IMPROVING TREATMENT PLANNING ACCURACY THROUGH MULTIMODALITY IMAGING

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Purpose: In clinical practice, physicians are constantly comparing multiple images taken at various times during the patient’s treatment course. One goal of such a comparison is to accurately define the gross tumor volume (GTV). The introduction of three-dimensional treatment planning has greatly enhanced the ability to define the GTV, but there are times when the GTV is not visible on the treatment-planning computed tomography (CT) scan. We have modified our treatment-planning software to allow for interactive display of multiple, registered images that enhance the physician’s ability to accurately determine the GTV.

Methods and Materials: Images are registered using interactive tools developed at the University of North Carolina at Chapel Hill (UNC). Automated methods are also available. Images registered with the treatment-planning CT scan are digitized from film. After a physician has approved the registration, the registered images are made available to the treatment-planning software. Structures and volumes of interest are contoured on all images. In the beam’s eye view, wire loop representations of these structures can be visualized from all image types simultaneously. Each registered image can be seamlessly viewed during the treatment-planning process, and all contours from all image types can be seen on any registered image. A beam may, therefore, be designed based on any contour.

Results: Nineteen patients have been planned and treated using multimodality imaging from November 1993 through August 1994. All registered images were digitized from film, and many were from outside institutions. Brain has been the most common site (12), but the techniques of registration and image display have also been used for the thorax (4), abdomen (2), and extremity (1). The registered image has been an magnetic resonance (MR) scan in 15 cases and a diagnostic CT scan in 5 cases. In one case, sequential MRs, one before treatment and another after 30 Gy, were used to plan the patient’s initial fields and boost, respectively. Case illustrations are shown.

Conclusions: We have successfully integrated multimodality imaging into our treatment-planning system, and its routine use is increasing. Multimodality imaging holds out the promise of improving treatment planning accuracy and, thus, takes maximum advantage of three dimensional treatment planning systems.

Multimodality imaging, 3D treatment planning, Image registration.

INTRODUCTION

In evaluating a patient for radiation therapy, it is common for radiation oncologists to compare multiple images to arrive at a target volume for treatment. In terminology outlined in International Commission on Radiation Units and Measurements (ICRU) report 50 (12), the physician is attempting to radiographically define the most accurate gross tumor volume (GTV). The starting point for three-dimensional (3D) treatment planning is the treatment-planning computed tomography (CT) scan. For some cases, this scan adequately depicts the GTV, but in many instances the GTV cannot be adequately or easily defined. The GTV may be better visualized on alternative radiographic studies, the GTV may have had a complete response to chemotherapy, or the GTV may have been removed surgically. With the alternative study in hand, the radiation oncologist is faced with the daunting task of manually transferring the data on the alternative study onto the treatment-planning CT scan. This process may


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Acknowledgements—This work was supported in part by the American Cancer Society Career Development Award, Scott L. Sailer recipient; and NIH Grant 1-PO1 CA47982-04: “Medical Image Presentation.”

Accepted for publication 30 October 1995.
result in inaccurate definition of the GTV and thereby
defeat one of the principle goals of 3D treatment planning.

We have integrated multiple images into our 3D treat-
ment-planning software that gives physicians access to
registered radiographic studies other than the treatment-
planning CT scan. Fraass et al. (7) described a method
of registration for radiation therapy in 1987. Images were
collected prospectively using immobilization devices and
external fiducial marks. The digital images were regis-
tered initially using the fiducial marks that were present
on each image, and final adjustments were made by regis-
tering contours of identical anatomic structures from each
image. As described, this was a general approach that
could be applied to a variety of images and a variety of
anatomic locations, but additional reports from this group,
as well as others, involve image registrations in the brain
(14, 23, 33, 35). Nuclear medicine groups have investi-
gated image registration predominantly in the abdomen
(6, 15, 30). These studies use prospectively collected
digital data (6, 15) and use external fiducials (6, 15) or
contour matching (30) to guide the registration process.
One group has registered digitized MR or CT scans with
digital single-photon emission computed tomography
(SPECT) images (30).

