Digital Filtering of the Bladder in SPECT Bone Studies of the Pelvis

Gerard J. Gillen, James H. McKillop, Thomas E. Hilditch, John K. Davidson, and Alex T. Elliott

West of Scotland Health Boards Department of Clinical Physics and Bio-Engineering, Department of Medicine, Glasgow Royal Infirmary; Department of Radiology, Western Infirmary, Glasgow, Scotland

A data processing technique for the removal of bladder activity from single photon emission computed tomographic bone studies of the pelvis has been developed. The method involves the replacement of count values in the bladder on all projection views by data which are representative of the activity in surrounding structures. Reconstruction is then performed using the amended set of projection views. The method was tested by examining a group of 13 patients referred for investigation of avascular necrosis of the femoral head. Significant improvements in image quality were observed, particularly with respect to the level of artifact production, which increased the number of cases in which a confident and correct diagnosis was made.

J Nucl Med 29:1587–1595, 1988

Single photon emission computed tomography (SPECT) studies of the skeleton have been utilized in the investigation of a wide variety of skeletal disorders (*1–4*). One of the most useful applications has been in the diagnosis of avascular necrosis (AVN) of the femoral head. However, SPECT images of the pelvis are often compromised by artifacts which are produced by the presence, within the bladder, of high levels of activity which increase over the acquisition period of the study. In practice, the influence of bladder activity can make 20% of SPECT scans of the pelvis unusable (*5*). In addition to this, the quality of an even larger proportion of scans is reduced.

The most direct method for the removal of the influence of bladder activity from SPECT bone studies of the pelvis is patient catheterization. However, a significant level of morbidity is associated with catheterization, which, if employed in all SPECT bone studies of the pelvis would seriously limit the applicability of the test. Thus, a method for the removal of the influence of bladder activity through some form of processing of the acquired data is required. (*6*). We have applied a method of interpolative background replacement to this problem which appears to be a practical solution.

Received Oct. 23, 1987; revision accepted Apr. 19, 1988.

For reprints contact: Gerard J Gillen, Dept. of Clinical Physics and Bio-Engineering, 11 West Graham St., Glasgow, G4 9LF, Scotland.

MATERIALS AND METHODS

Artifact Production

There are several ways in which the presence of activity within the bladder affects the images in a reconstructed SPECT study. Artifacts, in the form of streaks which extend across the whole width of a transaxial section, (Fig. 1), are produced as a result of the fact that the activity within the bladder increases during the acquisition period of the scan. The streaks have a characteristic fan shaped pattern (*5*), which is a consequence of increased bladder counts in projection views acquired as the camera rotation angle proceeds towards 360°. The most intense streak results from the back projection of bladder counts in the last view collected, when the bladder activity is a maximum, with streak intensity gradually decreasing for views acquired and back projected at smaller angles. This explains why the streak artifacts occur mainly in a NNE to SSW direction when the starting angle for the study corresponds to an anterior view of the patient. As can be seen from Figure 1 the count densities in the streak artifacts can be higher than those in the femoral heads themselves. In addition, there are many cases in which they will overlap one or both femoral heads, substantially reducing the confidence with which structures within the image can be identified.

Perhaps the most pernicious effect, however, that bladder activity can have on SPECT bone studies of the pelvis is the production of photon deficient areas which are most obvious in sections taken in the coronal plane. This is illustrated in Figure 2 where the cold areas in the femoral heads are due to artifacts produced by high levels of activity in the bladder. This is obviously of concern when the scan is being performed

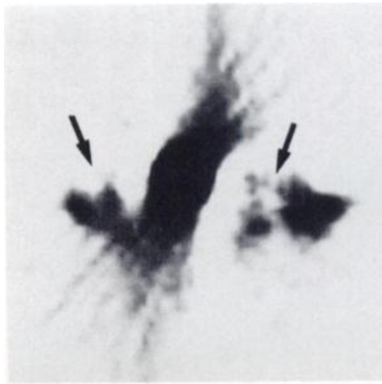


FIGURE 1
Streak artifacts in a transaxial section through the hips produced by changes in the level of activity in the bladder during the acquisition period of the study. In this case there is AVN of both femoral heads; the confidence with which this can be diagnosed is reduced by the presence of the artifacts. This section was obtained from a SPECT acquisition in which projection data were acquired at 64 equally spaced angles over a 360° rotation. The patient was supine and the starting position corresponded to an anterior view.

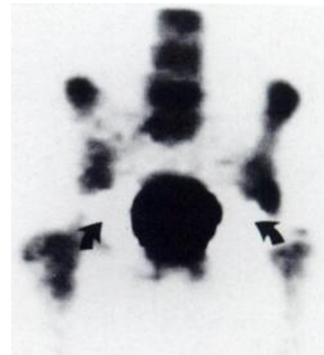


FIGURE 2
Cold area artifacts are present in both femoral heads in this coronal section. They are produced by the high level of activity in the bladder which influences the calculation, in the filtered backprojection reconstruction, of the count densities in the lower activity structures.

to detect AVN of the femoral head where the presence of a cold area is the most important diagnostic feature (*7-9*).

