component of a resting Tl-201 myocardial image cannot

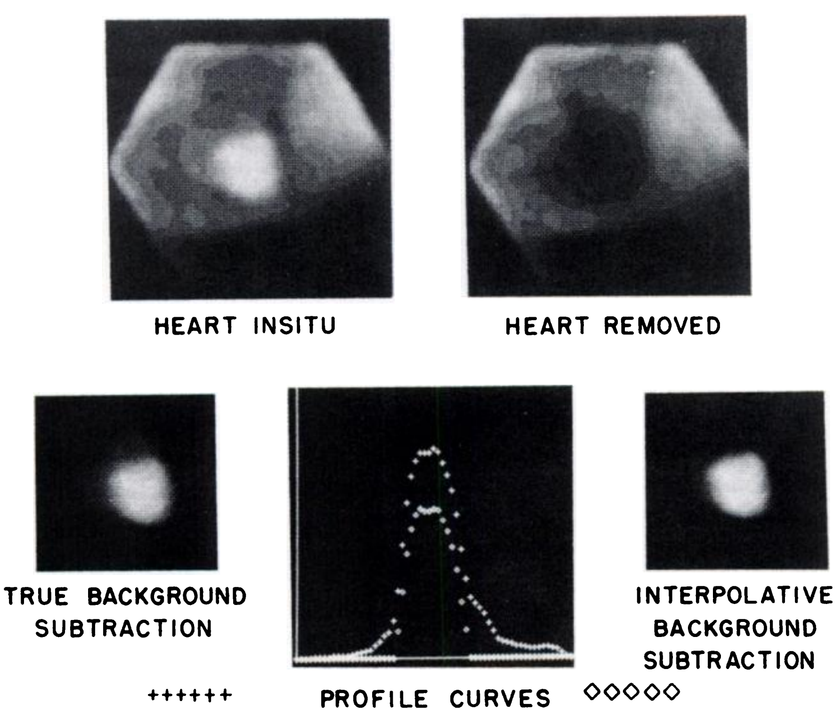

FIG. 6. Images from study of Dog 2, with all images smoothed. Interpolative background subtraction appeared similar to true background subtraction, but profile analysis showed that true myocardial counts were lost by interpolative method.

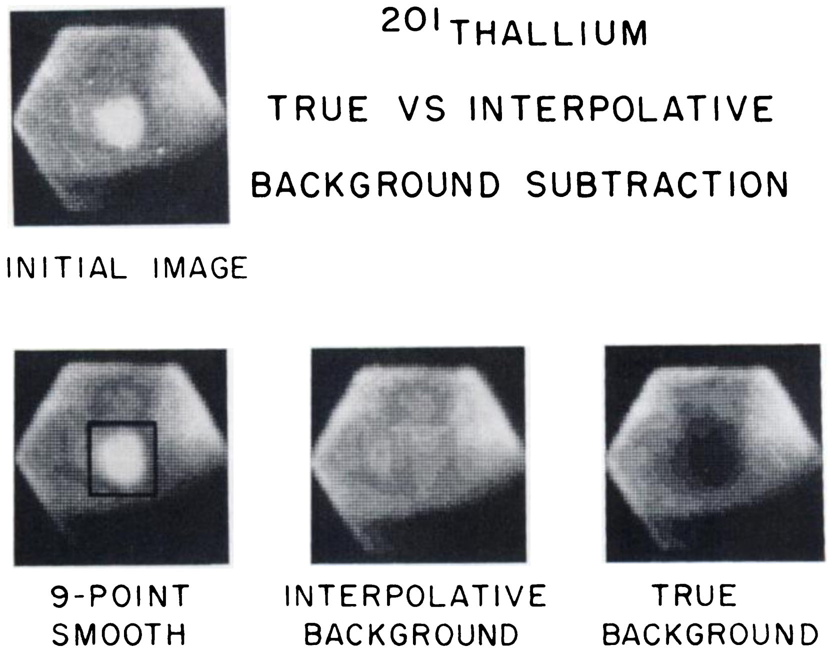

FIG. 7. Direct comparison of (A) true background obtained with heart removed with (B) background estimated by interpolative method. Interpolative estimate is not accurate.

be directly determined from the activity surrounding the heart. First, the activity surrounding the heart is considerably greater than the true background activity and, second, the pericardiac activity is inconsistently related to true background activity. The major reason for the overestimation of background would appear to be anatomic; the normal heart displaces Tl-201-containing lung tissue and the non-myocardial (or background) activity is necessarily less in this region. With the 80-keV x-rays imaged, the attenuating effects of the heart per se appear minimal as judged by the similar images obtained with the air-filled and water-filled balloons. The inconsistent relation noted between the true background and the activity surrounding the heart is also probably due to variations in anatomic relations and differences in the amount of activity in nearby structures such as the liver.

The validity of generalizing these findings from a dog model to human images is uncertain. We believe the model is valid for the following reasons: (A) Tl-201 images in humans and dogs appear quite similar and the resting myocardial-to-background ratios are approximately the same (2:1); (B) although the relationship between organs varies from dog to man, the organs composing the image (heart, lung, skeleton, chest wall, and liver) are the same and there is no reason to suspect major species differences in tissue distribution of Tl-201 (*4*); (C) lastly, our experience with background subtraction in humans has suggested that 20% subtraction is optimal for the resting image, and this is virtually identical to the actual measured true background in the dog model (21%).

It should be emphasized that the data presented apply specifically only to resting Tl-201 images using 80-keV radiation. Studies using other radionuclides with different energies and biologic distributions could be quite different.

In summary, the results suggest that background subtraction should be applied to myocardial images with caution. Methods that estimate background to be substantially greater than 20% are probably inaccurate; data from our model indicate that subtraction of more than 20–30% of the maximal myocardial counts in a Tl-201 image will arbitrarily reduce the estimate of myocardial counts. The pericardiac region will not reliably estimate the true cardiac background. The use of interpolative background subtraction based on pericardiac activity is particularly troublesome. Not only does this method overestimate background, but regions of high nearby activity (which may or may not affect the myocardial portion of the image) could produce erroneous regional decreases in myocardial activity in an image so processed.

If background subtraction must be used for resting Tl-201 images, simple threshold subtraction, not exceeding 20–30% of the maximal myocardial counts, would seem most reasonable considering the data presented here.

ACKNOWLEDGMENT

This work was supported in part by the Veterans Administration, NHLI Grants 1RO1-HL-18805 and RO1-HL-

18492-01, the American Heart Association of Washington, and the Poncin Fund. FORTRAN programs were kindly supplied by M. Goris, Stanford University.

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