A Quantitative Phantom Analysis of Artifacts Due to Hepatic Activity in Technetium-99m Myocardial Perfusion SPECT Studies

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We have observed that filtered backprojection may cause artifactual decreased myocardial wall uptake in the reconstructed images if the hepatic-to-cardiac activity ratio (HCR) in ^{99m}Tc clinical myocardial SPECT studies is sufficiently high (>1). **Methods:** To quantitatively relate hepatic uptake to this phenomenon, a commercial chest and heart phantom was modified with the addition of a customized liver insert, which was filled with various concentrations of ^{99m}Tc to simulate HCRs of 0:1, 1:1 and 2:1. The phantom was imaged with a high-sensitivity, three-detector camera, low-energy, high-resolution (LEHR) collimation and 180° noncircular orbits. **Results:** Quantitative circumferential profile analysis of the reoriented SPECT images demonstrated artifactual inferior/inferoseptal maximal activity decreases of 17.8% and 46.2% for the 1:1 and 2:1 HCRs, compared to the 0:1 HCR. Hepatic scatter probably partly mitigates the decrease. Smoothing the projection data before reconstruction worsened the artifacts' severity. Using Butterworth filters of order 5 and cutoff frequencies of 0.1, 0.2 and 0.215 Nyquist (clinical standard) resulted in artifactual inferior wall activity decreases of 5%, 8% and 16%, compared to using the same filter with a cutoff of 0.3 for an HCR of 2:1. **Conclusion:** These data indicate that if count statistics are good and liver uptake is high, higher frequency cutoffs in pre-reconstruction filters may improve specificity in ^{99m}Tc-labeled myocardial perfusion SPECT studies.

Key Words: technetium-99m SPECT; phantom analysis; artifacts, hepatic-to-cardiac activity ratio

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Tomographic image reconstruction from projections via filtered backprojection is the current standard in cardiac SPECT. First described by Shepp and Logan (*1*), this process differs from simple backprojection in that it convolves the projection data with a piece-wise negative filter function, so as to create a band of negative or "cold" pixels immediately around "hot" objects and thus eliminate "star artifacts" (*2*). When the structure or organ one wants to image is close to a hotter structure, as is the case for the hips in the presence of a hot bladder in SPECT studies of the pelvis, filtered backprojection has been shown to severely corrupt hip activity (*3,4*). Further limitations and streaking artifacts introduced if the bladder's activity is varying during the SPECT acquisition have also been previously described (*5,6*). In myocardial perfusion SPECT, intense hepatic activity sometimes totally obscures the inferior myocardium. This problem is most commonly seen with ^{99m}Tc myocardial perfusion agents due to their prominent hepatobiliary excretion and is most commonly associated with rest or pharmacologic stress studies in which the hepatic uptake is most marked (*7*). An example of prominent hepatic uptake in a ^{99m}Tc-teboroxime study is shown in Figure 1 for a 4-min acquisition. This phenomenon may also be seen in rest or pharmacologic stress ^{99m}Tc-sestamibi studies if the injection to imaging delay is compromised (i.e., less than 1 hr). A more insidious case is that where no obvious artifacts are present, but the proximity of a hot liver to the heart may cast doubts on the interpretation of an apparent perfusion abnormality in the inferior or inferoseptal myocardial wall, as shown in Figure 2 for a 15-min, adenosine stress ^{99m}Tc-sestamibi study.

In this work, we postulate that high hepatic uptake can create artifactual perfusion defects in the inferior/inferoseptal myocardial wall. After proving that assumption with the help of a liver and heart phantom containing various ratios of ^{99m}Tc concentrations, we investigated the effect of the hepatic activity level and amount of pre-reconstruction smoothing on the severity of the artifacts (*8*).

MATERIALS AND METHODS

We modified a commercial chest and heart phantom (Data Spectrum elliptical bath, cardiac insert model 7070, Chapel Hill, NC) with the addition of a custom-made, lucite liver insert in the shape of a wedge (Fig. 3). The insert was strapped to the myo-

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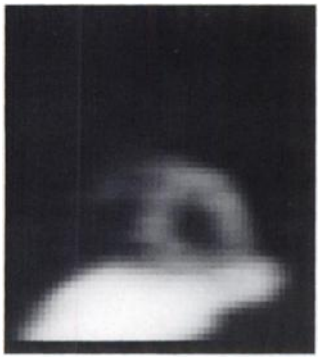

FIGURE 1. Short-axis image from a 4-min ^{99m}Tc-teboroxime study of a normal patient who underwent adenosine stress within the protocol described in (*7*). Note that high hepatic uptake makes it impossible to interpret the perfusion pattern of the inferior myocardial wall.