Our approach is somewhat unique in that it can be
applied to a wide variety of body sites, it can use images
digitized from film, the images are seamlessly integrated
into the treatment planning process, and the registration
uses the full 3D data set and does not rely on external
fiducials or contour matching algorithms. The initial clin-
cal use of this system is described.

METHODS AND MATERIALS

Treatment planning for all patients was performed using
PLan UNC, a 3D treatment-planning software pack-
age that has been developed at the University of North
Carolina at Chapel Hill. It is a modification of the virtual
simulator, which has been extensively described (4, 29,
31). Radiation treatment planning for all patients was
performed using this platform. Recently, PLan UNC has
been modified to display registered radiographic studies
other than the treatment-planning CT scan. The treatment-
planning CT scan is transferred directly from the CT scan-
er to the treatment-planning computer. Other radiog-
graphic studies performed within our hospital can be
transferred directly to the treatment-planning computer,
but studies can also be digitized from film (2) and used
in PLan UNC. Contours of interest are defined by the
physician and dosimetrist on all pertinent radiographic
studies. In the beam’s eye view (BEV), contours from all
images can be selectively displayed on digitally recon-
structed radiographs (DRRs; Fig. 1). The contours are
also displayed on a planar, radiographic image (treat-
ment-planning CT scan or other image). Only one image
can be viewed at a time, but the viewed image can be
switched from one image type to another image type with
minimal delay by selecting a button in the image panel.
At the present time, only two image types can be held in
memory at any given time, but work is progressing to
allow for additional simultaneous images. Contours de-
finite on images other than the currently displayed image
are tiled and then realigned at the appropriate angle onto
the image currently displayed (Figs. 1 and 2). Radiation
beams can be designed by automatically shaping around
any contour. Radiation beams designed in the BEV win-
dow can be displayed on any available image (Fig 7).

Images are registered using a “fusion” tool developed
at the University of North Carolina. This is a manual, but
highly interactive set of tools with which the user interacts
with two 3D data sets. Tools available to the user include
shaded surfaces (3, 8, 20, 28), volume rendering (17, 24,
26, 27), real-time DRRs (4, 32), and arbitrary cut planes.
The arbitrary cut planes are the most useful. The images
in the arbitrary cut planes can be toggled on and off or
faded from 100% intensity of data set one (0% intensity
of data set two) to 100% intensity of data set two (0% in-
tensity of data set one). This fading tool mimics the
function of the right and left balance control on a stereo
receiver: when the control bar is placed in the “middle”
both images are at 100% intensity. Viewing partially
transparent, mixed images (i.e., 100% intensity of one
data set and 75% intensity of another data set) using gray
on gray, color (red or green) on gray, or color on color,
enhance the image registration process (10). The tool
outputs a transformation matrix that is readable by PLan
UNC. In addition to a wide variety of manual techniques,
the tool can invoke the Chen and Pelizzari automated
point–surface matching technique (21) and registration
software described by Robb (25). The tool also has soft-
ware “hooks” available for invoking other installed auto-
matic registration tools. Despite the availability of the
automated methods, all patients have been registered us-
ing the interactive manual methods.

Patients were chosen for image registration based on
physician request. Image registration is approved by the
patient’s physician before clinical implementation. We
feel this is essential, because it gives the clinician a feel
for the accuracy of the registration when he or she pro-
cceeds to the beam design phase of treatment planning.

RESULTS

The first clinical use of image registration was in No-

vember 1993. Through August 1994, 19 patients have
undergone image registration using 20 images. For one
patient, two registered images were used. He developed
an intracranial recurrence of a paranasal sinus carcinoma
extending from the cribriform plate into the frontal lobe.
The inferior aspect of the lesion was at the upper border
of his previous postoperative radiation portal. One of the
registered images was a pretreatment magnetic resonance
(MR) scan, and the other was a MR obtained after 30
Gy. These images were used to plan the initial fields and
Multimodality imaging in treatment planning

Fig. 1. Selected panels from PLan UNC. The left and middle image come from the image panel, which displays one of two registered images (in this case, the treatment-planning CT scan or the preoperative MR scan). The right image comes from the beam's eye view (BEV) panel, which displays a real-time digitally reconstructed radiograph (DRR) based on the treatment-planning CT scan. The preoperative MR target contour (red) and the treatment-planning CT target and eye contours (green) are shown on the MR scan, CT scan, and the DRR. The slice angles for the CT and MR scans are shown on the DRR. See the text for further discussion of this case.