The cold areas arise as a result of the fact that the activity in the bladder can be much larger than that in the surrounding structures. In the reconstruction of the data the high bladder count densities produce a reduction in the counts in neighboring regions. The loss of counts occurs when the projection data are filtered prior to backprojection. The filter which was used is a ramp function modulated by a Shepp-Logan window; the values of the filter function in the spatial domain are shown in Table 1. When the negative values in the filter are multiplied by the counts in the bladder, large negative values will be produced. These can be larger than the sum of the positive values obtained for the pixels in regions close to the bladder after the convolution of the projection data with the filter. Typically, the femoral heads are separated from the bladder by ~4 to 10 pixels.

The magnitude of the negative values in the filter can be reduced by choosing a sharper filter function. However, even if an unmodulated ramp function with a discrete cutoff at the Nyquist frequency is used there is only a minimal reduction in the level of artifact production.

It is also possible that the count losses could be due to arithmetic overflows during the reconstruction. This was tested by dividing the pixel counts in the planar projection images by a constant value, e.g., 50 before the reconstruction was performed in order to reduce the magnitude of the numbers being handled by the reconstruction algorithm. However, no matter how large the divisor was made the cold area artifacts were still observed; it is the fact that the bladder activity is high relative to the surrounding structures rather than its absolute value which causes the artifacts to be produced.

In general, all practically useful filter functions will produce large negative values when convolved with data which has a

TABLE 1
Spatial Domain Values of the Filter Used in the SPECT Reconstruction

Point number	Value
1	13628
2	−4543
3	−909
4	−389
5	−216
6	−138
7	−95
8	−70
9	−53
10	−42
11	−34
12	−28
13	−24
14	−20
15	−17
16	−15
17	−13
18	−12
19	−11
20	−9
21	−9
22	−8
23	−7
24	−6

The values in the spatial domain are shown for the ramp filter modulated by a Shepp-Logan window function. The filter is convolved with projection data 64 pixels in length before backprojection. The filter has been truncated to 24 points to reduce computing time.

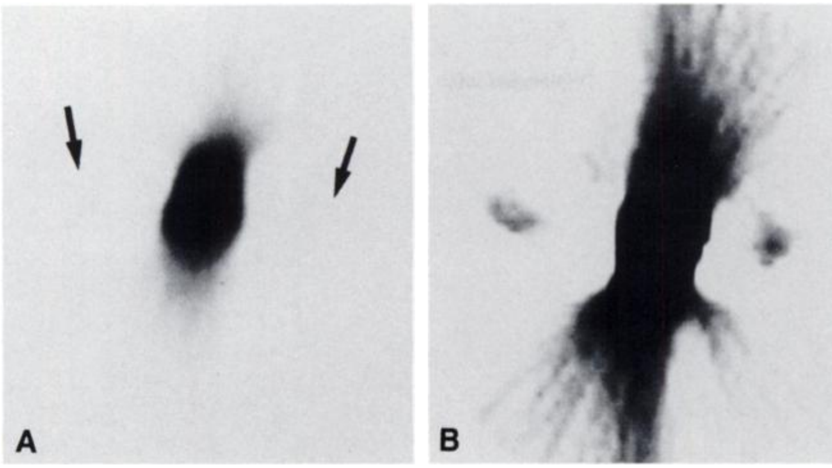


FIGURE 3
The large levels of activity in the bladder can make the femoral heads difficult to visualize as shown in the transaxial section in A. Reducing the upper threshold level of the display window can, in some cases, improve femoral head visibility, B. However, large areas with the same grey scale value are produced and the final contrast within the structures outside the bladder region is often still poor.

large dynamic range. Thus, it is likely that this problem is common to all reconstruction algorithms which utilize the filtered backprojection technique.

In addition to the production of artifacts, other difficulties can arise because the amount of activity in the bladder can be much larger than that in the femoral heads. This can make the femoral heads difficult to display properly, particularly in the transaxial sections, as demonstrated in Figure 3. In the coronal plane the problem is less severe because the center of the bladder is generally anterior to the center of the femoral heads. Nevertheless, problems still arise in a substantial proportion of cases because the posterior edge of the bladder can extend into the coronal plane of the femoral heads.

Post-reconstruction processing

There are several methods which can be used to reduce the effects of the bladder activity by processing the SPECT data after reconstruction. For instance, the display problems can be overcome in some cases simply by reducing the upper threshold level of the display window being used to view the reconstructed images to a point where the femoral heads can be properly visualized. However, this will often mean that large areas of the image will be displayed with the same gray scale value which produces an effect which is visually distracting (Fig. 3B). In addition, unless a nonlinear scale is used, the activities in the femoral heads may only cover a few gray scale levels which will produce an apparent loss of contrast because of the compression of the dynamic range of structures whose activity levels are a small fraction of the maximum (*10*).

An alternative method is to define a region of interest (ROI) around the bladder for each affected transaxial section and to set the value of each pixel within it to zero. A short program can be written to achieve this if a facility is not available with the manufacturer's software. If the ROI is chosen for the section through the bladder center then it should be large enough to mask the bladder in the other transaxial sections. Thus only a single ROI needs to be defined. Having masked the bladder from the transaxial data, sections in the coronal and sagittal planes will also be free from the effects of high bladder activity.

