Evaluation of Techniques for the Elimination of "Hot" Bladder Artifacts in SPECT of the Pelvis

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The purpose of this study was to validate the usefulness of two digital filtering techniques used to eliminate the artifacts caused by rapid bladder filling during SPECT of the pelvis. A dynamic phantom model was used containing two hips and a bladder. The phantom was studied under three conditions—bladder empty, filling, and full. The ability of the pixel truncation and interpolative background replacement techniques to eliminate bladder artifacts was assessed. Both techniques gave similar results and resulted in significant (but not complete) recovery of activity in the hips. Quantitative analysis of pixel counts over each hip shows that the measured activity was variable and ~20%–30% less than that seen in the empty bladder study. The use of left/right ratio to quantitate differences in hip activity was highly inaccurate despite the use of these filtering techniques. In summary, while these techniques significantly improve image quality, caution should be exercised, particularly in the evaluation of the medial aspects of the hips.

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Bone scintigraphy has been used for many years in the diagnosis of avascular necrosis (AVN) of the hip (*1*, *2*). Recently, several studies have shown that the use of SPECT can significantly improve the sensitivity and specificity of bone scintigraphy in detecting AVN (*1*,*3*). However, a significant limitation to the routine use of SPECT for this purpose is the presence of artifacts in the reconstruction images due to large amounts of activity in the bladder. In one study, Collier et al. (*1*) found that ~19% of studies could not be read due to imaging artifacts created by rapid bladder filling during SPECT acquisition. Bladder catheterization has been suggested to eliminate this problem. However, the morbidity associated with this has persuaded many clinicians to fall back on conventional and pinhole views as the method of choice for imaging the hips in such patients, despite the fact that planar techniques are known to have significantly poorer sensitivity and specificity when compared with tomographic techniques (*3*).

Over the last two years, a number of different techniques have been described that attempt to correct for the effects of bladder activity in SPECT of the hip (*4*–*7*). While these techniques have all been reported to significantly improve the visualization of the femoral heads, the accuracy and validity of these techniques has not been critically examined.

The purpose of this study was to determine the degree to which such techniques can correctly eliminate artifacts caused by a hot bladder, using a dynamic phantom model of the hips and bladder.

MATERIALS AND METHODS

Pelvic Phantom

For this study, we used a commercially available cardiac phantom (Model RH-2, Capintec Inc., New Jersey), which was modified for the purpose at hand. The phantom consisted of a lucite body 30 cm wide, 20 cm thick, and 19 cm high, containing a Teflon rod to simulate the thoracic vertebrae and was subdivided into three compartments. The two side compartments contained wood powder to simulate the lungs. A central compartment could accommodate a heart model.

For this study, the wood powder was removed and each side compartment filled with a solution of technetium-99m-pertechnetate ([^{99m}Tc]pertechnetate) in water (350 μCi ^{99m}Tc per compartment) to simulate soft-tissue activity. A "hip" phantom (Fig. 1A) was inserted into each of the side compartments. The hip phantom consisted of a hollow lucite cylinder of 15 cm height and 5 cm diameter containing three solid lucite rods of diameters 12, 9, and 8 mm (Fig. 1A). The hip phantoms were each filled with 150 μCi [^{99m}Tc]pertechnetate and water. A "bladder" phantom was placed in the central compartment. This consisted of a 500-ml saline bag connected through a port in the cover of the phantom, to an outside reservoir (Fig. 1B). Drainage of the reservoir into the bladder under gravity effectively simulated increasing bladder activity. The reservoir was filled with 9.5 mCi [^{99m}Tc]pertechnetate in 350 ml of water. The remaining space in the central compartment was filled with water. To accommodate overflow in this compartment as the bladder filled, a second port connected the central compartment to an overflow bag. The rate of flow of ^{99m}Tc from the reservoir into the bladder was