Fig. 2. This figure shows the middle portion of two screen views from PLan UNC. In the upper part of the figure, the CT data set is selected (note “IM 0” in the Image panel) and in the lower part of the figure the MR data set is selected (note “IM 1” in the Image panel). These two views from PLan UNC can be alternated with no delay by clicking on the IM button in the Image panel. The left portion of figure shows a planar image from the selected image type and the right portion of the figure shows the BEV panel which contains a DRR based on the treatment-planning CT. Between these two panels is the Image selection panel that shows miniaturized versions of all the images in the chosen data set. The MR target contour (red) and treatment-planning CT target and eye contours (green) are shown overlaid on the planar images and on the DRR. A right lateral beam (yellow), based on the MR contour, is shown in the BEV panel, the Image panel, and the Image selection panel.

Fig. 4. Selected panels from PLan UNC. The left and middle image come from the image panel, which displays one of two registered images (in this case, the treatment-planning CT scan or the preoperative CT scan). The right image comes from the BEV panel, which displays a real-time DRR based on the treatment-planning CT scan. The preoperative CT tumor contour (green) and the treatment planning CT target contour (red) are shown on the preoperative CT scan, the treatment-planning CT scan, and the DRR. See the text for further discussion of this case.

A summary of the anatomical sites, diagnoses, and images used are presented in Tables 1 through 3. Brain was the most common site because of the vast superiority of brain tumor visualization using MR compared to CT scan (9). All registered images were scanned from film. We have recently implemented a protocol to transfer digital data from the Radiology Department to our department; therefore, we will be able to use digital data in the future. We feel this will greatly enhance our ability to perform image registration, although for many patients, this direct digital access to other radiographic studies will not be

Fig. 5. Selected panels from PLan UNC. The left and middle image come from the image panel, which displays one of two registered images (in this case, the treatment-planning CT scan or the preoperative CT scan). The right image comes from the BEV panel, which displays a real-time DRR based on the treatment-planning CT scan. The preoperative CT target contour (red) is shown on the preoperative CT scan, the treatment-planning CT scan, and the DRR. See the text for further discussion of this case.

the boost fields, respectively. Nine of the 19 (47%) cases were done in July and August 1994, which indicates increased physician use of the technology as its usefulness became evident. From November 1993 to August 1994, 151 patients have undergone 3D treatment planning.
I. J. Radiation Oncology ● Biology ● Physics

Volume 35, Number 1, 1996

Fig. 3. Selected panels from PLan UNC. The left and middle image come from the image panel, which displays one of 2 registered images (in this case, the treatment-planning CT scan or the preoperative MR scan). The right image comes from the BEV panel, which displays a real-time DRR based on the treatment planning CT scan. The preoperative MR target contour is shown on the MR scan, CT scan, and the DRR. See the text for further discussion of this case.

available, because patients often have pertinent radiographic studies performed outside our institution.

Case reports

Tumor is not visible on the treatment planning CT scan. A 59-year-old male with a right temporo-parietal glioblastoma multiforme was treated with subtotal resection followed by postoperative radiation and BCNU. The pre-treatment MR and treatment-planning CT scan are shown in Fig. 1. There are postoperative changes and hypodense areas seen on the treatment-planning CT scan, but the tumor is much more visible on the preoperative MR scan. The treatment-planning CT target contour was drawn before the MR data were registered. The posterior extent of the tumor seen on MR was inaccurately translated to the treatment-planning CT scan because of the vastly different angles of CT and MR slice acquisition. The posterior portion of the CT target contour was too inferior. The patient was planned based on the MR target contour as seen on the DRR. In this case, the increased accuracy of tumor definition provided by image correlation is obvious.