The problems encountered in the display of the femoral heads due to the large count densitites often found in the bladder are resolved using this postreconstruction masking approach. However, the more serious problem of artifact production is not addressed.

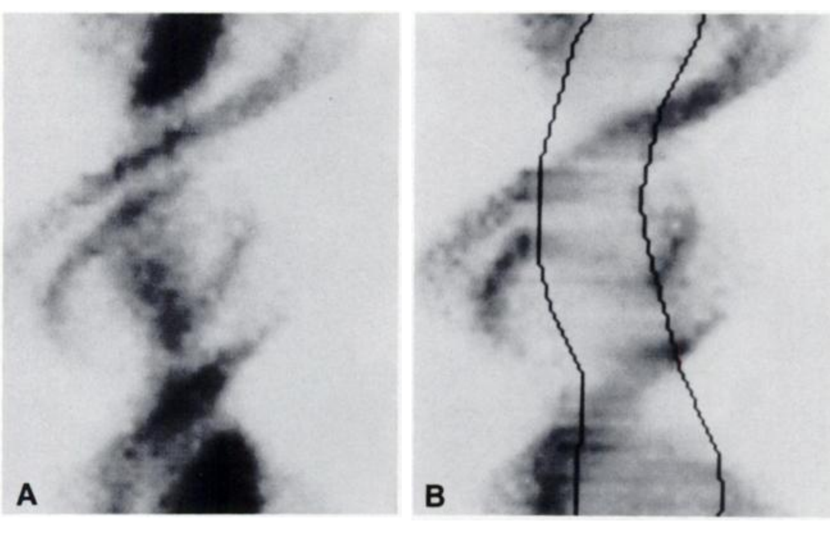


FIGURE 4
Sinogram matrix corresponding to the transaxial section through the center of the bladder, A. The high and changing count levels in the bladder can be replaced by data which are representative of the activity in surrounding structures by the process of interpolative background replacement, B.

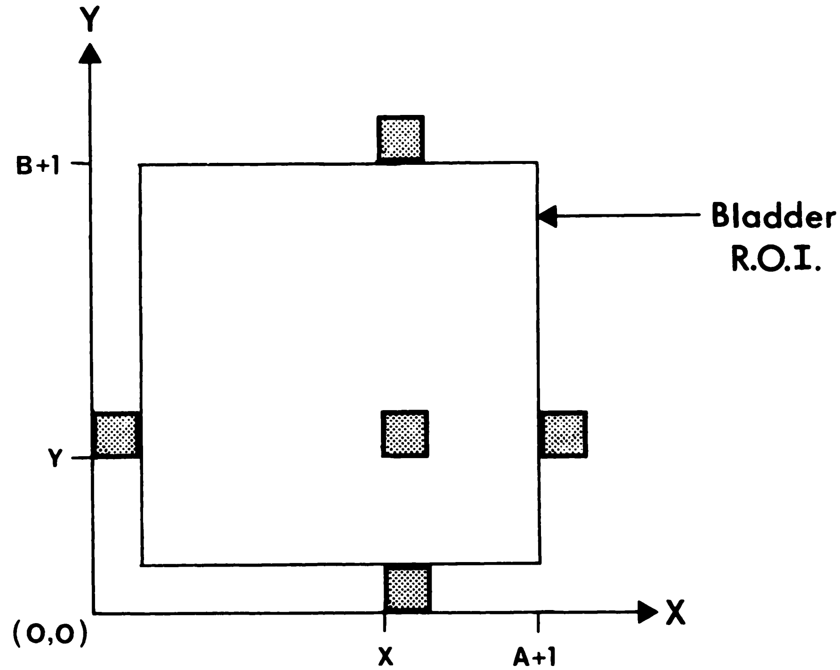


FIGURE 5
To calculate the replacement value of a pixel within the rectangular bladder ROI, the count values of 4 pixels positioned immediately outside it are used. For a rectangular ROI of width A and height B pixels the value of the bladder pixel at position (x, y) is given by:
$C(x, y) = C(x, 0) \times (B - y)/(2 \times (B - 1)) + C(0, y) \times (A - x)/(2 \times (A - 1)) + C(x, B + 1) \times (y - 1)/(2 \times (B - 1)) + C(A + 1, y) \times (x - 1)/(2 \times (A - 1))$.
This is performed for $1 < y < B - 1$ and $1 < x < A - 1$.

Prereconstruction Processing

The only way in which artifacts can be avoided is to correct for the high and changing levels of activity in the bladder before the reconstruction is performed. This can be accomplished by manipulating the data in the planar projection views which are acquired at each angle as the camera is rotated around the patient. To do this, however, a method for defining the location of the bladder in each projection view must be employed. A direct approach involving the designation of a ROI around the bladder on each of the projection views, of which there are typically 64 or 128, would be an extremely time-consuming and laborious procedure. Thus, a method for defining the location of the bladder which involves the definition of only a single ROI has been developed.

