Image Registration of SPECT and CT Images Using an External Fiduciary Band and Three-Dimensional Surface Fitting in Metastatic Thyroid Cancer

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Image registration of ^{131}I SPECT with CT scans was performed in a patient with metastatic thyroid carcinoma using an external fiduciary band and a three-dimensional surface-fitting algorithim. Areas of metastatic disease taking up ^{131}I were accurately localized to the liver, lungs and vertebral bodies; providing information that could not be obtained by planar or SPECT images alone. Based on these findings, further invasive diagnostic procedures were not performed, therefore considerably altering management in this patient. This approach to image registration has immediate clinical utility in the registration and interpretation of SPECT studies with corresponding CT or MRI scans.

Key Words: image registration; external fiduciary band; three-dimensional surface fitting

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In the interpretation of SPECT studies, correlation of SPECT images with CT or MRI is essential to distinguish sites of normal physiologic uptake and to accurately localize sites of disease. Registration of functional images with anatomic images is an approach that addresses the strengths of both techniques, and allows more accurate interpretation of SPECT studies (*1–6*). The use of three-dimensional surface matching algorithims utilizing normal tissue uptake for dataset matching is one approach that has shown great promise in recent clinical studies (*5–8*). Such image registration approaches are extremely difficult to implement when isotopes are used which do not have specific or nonspecific uptake in organs which can be used for surface matching.

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This case report describes the use of an external fiduciary band that enabled accurate image registration of an ^{131}I SPECT with CT images obtained from hard copy films in a patient with metastatic thyroid cancer. The presence of hepatic metastases from thyroid cancer was confirmed by this technique, preventing additional invasive investigations. The impact of this information on patient management and the potential clinical utility of this image registration approach is discussed.

CASE REPORT

Patient History and Procedures

The patient, a 56-yr old female, initially presented with a right-sided multinodular goiter in 1966, underwent a right total lobectomy. She had no further significant medical problems until February 1993 when she presented with right-sided neck pain. On examination no masses were felt in the neck, but a chest x-ray (CXR) and subsequent CT scan of the chest and abdomen revealed multiple pulmonary nodules in both lungs, a 3.5-cm mass in the right lobe of the liver and a solitary right eleventh rib lytic lesion. A biopsy of a right lung lesion was performed via video thorascopy in April 1993 and pathology revealed metastatic papillary thyroid carcinoma, follicular variant.

In view of the pathologic diagnosis, and the reluctance of the patient to undergo further surgery, the patient was referred to nuclear medicine for ^{131}I dosimetry and ablation of the remaining left lobe of the thyroid gland. A ^{99m}Tc-pertechnetate scan performed at that time showed an intact left lobe of the thyroid gland. A dose of 3.7 MBq (100 μCi) of ^{131}I was administered, and imaging showed an intact left lobe, and 24-hr neck uptake of 11% of the administered dose. An ablative dose of 3 GBq (75 mCi) of ^{131}I was administered, and the post-treatment whole-body scan (48 hr post-therapy) showed uptake in the neck, and in multiple bony metastases in the skull, right shoulder and trochanteric region of the right femur.

Following the ablation therapy, the patient was evaluated with a repeat CT scan. This revealed three solid masses in the liver, suspicious of metastatic disease. A CT-guided fine-needle biopsy of one of the liver lesions was performed in August 1993, but revealed no evidence of malignancy. Her thyroglobulin at this