A 32-year-old male with a left fronto-temporal oligodendroglioma was treated with subtotal resection followed by postoperative radiation therapy. The pre-treatment MR and treatment-planning CT scan are shown in Fig. 3. There are postoperative changes and hypodense areas seen on the treatment-planning CT scan, but the tumor is much more visible on the preoperative MR scan. The MR target contour was used to design the radiation portals.

Tumor has been removed surgically. A 51-year-old female with a high-grade malignant fibrous histiocytoma of the inferior vena cava was treated with surgical resection followed by postoperative chemotherapy (one cycle of adriamycin and ifosfamide) and radiation. The preoperative CT scan and treatment-planning CT scan are shown in Fig. 4. The preoperative tumor volume was identified on the preoperative CT scan, and when displayed on the treatment planning CT scan, this contour was used to help design a postoperative target volume that encompassed areas of positive margin near the para-aortic vessels. Treatment fields were designed based on this postoperative contour. In the DRR panel, the planes of the preoperative CT contours and the treatment-planning CT contours are slightly skewed in relation to each other because the patient was not in the same position for each data acquisition.

A 68-year-old male with a squamous cell carcinoma of the lung was treated with a left upper lobectomy followed by postoperative radiation. Hilar lymph nodes were negative, but at the time of surgery, tumor was stuck to the chest wall and was sharply dissected away from the chest wall. The preoperative CT scan and treatment planning CT scan are shown in Fig. 5. There was no gross disease seen on the treatment planning CT scan. The preoperative CT scan was used to draw a contour, which identified the most likely site of microscopic disease along the chest wall, and this contour was then displayed on the treatment-planning CT scan and the DRR. Treatment fields were designed based on the preoperative contour.

Tumor has responded to chemotherapy. A 52-year-old male with a stage IB/E diffuse large cell lymphoma of the sternum was treated with three cycles of cyclophosphamide, adriamycin, vincristine, and prednisone (CHOP) followed by consolidative irradiation. The disease initially extended into the soft tissue anterior to the sternum and involved lymph nodes posterior to the sternum. The pre-treatment CT scan and treatment planning CT scan are shown in Fig. 6. Because there was a complete response to chemotherapy, the patient’s treatment portals were designed based on the contour from the registered pre-treatment CT scan. The prechemotherapy CT contour extends anterior to the anterior skin of the treatment-planning CT scan because the disease anterior to the sternum has responded to chemotherapy.

Fig. 6. Selected panels from PLan UNC. The left and middle images come from the image panel, which displays one of two registered images (in this case, the treatment planning CT scan or the prechemotherapy CT scan). The right image comes from the BEV panel, which displays a real-time DRR based on the treatment-planning CT scan. The pretreatment CT tumor contour is shown on the pretreatment CT scan, the treatment planning CT scan, and the DRR. See the text for further discussion of this case.
Overall, 195 out of 402 (49%) patients had their treatment plan altered because of CT. An examination of patients and marginal tumor coverage in 28 out of 152 patient's surface, so as to identify areas of concern. In addition or by direct inspection), the clinical target volume (CTV; GTV plus subclinical microscopic extent), and the planning target volume (PTV; CTV plus patient motion and internal organ motion with the simulation film). In ICRU report 50 terminology (12), the gross tumor volume (GTV; tumor grossly visible radiographically or by direct inspection), the clinical target volume (CTV; GTV plus subclinical microscopic extent), and the planning target volume (PTV; CTV plus patient motion and internal organ motion) are transferred manually to the simulation film. Registration can be facilitated by placing opaque markers either internally or on the patient's surface, so as to identify areas of concern. In addition, direct images of the tumor, from CT or MR, can be hand drawn on the simulation film using "eye-ball" registration.

There is mounting evidence, however, that this "eye-ball" registration is frequently done poorly. For example, in a review by Tepper and Padikal of six published reports, treatment planning without CT was found to result in inadequate tumor coverage in 113 out of 402 (28%) patients and marginal tumor coverage in 28 out of 152 (18%) patients when the final plans were checked with CT (34). Overall, 195 out of 402 (49%) patients had their treatment plan altered because of CT. An examination of the radiation treatment portals in a recent national cooperative trial for the treatment of lung cancer revealed that in 34 out of 151 (23%) cases, the target was incompletely covered even though all of these patients had preplanning diagnostic CT scans (5).