Bladder Identification

This method involves the designation of a ROI on a sinogram. A sinogram is a two-dimensional matrix which contains all of the data required to reconstruct a single transaxial section. It is created by taking a row of pixels from the same level of each of the projection views, i.e., those which correspond to the same transaxial section, and ordering them sequentially to form a new data matrix.

An example of a sinogram view corresponding to a transaxial section through the pelvis at the level of the bladder and femoral heads is shown in Figure 4A. Objects within the transaxial section have a sinusoidal form in the sinogram view. The amplitude and phase of the sinusoid depend on the position of the object within the section. In the sinogram

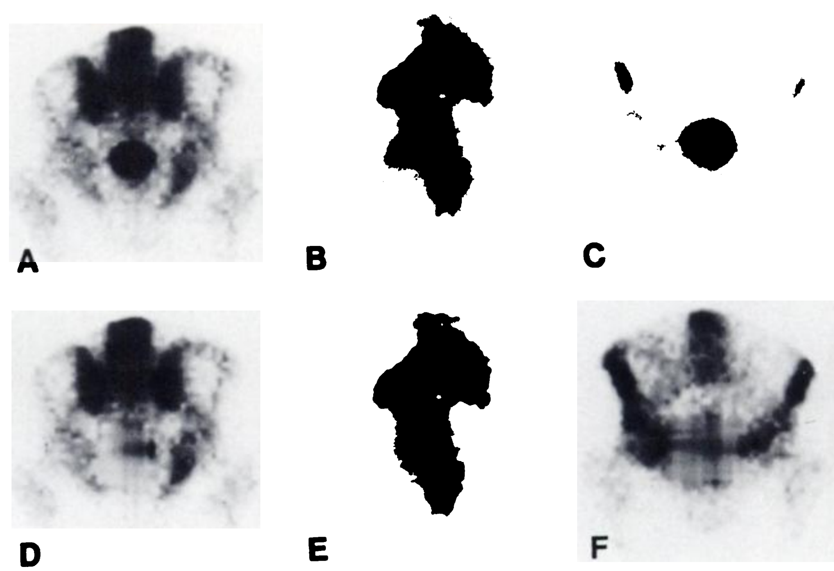


FIGURE 6
The projection views collected when the camera angle was 0, 270, and 360° are shown in the top row (A, B, and C). Beneath them are the projection views after interpolative background replacement of the bladder activity (D, E, and F, respectively). These new views are used to reconstruct the transaxial sections.

TABLE 2
Bladder and Femoral Head Count Densities in Projection Views

Patient	B1	B2	FL	FR	B2/B1	B2/FL	B2/FR	(B2-B1)/FL	(B2-B1)/FR
A	219	288	85	102	1.32	3.39	2.82	0.81	0.68
B	478	821	190	100	1.72	4.32	8.21	1.81	3.43
C	1068	1123	328	398	1.05	3.42	2.82	0.17	0.14
D	274	285	281	255	1.04	1.01	1.12	0.04	0.04
E	547	662	75	75	1.21	8.82	8.82	1.53	1.53
F	301	733	119	117	2.44	6.16	6.26	3.63	3.69
G	528	550	55	72	1.04	10	7.63	0.4	0.3
H	337	538		104	1.6		5.17		1.93
I	366	948	170	170	2.6	5.58	5.58	3.42	3.42
J	753	1265	73	100	1.67	17.2	12.56	6.89	5.03
K	273	551	236	110	2.02	2.33	5	1.78	2.53
L	2932	2844	163	177	0.96	17.3	15.6	0.66	0.61
M	422	962	107	112	2.28	9	8.6	5.05	4.82

The maximum pixel values are shown in the bladder at the start and finish of the SPECT acquisition, B1 and B2, and in the left and right femoral heads, FL and FR. The relative change in the bladder counts during the acquisition, B2/B1, and the ratio of counts in the bladder to that in each of the femoral heads, B2/FL and B2/FR, is calculated. In addition, the change in bladder counts is expressed as a fraction of the counts in each femoral head.

In Patient H there was a prosthesis in the left hip.

shown in Figure 4A the bladder is easily identifiable as the most active structure closest to the central vertical axis.

If the sinogram corresponding to the transaxial section through the widest part of the bladder is selected, and a ROI defined to include it, then this is equivalent to identifying the positions of its right and left hand edges in each projection view. The superior and inferior edges of the bladder can be identified by examining the final projection view which is collected when the bladder is at its fullest. Thus, the information required to specify a rectangular area which includes the bladder on all projection views can be determined with very little user input.

Having defined a region to include the bladder on each projection view the simplest way to remove the influence of bladder activity is to set the value of all pixels in the bladder region to zero. The amended views can then be used for the reconstruction calculations. This simple approach will certainly remove the high count levels within the bladder in the reconstructed transaxial sections. However, the backprojection of zero count values and the effect of a discontinuity in the projection profiles would be expected to produce artifacts of their own. In addition to this, counts are removed from the femoral heads themselves when they are included in the region defining the bladder when the two structures overlap, i.e., lateral projections. Thus this approach is only likely to be of value in cases where the artifacts produced by the data manipulation process are less severe than those which were originally created by the varying bladder activity.

