Body Contour Determination and Validation for Bremsstrahlung SPECT Imaging

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The purpose of this study was to validate a previously reported body contour measurement using Compton backscatter sources with bremsstrahlung SPECT imaging. **Methods:** Bremsstrahlung SPECT imaging was performed with ^{32}P using a dual-headed camera system fitted with medium-energy, parallel-hole collimators. Two sources of ^{99m}Tc were placed directly on each collimator. Energy windows of 100 keV ± 25% were used to image the ^{32}P and also to record the Compton scatter from the ^{99m}Tc sources. Eleven patients enrolled in clinical Phase I therapeutic protocols were injected with ^{32}P-chromic phosphate and SPECT images were acquired and reconstructed in the transaxial plane. The ^{32}P distribution and the patient body contour were both visualized in these slices. The anteroposterior and lateral patient dimensions were measured by generating count profiles parallel to the anteroposterior and lateral body contour, respectively, at the midline in a transaxial slice. The distance in centimeters between the two centroids of each profile is representative of the anteroposterior and lateral dimensions and was determined for each patient. These anteroposterior and lateral dimensions were compared to the same distance measurements made in these patients by CT in an anatomically comparable transaxial slice. A cylindrical SPECT phantom was also studied to further validate the contour measurements. **Results:** The mean percent difference in the patient dimension measurements between SPECT and CT was −0.8% with a range of −8.5% to 9.9%. The percent difference between the known and SPECT measured dimensions in the cylindrical phantom was 0.5%. **Conclusion:** The two external Compton scatter source method is accurate for determining the body contour.

Key Words: bremsstrahlung; SPECT; phosphorus-32; radionuclide therapy

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A major obstacle to quantitative SPECT is accurate attenuation correction. The work reported here investigates a previously reported automated body contour definition as applied to bremsstrahlung SPECT using ^{32}P-chromic phosphate (*1*).

Most commercially available attenuation correction algorithms for SPECT require the accurate delineation of the body contour (*2*). The measurement of the body contour has been performed using the object emission data itself from the photopeak (*3,4*), a Compton scatter window (*5*) or by other acquisition protocols including: the use of point or distributed sources (*6,7*), a ring source (*2*), a 90° or backscatter Compton scatter source (*1,8*) or a transmission SPECT study (*9,10*). The body contour data are then fit to either an elliptical, convex or arbitrary boundary (*2*). Except for the transmission study, all attenuation methods based on this boundary information assume that the patient has uniform attenuation coefficients within the boundary.

We previously described a technique for body contour delineation using two ^{99m}Tc backscatter sources in a group of research subjects who were participants in Phase I therapeutic trials using 2.5 million particles of macroaggregated albumin, followed by colloidal ^{32}P-chromic phosphate (*1*). A first-order postprocessing attenuation correction using Chang's method (*11*) was applied to the reconstructed transverse ^{32}P bremsstrahlung SPECT slices using a computer-generated body contour based on the backscatter sources for each transverse slice and an experimentally determined effective linear attenuation coefficient (*7*).

The objective of the current study is to determine the accuracy of the boundary information obtained using the ^{99m}Tc Compton scatter sources in patients receiving ^{32}P-chromic phosphate. Reconstructed transaxial slices from the bremsstrahlung SPECT studies are used to measure the anteroposterior and lateral patient dimensions. These dimensions were then compared to the same distance measurements made in these patients by CT in an anatomically comparable transaxial slice. A cylindrical phantom was also studied to further validate the boundary measurements.

MATERIALS AND METHODS

SPECT

SPECT imaging was performed using a dual-headed camera system fitted with medium-energy, parallel-hole collimators and interfaced to a computer. An energy window setting of 100 keV ± 25% was used, since we have previously shown that the narrow window setting has optimal resolution characteristics for ^{32}P (*12*). This energy window is also useful for detecting Compton-scattered photons from ^{99m}Tc (*1*) since 90° scatter represents an energy of 110 keV and 180° backscatter represents an energy of 90 keV. Two sources of ^{99m}Tc (3-cc syringes filled to 0.5 cc) containing 74–185 MBq each were first placed directly on the collimators, one per collimator, just outside the field of view of the camera (*1*). The syringes were oriented parallel to the axis of rotation and were placed at opposite lateral ends of the two collimators, that is, one syringe is placed to the far right on the upper collimator and the second syringe is placed to the far left on the lower collimator. Data were then acquired in a 64 × 64 image matrix for 32 projections over 180° for each camera head (a total of 64 projections over 360°) for 20 sec per projection using the auto contour rotation mode. A single projection image in the patient studies typically contained 20–25 kcts. The raw data were reconstructed by filtered backprojection using a fifth order Butterworth window with an empirically chosen cutoff at 0.6 of the Nyquist frequency (0.31 cycles/cm) in the transaxial, sagittal and coronal planes. The reconstructed slices were 1-voxel thick (9.6 mm). The patient body contour was visualized on each reconstructed transaxial slice due to the detection of the Compton scattered photons from the two external sources.