Computed tomography based 3D treatment-planning systems have now effectively removed much of the error caused by using the "eye-ball" image–image registration of conventional two-dimensional treatment planning. Once the relevant anatomic structures and target volumes are defined on the planning CT scan, these contours can be projected automatically onto the simulation film through the use of the digitally reconstructed radiographs (DRR) (32). A printout of the DRR on film can then be used for portal design with assurance that the data from CT has been accurately registered. Nevertheless, there are short comings. The "perfectly" registered set of contours and a DRR must still be registered with the patient as discussed above. In addition, whereas the GTV may be easily defined on the treatment-planning CT scan, the CTV and PTV definitions are not directly dependent upon image information. They are based on known clinical behavior of various tumors (CTV) and studies of patient setup uncertainty and internal organ motion (PTV). Furthermore, the clinically relevant accuracy of the image–image registration achieved with 3D treatment planning is limited by the accuracy of the drawn contour. There is no doubt that the contour is accurately registered with the DRR, but the GTV (or other structure) may not be accurately registered if the contour does not represent the GTV.

Any technique that increases the accuracy of GTV definition would increase the accuracy of the initial image–image registration. Incorporating images other than the treatment-planning CT scan into the treatment-planning process is an essential part of increasing this accuracy, because while the GTV may be easily identified on the treatment planning CT scan, this is not always the case. For most treatment planning systems, the CT scan is required for dose calculations, and therefore, must be used, even if it is not the ideal imaging modality for that particular tumor. For instance, the tumor may be more

### Table 1. Sites planned with multimodality treatment planning

<table>
<thead>
<tr>
<th>Site</th>
<th>Number (percent)</th>
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<tbody>
<tr>
<td>Brain</td>
<td>12 (63%)</td>
</tr>
<tr>
<td>Thorax</td>
<td>4 (21%)</td>
</tr>
<tr>
<td>Abdomen</td>
<td>2 (11%)</td>
</tr>
<tr>
<td>Extremity</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
</tr>
</tbody>
</table>

### DISCUSSION

From a certain vantage point, much of radiation therapy treatment planning and delivery can be seen as a series of image–image and image–patient registrations. Image–patient registrations deal primarily with the precision of radiation delivery, and pose similar problems for both conventional and three dimensional (3D) treatment planning. This must not be forgotten, as emphasis is placed on image correlations performed in the virtual world. The radiation therapist must make sure that the simulation film (conventional treatment planning) or the digitally reconstructed radiograph (DRR; 3D treatment planning) is registered with the patient. This is usually accomplished with tattoo marks, lines painted on the patient, and sometimes with mechanical restraints on the patient's position. At the time of treatment, the clinician must make sure that the portal images, and, therefore, the patient, are properly registered with the simulation film or the DRR. Three-dimensional treatment planning adds very little to the precision of this image–patient registration.

One of the major differences between conventional and 3D treatment planning, however, is the accuracy of the initial image–image registration. In the initial phase of conventional treatment planning, the clinician must register his or her knowledge of likely tumor extent, probable patient motion, and internal organ motion with the simulation film. In ICRU report 50 terminology (12), the gross tumor volume (GTV; tumor grossly visible radiographically or by direct inspection), the clinical target volume (CTV; GTV plus subclinical microscopic extent), and the planning target volume (PTV; CTV plus patient motion and internal organ motion) are transferred manually to the simulation film. Registration can be facilitated by placing opaque markers either internally or on the patient's surface, so as to identify areas of concern. In addition, direct images of the tumor, from CT or MR, can be hand drawn on the simulation film using "eye-ball" registration.