Interpolative Background Bladder Replacement

In response to these problems a more sophisticated approach was developed and investigated. The basis of this technique lies in an attempt to replace the counts in the area occupied by the bladder by data which are as representative as possible of the activity in the surrounding regions. Thus the high and inconsistent count data in the bladder, which produce the problems in the reconstruction of the SPECT studies, are replaced by lower, more consistent count information.

A rectangular ROI is defined for each projection view to include the bladder making use of the sinogram technique described previously. New values for the counts in the pixels within the defined region are calculated from the counts in the pixels which lie around its perimeter. The way in which the new values are calculated is similar to the process involved in the Goris interpolative background subtraction technique (*11*). However, there is a fundamental difference in that the values calculated from the edge pixels are not subtracted from the counts in the defined region but are actually used to replace them.

For each pixel within the bladder region a new value is calculated using the counts in the four pixels which are situated around the perimeter of the ROI and which lie directly above, below and to the left and right of it. The procedure is illustrated in Figure 5. A proportion of the counts in each of the four edge pixels is taken and the results added together to produce the new value for the bladder pixel. The proportion of the counts for each edge pixel which are used in the calculation depend on its distance from the bladder pixel in question. The larger the distance the smaller the proportion used. The values for the proportions fall in a linear fashion from unity, when the bladder pixel is adjacent to the edge pixel, to zero when it is adjacent to the opposite edge of the ROI. The values are divided by a factor of two to make the average of the pixel counts within the bladder region equal to the average of the edge pixel values.

The results of this procedure are shown for a sinogram in Figure 4B and for planar projection views taken at a selection of camera angles in Figure 6. As can be seen, reasonable, representative and well-behaved images are produced by the replacement of the bladder activity. The largest errors occur when the bladder and femoral heads overlap although, once the backprojection has been performed, the total error in the femoral head counts should be low because the bladder the

TABLE 3
Assessment of Processing Methods Score for Image Quality of Each Section

Patient	Coronal sections NP	Coronal sections PRM	Coronal sections IBR	Transaxial sections NP	Transaxial sections PRM	Transaxial sections IBR	Final clinical diagnosis	
A	2	2	2	1	1	2	L−	R−
	L− R−	L− R−	L− R−	N.I.	N.I.	L− R−		
B	1	2	2	1	1	2	L+	R−
	L+ R−	L+ R−	L+ R−	N.I.	N.I.	L+ R−		
C	2	2	2	1	2	2	L+	R+
	L+ R+	L+ R+	L+ R+	L+ R+	L+ R+	L+ R+		
D	2	2	2	2	2	1	L+	R−
	L+ R−	L+ R−	L+ R−	L+ R−	L+ R−	L+ R−		
E	1	2	2	1	1	1	L−	R−
	N.I.	L+ R−	L− R−	N.I.	N.I.	N.I.		
F	2	3	3	1	1	2	L−	R−
	L− R−	L− R−	L− R−	N.I.	L− R−	L− R−		
G	1	3	3	1	1	2	L−	R−
	N.I.	L+ R+	L− R−	N.I.	N.I.	L− R−		
H	2	3	3	1	2	3	L−	R+
	L− R+	L− R+	L− R+	L− R+	L− R+	L− R+		
I	2	3	3	1	2	2	L+	R+
	L+ R−	L+ R+	L+ R+	N.I.	L+ R+	L+ R+		
J	1	2	2	1	1	2	L−	R−
	N.I.	L+ R+	L− R−	N.I.	N.I.	L− R−		
K	2	2	3	2	2	3	L+	R−
	L+ R−	L+ R−	L+ R−	L+ R−	L+ R−	L+ R−		
L	1	2	3	1	1	3	L+	R+
	N.I.	L+ R+	L+ R+	N.I.	N.I.	L+ R+		
M	2	3	3	2	3	3	L+	R+
	L+ R+	L+ R+	L+ R+	L+ R+	L+ R+	L+ R+		

The left and right femoral heads are designated by L and R, the presence or absence of AVN by + or −, and if a study was not interpretable it was coded N.I. A score was allocated to each section on the basis of image quality. An image of poor quality in which interpretation was difficult was scored 1; if the image could be interpreted clearly a score of 2 was given; an image in which a confident interpretation could be made and in which the anatomical features were clearly demonstrated was given a score of 3.

femoral heads overlap is a relatively small number of camera angles.

Assessment of Processing Techniques

To assess the relative merits of the processing techniques just described, the SPECT studies of a group of 13 patients referred for the investigation of AVN of the femoral head were analyzed.

Each patient received 600 MBq [^{99m}Tc]methylene diphosphanate intravenously with SPECT imaging commencing 4 hr later. The patients were well hydrated and emptied their bladders before the start of the acquisition. Data were collected by the gamma camera (ZLC/Digitrac Orbiter, (Siemens Inc., Des Plaines, IL) using a circular orbit with 64 angles over 360 degrees and an acquisition period of 30 sec per angle. The data matrices were of size 64 × 64 and each pixel had linear dimensions of 7 mm. Reconstruction was performed using filtered backprojection with a Shepp-Logan filter on a standard nuclear medicine computing system (V76 processor, Nodecrest Inc., Byfleet, UK).