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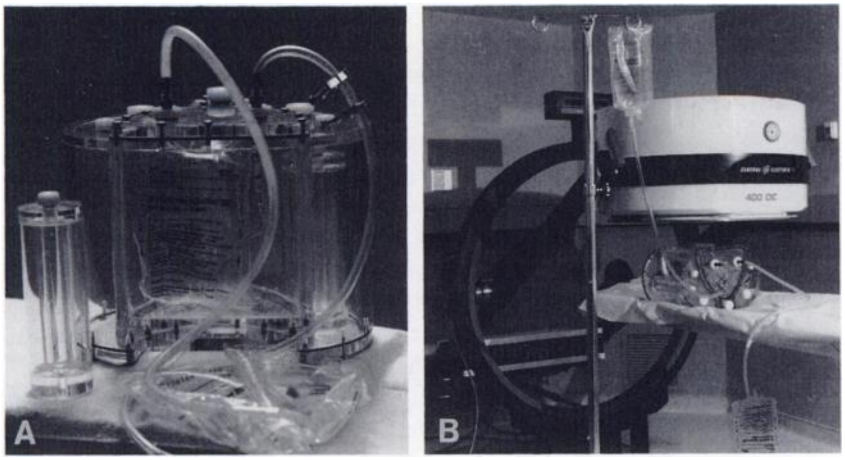

FIGURE 1
(A) Modified cardiac phantom containing a 500-ml saline bag to simulate the bladder and two lucite circular phantoms to simulate the hips. Each hip phantom contains three rods of lucite. The tubes connect the bladder and central compartment to a reservoir and overflow bag, respectively. (B) The pelvic phantom in position under the gamma camera. The reservoir for the bladder is on the i.v. stand and the overflow bag is shown below the phantom.

controlled by two adjustable clamps. The flow rate was set so that the bladder filled over a 25-min period. The hip and background activities in the side compartments were chosen to give similar count densities to those seen clinically. The bladder activity was chosen to give a bladder-to-hip activity ratio of ~15:1–20:1. These ratios represent the maximum bladder-to-hip ratio one would expect to encounter in clinical studies (*6*). The entire phantom model complete with reservoir and overflow bag is shown in Figure 1B.

Data Acquisition

All studies were performed on a conventional gamma camera system (400 AC Starcam, General Electric, Milwaukee, WI) equipped with a low-energy high-resolution collimator. Three sequential tomographic acquisitions were performed. For each acquisition, 64 images were acquired into 128 × 128 matrices over a 360-degree circular orbit. The direction of rotation was clockwise for the first acquisition and reversed for each subsequent acquisition. The time per image for the first acquisition was 20 sec, with the time per image being increased for subsequent acquisitions to compensate for decay of the [^{99m}Tc]pertechnetate. The three acquisitions were performed under the following conditions:

Study 1: Control study—no activity in the bladder.
Study 2: The bladder was filled during the course of the acquisition.
Study 3: The bladder was full for the duration of the acquisition.

Data Preprocessing

Two preprocessing algorithms were evaluated with Studies 2 and 3, to determine their ability to correctly eliminate artifacts caused by the bladder activity. Method 1 employs the pixel truncation (PT) technique described by Bunker et al. (*5, 7*). In this method, the hottest pixel value over the hips is determined from the anterior projection. This value is increased by two and the new value used as the upper limit of pixel counts in all 64 views. All pixels with counts greater than this upper limit are reset to the limit.

Method 2 employs the interpolative background replacement (IBR) technique described by Gillen et al. (*6*). This method represents a modification of the interpolative background subtraction technique first described by Goris et al. (*8*) for use in planar thallium myocardial imaging analysis. Briefly, for each projection image in the SPECT study, a rectangular box is placed over the bladder region. For each pixel within the bladder region of interest, a new value is calculated using the counts in the four pixels which are situated around the perimeter of the region and which lie directly above, below, and to the left and right of it.