cardium with Velcro so that its left superior lobe would be present in a few transaxial images of the heart, then filled with various concentrations of ^{99m}Tc to simulate hepatic-to-cardiac activity concentration ratios (HCRs) of 0:1, 1:1 and 2:1; the latter two being ratios commonly seen clinically. In all three cases, the total activity in the myocardium was 500 μCi, a value representative of the statistics encountered in clinical practice. The phantom in each configuration was then imaged for 15 min with a high-sensitivity, three-detector camera (Prism 3000, Picker, Bedford, OH), LEHR collimation and a noncircular (phantom-contoured) orbit. The three projection data sets were smoothed with a two-dimensional Butterworth filter (order = 5, cutoff = 0.215 Nyquist), as routinely done for patient studies and reconstructed over 180° (45° RAO to LPO) with a ramp filter and filtered backprojection. The transaxial image sets were manually re-oriented (using identical parameters) into short-axis image sets, and quantitative circumferential profile analysis of the resliced SPECT images was performed using the Explorer® software analysis package (*9*).

In order to investigate the effect of pre-reconstruction filtering, we also smoothed the projection data set corresponding to HCR = 1 with a two-dimensional Butterworth filter (order = 5) and four different cutoff frequencies (0.1, 0.2, 0.215 and 0.3 Nyquist) before reconstruction, which was performed as described above. Figure 4 shows the combination of the Butterworth and the reconstruction ramp filters in the space and the frequency domain for five different cutoff frequencies (0.05, 0.1, 0.15, 0.2 and 0.25 Nyquist), two of which (0.1 and 0.2 Nyquist) were used in this work. Region of interest (ROI) analysis was performed on the re-oriented images using Explorer®. In particular, two circular ROIs of equal size were centered on the anterolateral (reference) and the inferoseptal (artifactual defect) myocardium of the image set, reconstructed with the sharpest filter combination (0.3 Nyquist and

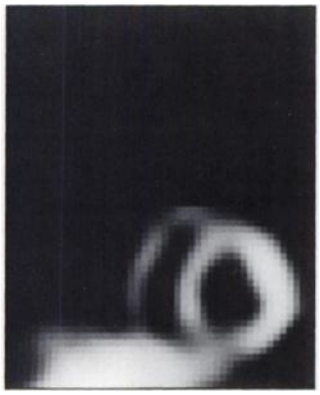

FIGURE 2. Short-axis image from a 15-min ^{99m}Tc-sestamibi study of a patient with left anterior and right coronary artery disease. Although anterior/septal/inferior hypoperfusion is fully expected for this pathology, high hepatic uptake may have further decreased apparent uptake in the right coronary artery territory.

FIGURE 3. Custom-made, lucite liver insert in the shape of a wedge secured to a commercial heart phantom (Data Spectrum model 7070).

ramp), then copied onto the other sets. The average counts-per-pixel in the defect normalized to those in the reference area were calculated for all sets.

RESULTS

Effect of Varying Hepatic-to-Cardiac Activity Ratios on Apparent Myocardial Radioactivity Concentrations

Figure 5 shows the same short-axis slice of the phantom for HCR = 0, 1 and 2. For ease of comparison, each image is displayed using a grey scale whose maximum value corresponds to the maximum activity in the myocardium in