Each study was analyzed without processing (NP), then with postreconstruction masking (PRM), and finally with interpolative background replacement (IBR) of the bladder employed. The quality of the coronal and transaxial sections taken through the hips was assessed for each method by an experienced nuclear medicine physician (JM). A scoring sys-

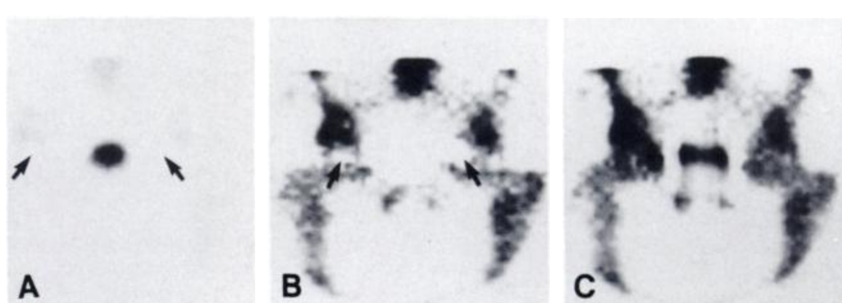


FIGURE 7
A coronal section in a patient with normal hips is shown with no processing (A), post reconstruction masking (B), and interpolative background replacement (C) employed. Cold areas which could be mistaken for AVN are seen in both femoral heads in A and B. However, in (C), the femoral heads are correctly shown to be normal.

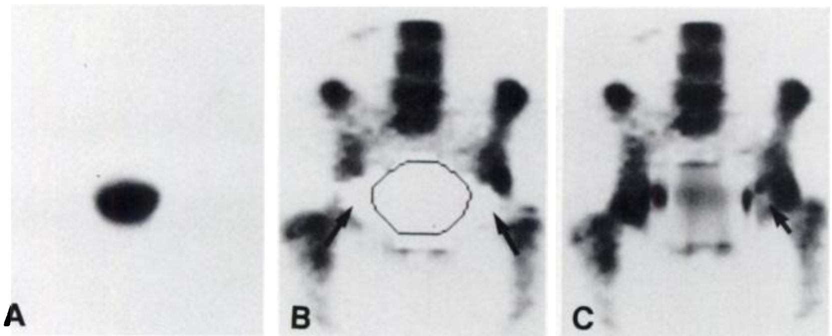


FIGURE 8
Coronal section through the hips of patient L with no processing (A), postreconstruction masking (B), and interpolative background replacement (C) employed. This patient was shown to have bilateral AVN but the severity was grossly exagerated in A and B. In C, small photon deficient areas are present in both femoral heads which was consistent with the rest of the clinical and radiologic data.

tem was employed whereby a score of one was given to an image which was of poor quality and difficult to interpret, a score of two to an image of intermediate quality which was, however, interpretable, and a score of three to an image of good quality in which the anatomical features were clearly defined. In addition, a preference was expressed for the technique which gave the best images even if there was no difference in the scores allocated to them. This was used to detect differences between the techniques which were masked by the relatively crude scoring system.

If the image was interpretable, each hip was assessed for the presence of AVN on the basis of the detection of a cold area within the femoral head. A final diagnosis of the presence of AVN was made separately through an assessment of all of the radiological information in conjunction with a detailed clinical history of the patient, but without reference to the SPECT data. The assessment of the SPECT images was performed blindly; the assessor has no knowledge of the final diagnosis which was performed independently by JD.

RESULTS

Table 2 shows the relative counts in the bladder and femoral heads for the first and last projection views on the SPECT studies. For this fairly typical group of patients the mean change in counts in the bladder over the period of acquisition of the scan was 54%. More significantly the mean increase in bladder counts was a factor of 2.2 greater than the mean femoral head counts. In addition, the bladder counts were on average 7.2 times the femoral head counts by the end of the acquisition.

Thus it is not surprising that many SPECT studies of the pelvis are difficult to interpret, given the large levels of activity found in the bladder and the magnitude of the changes in bladder counts over the period of acquisition of the scan compared to the count densities found in the femoral heads.

Assessment of Digital Filtering Techniques

The scores allocated to the different processing methods are shown for each patient in Table 3. For the coronal sections the image quality was improved after processing in 9/13 patient studies with PRM and in 10/13 studies with IBR. In only two studies was a different score allocated to the PRM and IBR methods with the IBR scoring higher. However, when a preference for the best images was expressed, those obtained using IBR were selected in nine cases, PRM in none, and NP in 1.

For the transaxial sections the image quality was improved after processing in 4/13 patient studies using PRM and in 11/13 studies with IBR. Comparing the image quality obtained with PRM and IBR there was an improvement in 8/13 studies using IBR with a deterioration in 1. As to which technique produced the best set of images IBR was selected in 11 studies, PRM in 1 and NP in 1.