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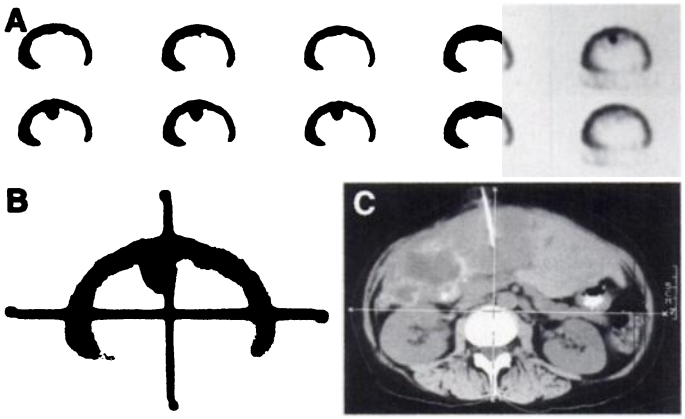

FIGURE 1. (A) Reconstructed 1-voxel thick (9.6 mm) transaxial slices of ^{32}P-chromic phosphate distribution in a 29-cc liver tumor with the patient body contour (and patient couch) clearly visualized in all the transaxial slices. (B) Anteroposterior and lateral line profiles used for the patient dimensions on the SPECT study are shown along with the corresponding profiles in the same patient's CT scan (C) using an anatomically comparable transaxial slice at the level of the interstitial ^{32}P injection.

Patient Studies

Clinical Phase I studies have been performed in nonresectable pancreatic cancer, nonresectable, nonoat-cell lung cancer, advanced head and neck cancer and liver metastases (*12*). The Phase I trial is based on the direct interstitial administration of 2.5 million particles of macroaggregated albumin followed by colloidal ^{32}P-chromic phosphate into the tumor-bearing region performed under CT guidance (*13*). All patients understood the nature of the procedure and gave informed consent as approved by our Institutional Review Committee. Eleven patients were included in this study. These patients were injected with 192–1121 MBq colloidal ^{32}P-chromic phosphate into tumors located in the pancreas (n = 5), liver (n = 2), lung (n = 2) and head (n = 2). All patients had a CT study the day of their ^{32}P SPECT study.

The anteroposterior and lateral contour dimensions were measured by generating count profiles parallel to the anteroposterior and lateral body contour, respectively, at the midline of each in a transaxial SPECT slice. The distance in centimeters between the two centroids of each profile was obtained by multiplying the number of pixels between the centroids by a 0.96 cm/pixel calibration factor. These anteroposterior and lateral dimensions were compared to the same distance measurements made in these patients by CT using an 8-mm slice thickness. All dimension comparisons were obtained using anatomically comparable transaxial slices at the level of the interstitial ^{32}P injection. The selected CT slice showed the needle tip within the tumor prior to injection and the selected SPECT slice contained the maximum activity of ^{32}P. The SPECT and CT measurements were performed independently by the two authors and the results were statistically compared using a paired Student's t-test.

Phantom Study

To further validate the contour dimension measurements, a cylindrical Carlson phantom (20.3 cm inside diameter) without the inserts was filled only with water. A SPECT study was performed on the cold phantom with the two ^{99m}Tc backscatter sources in place using the clinical acquisition and reconstruction parameters described above.

RESULTS

Figure 1A shows the reconstructed transaxial slices in a patient injected with 548 MBq ^{32}P-chromic phosphate into a liver tumor with the patient body contour clearly visualized in all the transaxial slices. The anteroposterior and lateral line profiles used to determine these body dimensions from the SPECT study are shown in Figure 1B along with the corresponding line profiles in the same patient's CT scan (Fig. 1C) using an anatomically comparable transaxial slice at the level of the interstitial ^{32}P injection.

The comparison between the CT and SPECT patient dimension measurements is shown in Table 1. The mean percent difference in these measurements was −0.8%, with a range of −8.5% to 9.9%. A paired Student's t-test at the $\alpha = 0.05$ level indicated that there was no significant difference between CT and SPECT measured anteroposterior and lateral patient dimensions ($p > 0.8$).

Figure 2 shows the reconstructed transaxial slices of the Carlson phantom. The phantom contour is clearly seen in all the reconstructed slices. Analysis of the anteroposterior and lateral phantom count profiles both resulted in a measurement of 20.2 cm, which is a 0.5% difference between the known and SPECT measured dimensions.

DISCUSSION

SPECT bremsstrahlung imaging has been reported by a number of investigators using ^{32}P (*1,12,14,15*) and ^{90}Y (*16*). In the present study, the body contour was determined in the reconstructed transverse slices using two externally placed Compton backscatter sources and commercially available reconstruction software.