Data Reconstruction and Analysis

Following any preprocessing as described above, data were prefiltered with a Butterworth filter (cutoff = 0.45 cycles/cm order 12) and backprojected using a Ramp filter. The filter parameters are similar to those used for clinical bone SPECT at our institution. One-pixel thick (3.2 mm) transaxial and coronal slices were then generated.

Results obtained from Studies 2 and 3, both with and without the preprocessing techniques, were compared qualitatively with those obtained from Study 1 to determine the effects of bladder activity on image quality and to determine the success or otherwise of Methods 1 and 2 in eliminating these effects. A more quantitative comparison of the above effects was obtained by placing small circular regions of interest over each hip and comparing the counts obtained to those obtained over the same hip from Study 1. This analysis was performed on 40 transaxial slices for each study and the variation along the length of each hip was plotted as a graph.

RESULTS

Figure 2 illustrates the effects of the PT and IBR techniques on the planar projection images. Figure 2 (1st row) shows the anterior and left lateral projection images from Study 1 (no bladder activity). Figure 2 (2nd row) shows the same projection views from Study 3 (bladder full of activity). Figure 2 (3rd, 4th rows) illustrates the effects of the PT and IBR techniques on the projection images from Study 3. Both techniques successfully eliminate the large difference in counts between the bladder and hips.

Figure 3 shows representative transaxial and coronal slices generated from the three acquisitions. The contrast in Studies 2 and 3 has been adjusted to permit visualization of the hips. Note the significant degradation in resolution of the hips caused both by the chang-

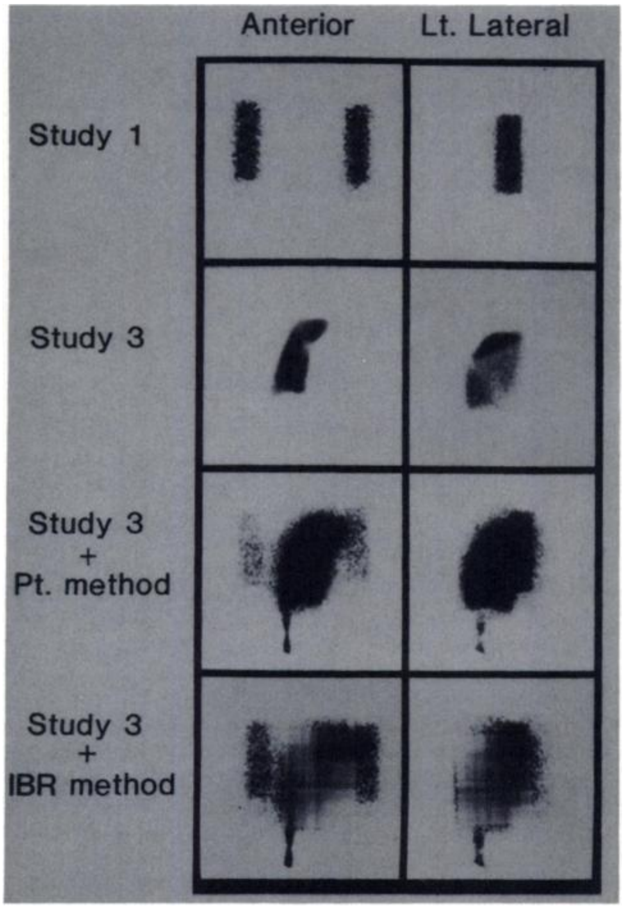

FIGURE 2
Planar projection views from Study 1 (1st row) and Study 3 (2nd row) taken at 0° and 90°, showing the original images and images from Study 3 after application of the PT (3rd row) and IBR (4th row) techniques. Each image is scaled to its own maximum.