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number (percent)</th>
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<tbody>
<tr>
<td>Glioma</td>
<td>8 (42%)</td>
</tr>
<tr>
<td>Sarcoma</td>
<td>2 (11%)</td>
</tr>
<tr>
<td>Lung cancer</td>
<td>2 (11%)</td>
</tr>
<tr>
<td>Metastatic/recurrent H &amp; N</td>
<td>2 (11%)</td>
</tr>
<tr>
<td>Breast metastatic to brain</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Lymphoma</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Pancreatic cancer</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Germinoma</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Thymic carcinoma</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
</tr>
</tbody>
</table>

H & N = Head and neck.
Michigan, 3D brain tumor protocols have been written in tumor detection than CT (9). At the University of the brain, MR is known to be more sensitive and specific that call for the use of MR as the primary tumor definition visible on alternative imaging studies (Figs. postoperative MR scan with the treatment-planning CT disease. For a patient with a partially resected glioblas-
cases shown in Figs. 4 and 5, the pretreatment tumor volume was not entirely contained within the radiation portal. Rather, the pretreatment tumor volumes were used to determine the most likely site for microscopic residual disease. For a patient with a partially resected glioblastoma multiforme, it may be more important to register a postoperative MR scan with the treatment-planning CT scan depending on the extent of the resection. In the patient cases shown in Figs. 4 and 3, the pretreatment tumor volume was not entirely contained within the radiation portal. Rather, the pretreatment tumor volumes were used to determine the most likely site for microscopic residual disease.

Table 3. Types of registered studies

<table>
<thead>
<tr>
<th>Registered study</th>
<th>Number (percent)</th>
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<tbody>
<tr>
<td>Pretreatment MR</td>
<td>13 (65%)</td>
</tr>
<tr>
<td>Postoperative MR</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Pretreatment CT</td>
<td>5 (25%)</td>
</tr>
<tr>
<td>Sequential MR</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
</tr>
</tbody>
</table>

MR = Magnetic resonance.
CT = Computed tomography.

visible on alternative imaging studies (Figs. 1 and 3). In the brain, MR is known to be more sensitive and specific in tumor detection than CT (9). At the University of Michigan, 3D brain tumor protocols have been written that call for the use of MR as the primary tumor definition modality (33). Magnetic resonance imaging is also thought to be superior to CT in other sites such as bone (22), soft tissues of the pelvis (19), and head and neck (18). In addition, the treatment-planning CT scan may not show the tumor because of a response to chemotherapy (Fig. 6) or because the tumor has been removed surgically (Figs. 4 and 5). In both of these instances, but especially in the latter, it can be difficult to fully understand the relation between where the tumor was before surgery or chemotherapy, and where radiation therapy should be delivered based on images that no longer show the GTV. In essence, the physician is trying to correlate multiple snapshots of the tumor over time. In the patient cases shown in Figs. 4 and 3, the pretreatment tumor volume was not entirely contained within the radiation portal. Rather, the pretreatment tumor volumes were used to determine the most likely site for microscopic residual disease. For a patient with a partially resected glioblastoma multiforme, it may be more important to register a postoperative MR scan with the treatment-planning CT scan depending on the extent of the resection. In the patient case shown in Fig. 6, the clinician wanted to treat the original prechemotherapy tumor volume. The registration process greatly facilitated this process.

One may be tempted to manually transfer data from these “other” images to the treatment-planning CT scan, but transferring such data from cross-sectional–based images onto another cross-sectional–based image by a manual method is probably even more difficult than transferring such data onto a two-dimensional (2D) conventional simulation film. This is demonstrated in Fig. 1. The green contour was drawn on the CT scan before the MR scan was registered, using a hard copy of the MR scan as a guide. The posterior extent of the tumor as seen on the MR slice was inappropriately contoured on the CT slice. The posterior portion of the tumor should have been contoured on a CT slice superior to the slice shown in Fig. 1. The superior CT slices did not show obvious tumor, and this error in tumor definition on the CT image was caused by the error-prone manual transfer of cross-sectional–based data from one image to another cross-sectional–based image when those images are obtained at different slice angles. Through image registration and the subsequent display of those images in the treatment-planning tool, this manual process is eliminated and multiple image types are readily available to the physician during the treatment-planning process. In Fig. 1, the red MR tumor contour is resliced onto the CT scan and the error in the green CT contour is obvious.