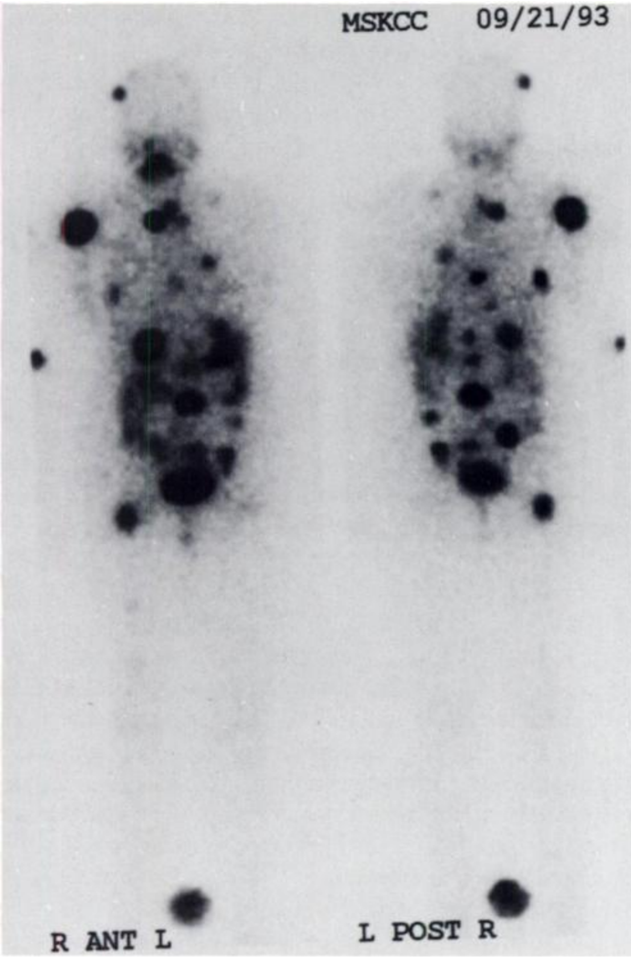

FIGURE 1. Anterior and posterior planar images 48 hr postingestion of 370 MBq (10 mCi) of ^{131}I, showing areas of increased uptake in the lower neck, both lungs, upper abdomen and in multiple bony sites consistent with metastatic thyroid carcinoma. The precise anatomic sites of uptake of ^{131}I in the lower chest and upper abdomen could not be determined from these images.

time, while on synthroid medication, had risen from 78.6 ng/dl (normal 2.7–21.0) in April to 538 ng/dl.

The patient underwent dosimetry for a therapeutic treatment with ^{131}I in September 1993. Prior to dosimetry she was withdrawn from synthroid medication for 5 wk and placed on a low iodine diet. Her TSH was 51.3 3 uIU/ml (normal 0.46–3.6) at the time of administration of 370 MBq (10 mCi) of ^{131}I. Whole-body and neck images were acquired at 24 and 48 hr postingestion of ^{131}I, and demonstrated multiple areas of increased uptake in the lower neck, both lungs, upper abdomen (possibly in the liver) and in multiple bony sites including the right parietal region of the skull, right shoulder, right proximal femur and possibly in a number of thoracic and lumbar vertebrae (Fig. 1).

In order to more clearly delineate the sites of metastatic disease in the abdomen and lower chest, a SPECT of the abdomen was performed 72 hr postingestion of ^{131}I. To allow image registration of the SPECT and CT scans to be performed, an external fiduciary band was fitted around the upper abdomen prior to the SPECT study, and this remained in place throughout the SPECT acquisition. The band consisted of a custom-made 10 cm wide elasticized material through which was threaded narrow plastic tubing. The tubing was filled with 2 MBq (50 μCi) of ^{99m}Tc-pertechnetate prior to SPECT imaging. The SPECT was acquired in a 360° elliptical orbit, with 64 stops at 30 sec per stop on a dual-head Genesys gamma camera (ADAC, Milpitas, CA) equipped with a high-energy, general-purpose collimator, linked to a dedicated Pegasys computer. Two windows were used for acquisition, one at 140 keV (20%) and one at 364 keV (20%). SPECT datasets for the ^{99m}Tc and ^{131}I energy windows were processed separately with a Butterworth filter (cutoff 0.3, order 10) and Chang attenuation correction applied.