ing activity within the bladder and the consequences of the close proximity of a hot bladder to the hips. Figure 3C also demonstrates streak artifacts due to changing bladder activity. These artifacts run from a NNE to SSW direction, consistent with a counterclockwise rotation and an anterior starting position. Figure 4 shows the effectiveness of the PT and IBR techniques in eliminating the above artifacts. As can be seen from the coronal slices, both techniques significantly improve the visualization of the hips. Compared with the control study, neither preprocessing technique fully eliminates the artifacts caused by a hot bladder. This is particularly noticeable on coronal slices showing the medial aspect of the hip phantoms (Figs. 4F and 4H). Both techniques give similar results irrespective of whether the bladder is filling or full for the duration of the acquisition. Examination of the transaxial slices shows that the PT technique leads to some distortion of the hips (Figs. 4A and 4E), while the IBR technique causes some slight loss of resolution due to its interpolative nature (Figs. 4C and 4G).

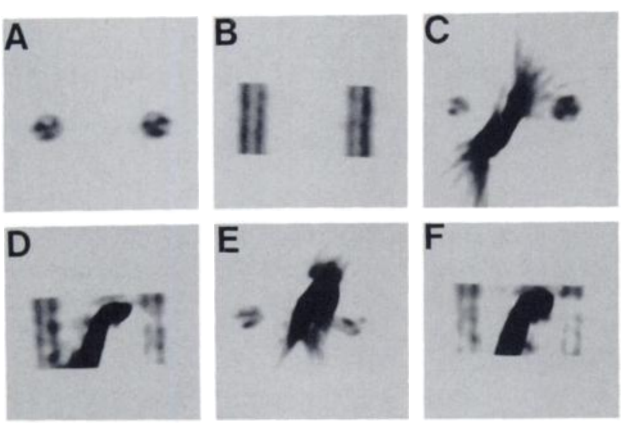

FIGURE 3
Transaxial and coronal slices taken from Study 1 (A,B), Study 2 (C,D), and Study 3 (E,F). All images have been rescaled to the same maximum.

Figure 5 compares the counts in the left and right hips for all three studies and for the different preprocessing techniques. As can be seen from Figure 5 (top line), the presence of bladder activity during SPECT causes significant corruption of counts in the hips and prohibits any estimation of a left-to-right count ratio. The asymmetry in the left and right hip activities is partly due to slight off centering of the bladder in the phantom and partly due to artifacts caused by increasing bladder activity during acquisition. While both the PT and IBR techniques have improved image quality as shown above, there still remains considerable distortion of activity within each hip.

DISCUSSION

There are two principle mechanisms by which bladder activity can cause artifacts in SPECT of the hips. Increasing bladder activity during the tomographic acquisition period will result in streak artifacts that run from a NNE to a SSW direction (Fig. 3C) for a zero degree starting angle. This changing activity is probably the most widely accepted cause of artifacts, however Gillen et al. (*6*) found that in thirteen patients, the bladder activity only increased by a factor of 1.61 between the beginning and end of the study. Furthermore, Bok et al. (*9*) have shown that if tracer activity changes by less than a factor of two, there is little image distortion present in the transaxial data.

Possibly the most significant source of error in any reconstruction process is the presence of a very hot source in a cool body. Gillen et al. (*6*) have shown that the backprojection process, in particular the Ramp filter, creates a large band of pixels with negative counts around a hot object. These negative counts effectively cancel out activity in surrounding structures, obscuring any detail in the hips. Both these mechanisms are well illustrated in Figure 3. From the coronal slices, it can be seen that the full bladder has caused greater corruption of hip activity (Fig. 3F) than that seen with change in bladder activity (Fig. 3D).