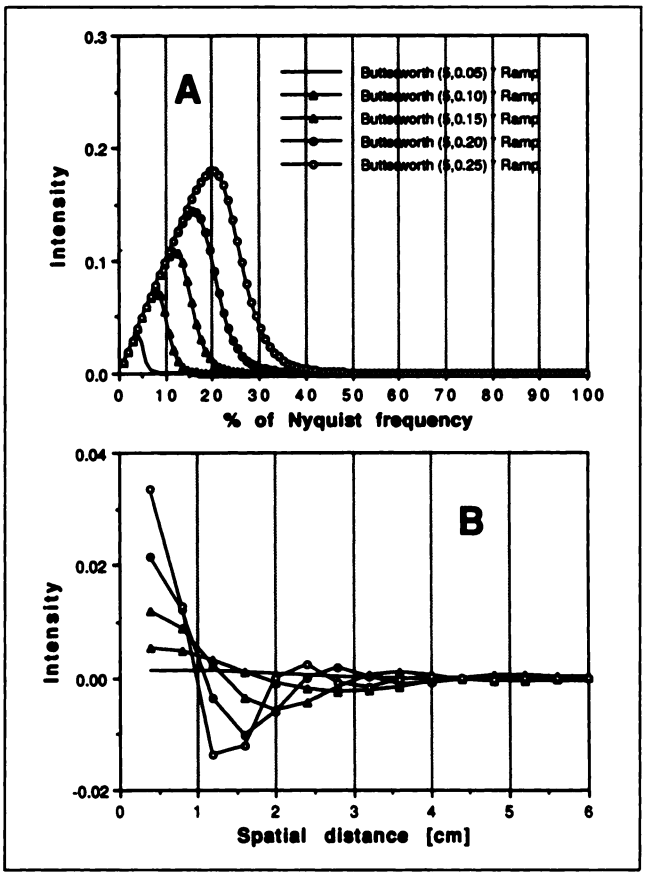

FIGURE 4. Combination of five Butterworth filters (order = 5, cutoff frequencies = 0.05, 0.1, 0.15, 0.2 and 0.25 Nyquist) with the same reconstruction ramp filter shown (A) in the frequency and (B) in the space domain. The band of "cold" pixels created in the backprojection process corresponds to the below-zero portions of the filters in the space domain.

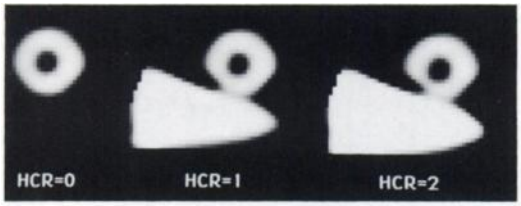

FIGURE 5. Homologous short-axis slices of the phantom, reflecting hepatic-to-cardiac activity concentration ratios (HCRs) of 0:1, 1:1 and 2:1. All projection data were reconstructed as in clinical practice, and each image is displayed normalized to its own myocardial maximum.

that image. Visual analysis reveals a normal myocardial perfusion pattern if the liver contains no activity (HCR = 0), and an artifactual inferoseptal perfusion defect of severity proportional to hepatic activity otherwise. Quantitative maximal circumferential profile analysis of the images (Fig. 6) shows a similar pattern, with 17.8% and 46.2% maximal decreases of inferoseptal activities for the HCR = 1 and HCR = 2 cases, respectively, compared to the reference HCR = 0 case. Hepatic scatter probably partly mitigates the decrease.

Effect of Varying Prereconstruction Filtering on Apparent Myocardial Radioactivity Concentrations

Figure 7 shows the same short-axis slice of the phantom for HCR = 1 and the four different cutoff frequencies of the prereconstruction Butterworth. Again, each image is normalized to its own myocardial maximum for display purposes. Visual analysis reveals a very large artifactual inferior/inferoseptal perfusion defect when the data are smoothed heavily (0.1 Nyquist) before reconstruction; lighter smoothing (0.2, 0.215 or 0.3 Nyquist) results in qualitatively similar images. Quantitative ROI analysis of the images, however, (Fig. 8) shows a clear inversely proportionate relationship between the artifact severity and the cutoff frequency of the prereconstruction filter, with inferoseptal average activity decreases of 5.0%, 8.0% and 15.6% for the 0.215 Nyquist, 0.2 Nyquist and 0.1 Nyquist smoothing, respectively, compared to the reference 0.3 Nyquist smoothing. Linear fitting of the data in this cutoff frequency range yields excellent correlation (r > 0.99),

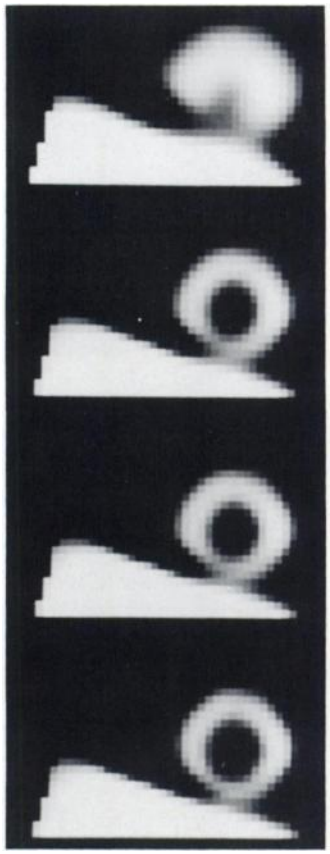

FIGURE 7. Short-axis slice of the phantom corresponding to projection data smoothed with a Butterworth filter of order 5 and cutoff frequencies of (top to bottom) 0.1, 0.2, 0.215 and 0.3 Nyquist before reconstruction. All images reflect an HCR of 1 and were reconstructed using backprojection with a standard ramp filter.