Image Registration

CT images of the lower chest and abdomen (10-mm slices) were digitized from original hard copy films by image capture with a video camera into digital format via an image capture board into a PC. Each image was recorded in 512 × 512 × 8 format, and care was taken to ensure that the alignment of CT or images was accurate and consistent throughout the image capture process. Images were then converted into 256 × 256 × 16 format. The acquisition of SPECT studies has already been described. Image datasets (^{99m}Tc and ^{131}I SPECT separately, and CT) were then transferred directly to a DEC MicroVax II computer (Maynard, MA). Three-dimensional surface contours of the ^{99m}Tc SPECT were then generated by outlining contours on serial axial slices of each scan around the outer surface of the upper abdomen, defined by the fiduciary band (Fig. 2). This was easily performed due to the prominent activity of the band circumferentially around the skin surface (Fig. 2). Similar contours were also drawn around CT slices in the lower chest and abdomen. Three-dimensional surface outlines of the SPECT images ("hat") were then fitted to the anatomical images ("head"; reference image) using an algorithim, developed by Pelizzari and Chen, that minimizes the mean squared distance between points on the two surfaces (*9*). This algorithim allows for translation, rotation and scaling in the xy plane, as well as movement in the z axis, to produce the accurate surface alignment (Fig. 2). Three-dimensional dataset matching was extremely accurate, with a residual minima (the mean sum of the squares between the target surface and the surface to be matched in mm) of only 10 achieved, comparable to brain surface matching studies (*9,10*). After dataset fitting, the ^{131}I SPECT was substituted for the ^{99m}Tc SPECT by altering the dataset identification within the computer program. The total time required to outline the image datasets and substitute the ^{131}I SPECT for the ^{99m}Tc SPECT dataset was 60 min.

Corresponding axial ^{131}I SPECT and CT slices were then displayed separately, and then merged together ("colorwash" display) to allow precise anatomical localization of areas of normal and abnormal SPECT uptake. These showed uptake of ^{131}I in the known lesions in the liver (Fig. 3), as well as confirming metastatic lesions in a number of upper lumbar and lower thoracic vertebral bodies, and in the lung.

In view of the confirmation of uptake of ^{131}I in the liver lesions, the patient was thought to have metastatic thyroid cancer in the liver, rather than liver metastases from another potential primary malignancy. Further invasive investigations of the liver lesions were not performed. On the basis of the widespread thyroid cancer present, and after dosimetry calculations, the patient was subsequently treated with 286 mCi ^{131}I.

DISCUSSION

One of the main difficulties associated with the interpretation of SPECT images is in determining the precise ana-

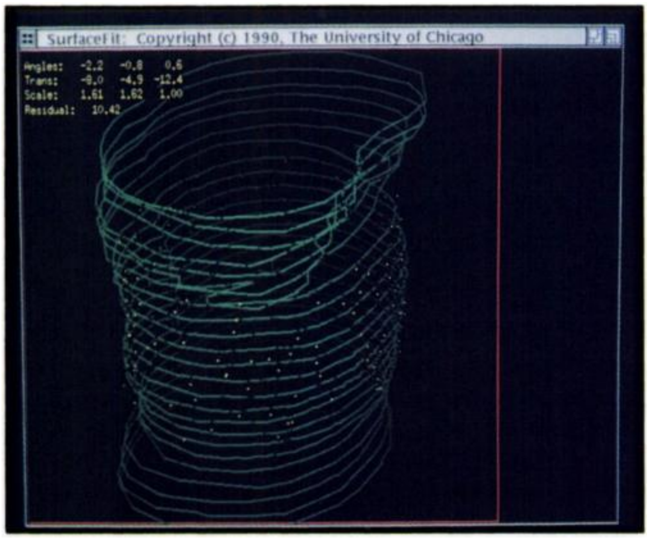

FIGURE 2. Three-dimensional surface contours of the SPECT and CT datasets following implementation of the fitting algorithim is shown. The green wire loops correspond to the surface contours of the CT scan, and the yellow points correspond to the SPECT surface contour outline of the external fiduciary band filled with ^{99m}Tc-pertechnetate. The precise dataset matching of the SPECT and CT datasets is clearly evident.

tomic sites of normal or abnormal radioisotope uptake (*1–2,6,8*). Such information can be crucial in the accurate interpretation of SPECT studies, and can dramatically alter patient management. Image registration techniques allow the correlation of functional (SPECT) and anatomical (CT or MRI) information, and have been shown to considerably improve the accuracy of SPECT interpretation in numerous published studies to date (*3–7,11–18*).