For all the patients in this study, the registered image was digitized from film using a technique developed by Boxwala and Rosenman (2). Others have used digitized images (30), or inferred their use (14). We feel this ability is essential in the clinical application of this technology, because a patient often presents after being evaluated at an outside institution with outside films. We currently have implemented a method to transfer diagnostic radiology studies directly to our treatment planning computer, and while these registered images have not been used in the clinic, they have been used for research. We feel the registration process is more robust using the complete (i.e., not scanned) digital data.

We have not fully analyzed the accuracy of the registration process. Others have done so, primarily working in the brain (1, 13, 36), but it is difficult to know what the “truth” is. It is our feeling that the absolute accuracy of the registration process is greatest for the brain and less robust for other sites because, for instance, there can be more variability in patient position when imaging the abdomen or thorax. The use of a curved couch for a diagnostic CT and a flat couch for a treatment planning CT is an example of this variability. In these cases, landmarks (great vessels, bone, trachea, kidneys, etc.) other than the skin are compared during the registration process. Often, these landmarks are chosen in close proximity to the tumor volume, so as to ensure the most reliable registration at the most crucial site. An analysis of accuracy is proceeding, but currently, a physician looks at the registered images using the “fusion” tool (the registration can, therefore, be readily changed by the physician), and the registration is approved before the images are used for treatment planning. In this way, as virtual simulation proceeds using the registered image and the treatment planning CT scan, the physician has a feeling for how accurate the registration is. The requirement of physician approval of registration before clinical implementation will likely continue even after a formal assessment of registration accuracy is made.

Others in the radiation oncology community are involved with image registration. Fraass et al. (7) describe some of the earliest registration work for 3D treatment planning. They describe a general approach to image registration using external fiducials and contour matching algorithms, but more recent reports using similar techniques have focused on the brain only (33, 35). Kessler et al. (14) have also extensively discussed integration of MR, CT, and positron emission tomography (PET) data sets in the brain. To register the images, they describe...
point matching, surface matching, line matching, and interactive matching using external fiducials, anatomical points, anatomical surfaces (contour derived), or outlines of anatomical structures. Although not explicitly stated, the use of digitized images is implied when the technique of surface matching is described and films from outside institutions are to be used in the planning process. Once the transformation that relates one image data set to another is derived, information unique to one data set can be displayed on another data set by generating surface tiles from the contour of interest and reslicing the surface representation in the correct orientation so that it can be viewed on the alternative study. There is also work with image registration in the brain for radiosurgery applications (11, 23).

In the radiology literature, work has focused primarily on registering single-photon emission computed tomography (SPECT) images with CT and/or MR images of the abdomen in colorectal carcinoma (6, 15, 30). Registration was aided by external fiducials (6, 15), internal landmarks (16), contours of anatomic structures (30), and patient immobilization devices (6). Digital data was usually used (6, 15), but one study used MR or CT images digitized from film (30).

While these approaches are similar to our approach, the system described here is unique in that it uses an interactive matching method that uses the entire 3D data set without using contours or external fiducials. This is invaluable in cases where external anatomy has changed significantly either because of weight loss or tumor response (Fig. 6). In these situations, the registration process can be performed using structures close to the radiation target, and while a perfect registration is not always possible, a clinically meaningful registration is performed at the site of interest. Radiation oncologists routinely perform this task in clinical practice, usually transferring data from multiple cross-sectional images at various points in time onto 2D simulation films. The integration of these images into the 3D treatment planning process is a logical and more accurate extension of this process.

This report demonstrates the use of registered images in routine 3D treatment planning. In contrast to other reports from the radiation oncology community, registered images are used for treatment planning of tumor sites other than the brain. Patients have been planned using a treatment-planning CT scan that is registered with an image data set digitized from film. We feel that this increases the accuracy of the gross tumor volume definition when compared to using the treatment-planning CT scan alone. Future investigation will focus on assessing the accuracy of the registration process and integrating other imaging studies into the treatment-planning process such as nuclear medicine SPECT images. In addition, we hope to incorporate the registration tool (the “fusion” tool) into PLAN UNC as an integrated module.

REFERENCES

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