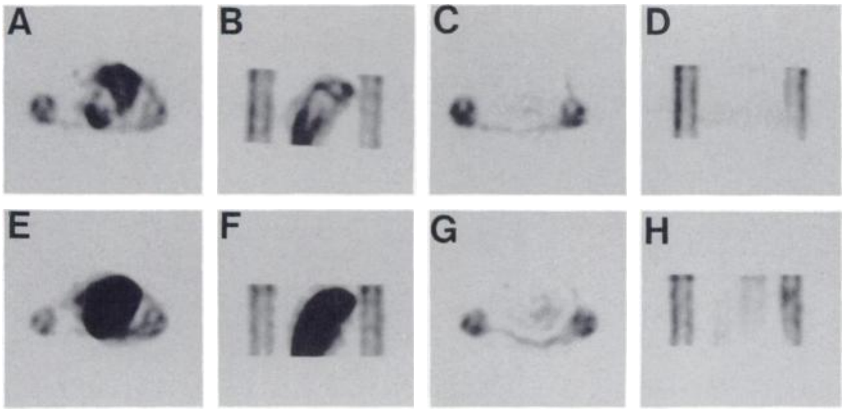

FIGURE 4
Transaxial and coronal slices taken from Study 2 following application of the PT (A,B) and IBR (C,D) techniques and from Study 3 following application of the PT (E,F) and IBR (G,H) techniques. All images have been rescaled to the same maximum.

Figure 4 demonstrates that both the PT and IBR techniques significantly reduce bladder artifacts and improve visualization of the hips. However, neither technique is successful in the complete elimination of these artifacts. As can be seen from Figures 4A and 4E, the PT technique does not fully correct for the distortion present in the left hip. The IBR technique can give rise to ring artifacts caused by a discontinuity between the original pixel counts and the interpolated pixel counts in the planar data (Figs. 4C and 4G). These distortions are less evident on the coronal slices, which show good recovery of hip activity and resolution with only a slight loss of counts in the medial aspect of the left hip.

Quantitative analysis of the counts in each hip (Fig. 5) indicates that both the PT and IBR techniques fail to restore the measured counts to their true value. While both techniques have substantially increased the pixel counts over each hip, these counts still lie ~20%–30% below the value recorded in the control study (Study 1). Furthermore, the degree of restoration of counts over each hip was variable. Hence, in the presence of a hot bladder, the use of a left-to-right ratio to quantitate differences in femoral head activity appears to be an unreliable technique, even with the use of correction algorithms for bladder activity.

In conclusion, in the presence of hot bladder activity, the application of digital filtering techniques to the projection data can result in a significant improvement in the visualization of hip activity in the reconstructed tomographic data. Neither of the techniques discussed above fully correct for the distortion present in the transaxial data and caution should be exercised, particularly in the evaluation of the medial aspect of the hips.

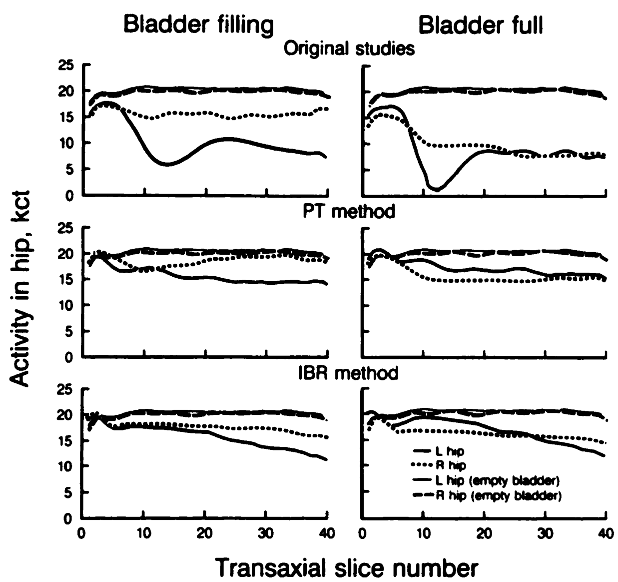

FIGURE 5
Plot of the activity (pixel counts) over each hip in Study 2 (bladder filling) and Study 3 (bladder full) over the length of the hip phantom. Results are shown for the original studies and after application of the PT and IBR filters to the projection data. Activity curves for Study 1 (empty bladder) are shown for reference in each graph.

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