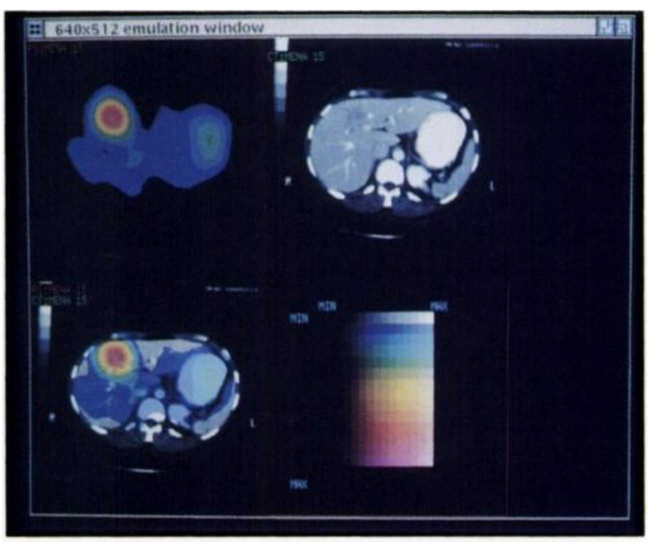

FIGURE 3. Final ^{131}I SPECT and CT image registration display at the level of the upper abdomen is shown. The SPECT transverse image is the top left image, the CT the top right image, and the registered image is shown in the bottom left image with the SPECT superimposed on the CT in a "colorwash" display. There is precise localization of the focal area of ^{131}I uptake in the hepatic lesion seen on CT scan. Additional uptake in the left side of the abdomen is also clearly identified to be gastric in origin.

The problems associated with the clinical implementation of image registration methods predominantly involve image acquisition, dataset transfer and fitting algorithims. At Memorial Sloan-Kettering Cancer Center, we have addressed these issues with a method of SPECT and CT-to-MRI image registration that: utilizes three-dimensional surface matching of identifiable internal or external fiduciary landmarks; requires minimal specific patient or study acquisition preparation; and permits the use of hard copy CT or MRI films (*6–8*). In SPECT studies of the body where identifiable surface contour or organ uptake is not present some form of fiduciary system is required. The use of an external fiduciary band is a flexible and easily implemented approach that allows accurate dataset matching in situations where anatomic matching is otherwise not possible. In comparison to other methods of external fiduciary marking, no specific anatomic knowledge is required when fitting the band at the time of SPECT acquisition, improving patient comfort and reducing preparation time (*3–4,12–13,17*). The width of the band produces sufficient surface contour information to allow accurate surface fitting with CT or MRI scans (Fig. 2), and CT or MRI scans can also be used without specific acquisition requirements such as corresponding external fiduciary marking. Problems in surface fitting of data related to patient positioning, twisting or motion can be minimized by careful standard patient positioning for SPECT and CT-to-MRI studies. Despite the potential problems of patient motion, the three-dimensional SPECT and CT datasets were matched by the fitting algorithim with comparable results to brain surface studies (*9*). The accuracy of image registration in this study was shown by the precise matching of ^{131}I uptake on sites of presumed metastatic disease on CT scan (Fig. 3).

The information provided by this image registration technique had an immediate impact on patient management. Liver metastases of thyroid carcinoma are extremely unusual (*19–20*), and a coexistant second primary tumor in this patient was considered quite likely prior to the ^{131}I dosimetry and SPECT image registration. A biopsy of the liver lesion seen in Figure 3 on CT had already been attempted, but was negative, and definite uptake of ^{131}I in the liver region had also not been clearly demonstrated in the previous postablation scan. The confirmation of ^{131}I uptake in the hepatic lesion identified on CT (Fig. 3) in the pretherapy dosimetry images obviated the need for repeat biopsy. This also confirmed the presence of metastatic disease in the lungs, and numerous lower thoracic and upper lumbar vertebral bodies, which could not be accurately localized with planar images alone (Fig. 1). Differentiation of gastric uptake of ^{131}I from sites of disease was also possible with this approach (Fig. 3). Both diagnostic and management decisions were therefore greatly altered by the utilization of this image registration approach. The potential ability of this technique to improve accuracy of SPECT interpretation in studies of lymphoma with ^{67}Ga, hepatic hemangioma with ^{99m}Tc-labeled red blood cells, or other body or brain studies is also considerable. Further studies are underway to define the utility of this approach in these clinical situations.

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