The most important finding was the presence of cold

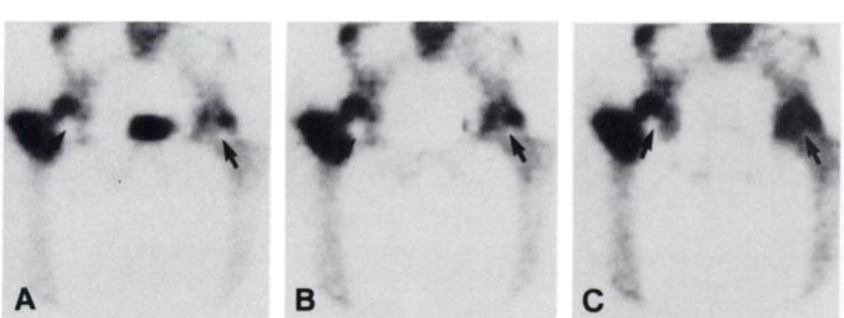
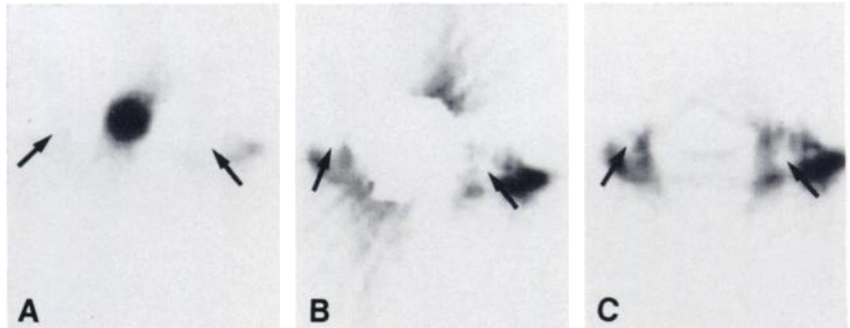


FIGURE 9
Coronal section through the hips of a patient with bilateral AVN of the femoral heads with no processing (A), postreconstruction masking (B), and interpolative background replacement (C) employed. In the assessment of the images all were assigned the same score, 3. However, it was felt there was a slight increase in the clarity with which anatomical features present in image C could be identified (e.g., the acetabulum of the right hip).

FIGURE 10

Transaxial sections through the hips of a patient with bilateral AVN. The sections are shown with no processing (A), postreconstruction masking (B) and interpolative background replacement of the bladder employed. The photon deficient areas in both femoral heads can be identified with greater confidence after the removal of the streak artifacts (C).



area artifacts on the coronal sections of four of the patients, E, G, J, and L, if there was no data processing performed or if PRM was used. These artifacts were removed when IBR was employed. This is illustrated in Figure 7 where Patient J, with normal hips, appeared to have cold regions within the femoral heads which were judged to be indicative of AVN. When IBR was employed it was clear that they were both normal. This was also the case with Patients E and G. The fourth patient in which cold artifacts were produced did in fact have bilateral AVN; however, the extent of the disease was grossly exaggerated (Fig. 8). The cold area artifacts were observed in the four patients who had a combination of high bladder activity and a large bladder to femoral head uptake ratio (Table 1).

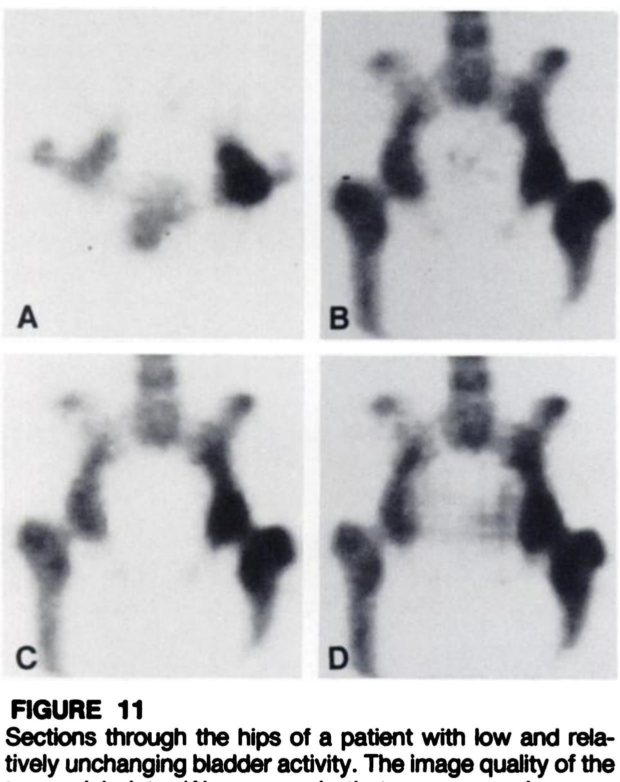


FIGURE 11

Sections through the hips of a patient with low and relatively unchanging bladder activity. The image quality of the transaxial data (A) was such that no processing was required. Similarly the coronal section without processing (B) was not improved significantly after postreconstruction masking (C) or interpolative background replacement of the bladder (D).

For the sections in the coronal plane, apart from the removal of the cold area artifacts, the application of IBR did introduce an improvement in general image quality (Fig. 9). In the image assessment the images produced using the IBR method were judged to show the anatomical structures most clearly in the majority of cases.