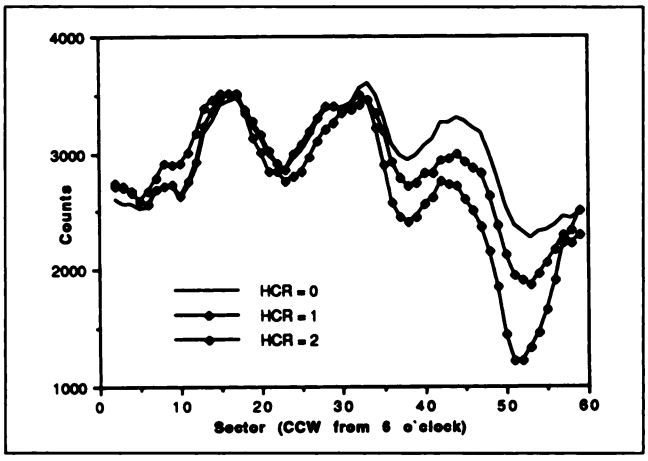

FIGURE 6. Quantitative maximal circumferential profile analysis of the images in Figure 5 with profiles normalized based on the sum of maximal counts in sectors 10 through 30. Inferoseptal maximal activity decreases by 17.8% and 46.2% in the HCR = 1 and HCR = 2 cases, respectively, compared to the reference HCR = 0 case.

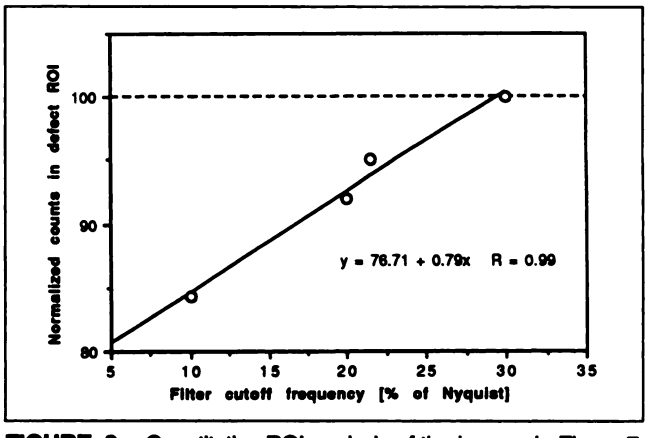

FIGURE 8. Quantitative ROI analysis of the images in Figure 7. Artifact severity appears inversely proportional to the cutoff frequency of the pre-reconstruction filter, with inferoseptal average activity decreases of 5.0%, 8.0% and 15.6% for the 0.215 Nyquist, 0.2 Nyquist and 0.1 Nyquist smoothing, respectively, compared to the reference 0.3 Nyquist smoothing.

although one would expect the linearity relationship to break down outside that range.

DISCUSSION AND CONCLUSIONS

Our study demonstrated that hepatic activity in myocardial SPECT studies using ^{99m}Tc may be responsible for apparent hypoperfused areas in the inferior/inferoseptal region of the myocardium, even in the absence of true perfusion abnormalities. This phenomenon is governed by two factors: (1) the physical distribution of activity in the thorax and abdomen, i.e., the level of hepatic uptake relative to the myocardium and its proximity to it, and (2) the type and amount of smoothing applied to the projection data before or during filtered backprojection. The occurrence and severity of artifactual perfusion defects is directly proportional to the ratio of hepatic-to-cardiac activity for a given level of smoothing, and linearly proportional to the amount of smoothing for a given hepatic-to-cardiac activity ratio. Based on these findings, it is possible to conclude that filtered backprojection reconstruction of cardiac studies in the presence of a hot liver would be best accomplished using a ramp filter and no pre-smoothing of the projection data. The reconstructed image volume could then be smoothed in the three-dimensional space, possibly after segmentation and removal of the liver. This approach would result in the least contamination of the inferior/inferoseptal myocardial wall distribution by the hepatic distribution. A completely different approach would entail recurring to algebraic reconstruction techniques: in expectation maximization algorithms, an activity concentration coefficient is estimated for each pixel in the image volume by iteratively maximizing the probability of the observations, thus eliminating the "cold pixel halo" issue typical of filtered backprojection (*10*).

Hepatic activity in ^{99m}Tc-sestamibi studies is virtually constant over the SPECT acquisition time, due to the relatively slow hepatic uptake/clearance of this agent (*11*). In ^{99m}Tc-teboroxime studies, where hepatic activity peaks at about 7–15 min from injection and the uptake/clearance dynamics of both the liver and the heart are comparable to the acquisition time (*12,13*), additional artifacts may result when "long" static SPECT studies are acquired (*5,14*). This problem can be reduced by performing a series of quick, consecutive SPECT acquisitions with continuous, alternating detector rotation (*7*). This approach ensures that the variation of hepatic activity over any individual SPECT rotation be less than twofold (*6*) and allows for that variation to be averaged out by summing data from adjacent rotations before reconstruction.

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