Reasonably accurate and precise quantitative SPECT imaging is clinically feasible, even without sophisticated scatter corrections, at least in uniformly attenuating parts of the body such as the

TABLE 1
Comparison of CT and SPECT Patient Dimensions*

Patient no.	Area	CT dimension (cm)		SPECT dimension (cm)	
		AP	LAT	AP	LAT
1	Abdomen-Liver	19.5	28.4	19.2	27.8
2	Abdomen-Pancreas	23.7	–	24.0	–
3	Head-Brain	18.1	–	16.3	–
4	Chest-Lung	25.2	–	25.9	–
5	Abdomen-Pancreas	22.2	–	24.0	–
6	Abdomen-Liver	25.5	32.6	25.0	32.6
7	Abdomen-Pancreas	23.3	27.7	22.1	27.8
8	Abdomen-Pancreas	26.9	32.8	28.8	33.6
9	Chest-Lung	24.8	–	26.9	–
10	Abdomen-Pancreas	20.2	27.4	19.2	27.8
11	Head	19.5	15.6	21.1	15.4

*All dimension comparisons were obtained using anatomically comparable transaxial slices at the level of the interstitial ^{32}P injection.
AP = anteroposterior dimension; LAT = lateral dimension.

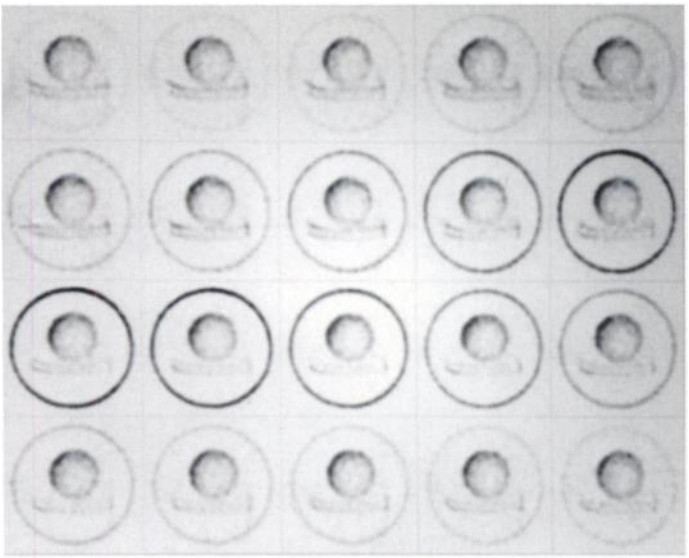

FIGURE 2. Reconstructed 1-voxel thick (9.6 mm) transaxial sections of the water-filled Carlson phantom. No activity is present in the phantom. The phantom contour (and couch) due to the ^{99m}Tc Compton backscatter sources is clearly visualized on all the slices.

abdomen and pelvis (*17*). Using a postprocessing algorithm, i.e., Chang attenuation compensation method using uniform attenuation coefficients (*11*), several investigators have obtained fairly accurate activity estimates for photon emitters (*17–19*). It should be pointed out, however, that any technique which does not specifically compensate for scatter will not be rigorously correct, especially in the presence of low-energy photons, which are known to contribute a significant amount of scatter.

The accurate delineation of body contour is a required parameter for most current commercially available attenuation correction algorithms (*17*), with the exception of those based on a transmission SPECT scan. Data from the transmission scan give not only the body contour but also a transaxial map of the attenuation coefficients. In areas of nonuniform density, such as the thorax, it is necessary to incorporate a nonuniform attenuation map in the Chang attenuation compensation method (*20*).

A variety of methods have been described for identifying the boundary of the patient (*1–10*). The direct window (*3,4*) and Compton scatter window (*5*) methods are not amenable for our imaging situation, that is, a well-localized activity distribution with minimal background activity. When a radionuclide is not widely distributed, boundary detection by these two methods has been shown to be difficult (*8*). With a distributed source, the boundary definition will be better, but this has been shown to be not as good as the one provided by the external Compton scatter methods using a collimated ^{99m}Tc source (*8*).

The use of externally placed sources directly on the collimator is a much simpler technique (*1*). The body outline definition is excellent and can be visualized on all reconstructed transverse slices. Only a single energy window was used for both ^{32}P bremsstrahlung detection and for ^{99m}Tc Compton backscatter photon detection. This is due to the fact that the backscattered photons have energies between 90 and 110 keV, a range which is within our ^{32}P energy window. Less than 5% of the counts in the ^{32}P energy window are due to the ^{99m}Tc scatter contribution.

The agreement of the patient dimensions as measured by SPECT compared to CT was excellent. The selected slices chosen for these comparisons are only qualitatively anatomically comparable since the SPECT and CT slice thicknesses differed slightly, 9.6 mm versus 8 mm, respectively, and we made the assumption that the SPECT slice containing the maximal activity of ^{32}P corresponded to the CT slice which showed the needle tip within the tumor. The cylindrical phantom results further confirmed the validity of the scatter method for boundary definition. The scatter technique works well in conjunction with the parallel-hole collimation used in this study but should not be applied when using fan or cone-beam collimation since the body would be truncated.

CONCLUSION

Accurate body contour delineation can be achieved for use in quantitative bremsstrahlung SPECT imaging. It can easily be performed in a clinical setting with commercially available reconstruction software.

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