For the sections in the axial plane there was a clear improvement in the quality of the images produced using the IBR method. This is illustrated in Figure 10 where the bilateral AVN of the femoral heads in Patient M can be identified with greater confidence after the removal of the streak artifacts. The improvement in image quality with IBR shown in this case was typical of that seen in the majority of subjects investigated. Without some form of processing, the transaxial sections were of no value in 7/12 of the patients studied as the assessor felt unable to attempt to judge the presence or absence of AVN. This was due to a combination of the presence of streak artifacts and the effects of the high bladder activity levels. After IBR only one patient had transaxial sections which could not be interpreted.

An examination of the projection images after IBR shows that although the high and changing count values in the bladder region can be successfully removed, they have been replaced by data which is essentially an estimate of the values which would have been obtained if the bladder had not been present. The accuracy of this estimate will determine the value of the technique. As discussed previously the largest errors will occur in the projection images where the bladder and femoral heads overlap. However, this only constitutes a small proportion of the total projection data and it is our experience from the clinical studies that serious artifacts are not observed. The major effect of the IBR method is to introduce a slight smoothing of the processed sections because the interpolated data is correlated and less noisy than the surrounding data.

It should be noted that there are a few cases where the influence of the bladder is insignificant and no processing at all is required. This is illustrated in Figure

11, for Patient D, in which the bladder counts were low and did not increase greatly during the acquisition period of the study. However, this was found to be the case in only one of the 13 patients who were investigated.

DISCUSSION

The aim of this study was to develop a practical method for reducing the influence of bladder activity, especially artifact production, in SPECT bone studies of the pelvis. The experience of Collier et al. (*5*) was confirmed in that ~20% of scans were completely uninterpretable without some form of image processing.

Postreconstruction masking of the bladder is a simple approach, equivalent to reducing the upper threshold level of the display window to a point where the dynamic range covers the count densities found in the femoral heads. It has the advantage over display window threshold adjustment in that visually disturbing areas of intense activity are avoided. The major disadvantage is that the problem of artifact production is not addressed.

For this reason the technique of interpolative background replacement of the bladder was developed and investigated. By replacing large and inconsistent bladder counts by data which are representative of the activity in the regions surrounding the bladder at each camera angle the level of artifact production was dramatically reduced.

Choosing the site of the bladder from the sinogram files reduces the level of user interaction to the definition of a single ROI. The time taken to perform the bladder replacement is less than that required to reconstruct the data. In total, time is saved using this procedure because the images can be interpreted without constant adjustments having to be made to the display window threshold levels. Thus, this is a practical solution to the bladder problem which is suitable for routine application in nuclear medicine departments possessing standard computing facilities.

It should also be noted that this method is not limited to SPECT. It is applicable to any reconstruction process, for example x-ray computed tomography, where one or more objects in the plane to be reconstructed have values which change or are significantly higher than the rest of the objects in the plane.

We conclude that the method of interpolative replacement of bladder activity significantly increases the image quality and clinical usefulness of SPECT bone studies of the pelvis.

REFERENCES

1. Jacobson H, Larsson, SA, Vesterskold L, et al. The application of single photon emission computed tomography to the diagnosis of ankylosing spondylitis of the spine. *Br J Radiol* 1984; 57:133–140.
2. Collier BD, Carrerra GF, Messer AJ, et al. Internal derangement of the tempero-mandibular joint: detection by single photon emission computed tomography. *Radiology* 1986; 149:557–563.
3. Feiglin D, Levine M, Stulberg B, et al. Comparison of planar and SPECT scanning in the diagnosis of avascular necrosis of the femoral head. *J Nucl Med* 1986; 27:952.
4. Collier BD, Johnson RP, Carrera GF, et al. Painful spondylolysis or spondylolisthesis studied by radiology and single-photon emission computed tomography. *Radiology* 1985A; 154:207–211.
5. Collier BD, Carrera GF, Johnson RP, et al. Detection of femoral head avascular necrosis in adults by SPECT. *J Nucl Med* 1985; 26: 979–987.
6. Collier BD, Hellman RS, Krasnow AZ. Bone SPECT. *Semin Nucl Med* 1987; 17:247–267.
7. Bauer G, Weber DA, Ceder L, et al. Dynamics of technetium-99m methylene diphosphonate imaging of the femoral head after hip fracture. *Clin Orthop* 1980; 152:85–92.
8. Greyson ND, Kassel EE. Serial bone scan changes in recurrent bone infarction. *J Nucl Med* 1976; 17:184–186.
9. Grieff J, Lanng S, Hoilund-Carlsen PF, et al. Early detection by 99m-Tc-sn-pyrophosphate scintigraphy of femoral head necrosis following medical femoral neck fractures. *Acta Orthop Scan* 1980; 51:119–125.
10. Sharp PF, Dendy PP, Keyes WI. Radionuclide imaging techniques. London: Academic Press, 1985: 174–177.
11. Goris ML, Daspit SG, McLaughlin P, et al. Interpolative background subtraction. *J Nucl Med* 1976; 17:744–747.