Modern cancer treatment is a multimodality treatment, where surgery, chemotherapy, and radiation therapy are used alone or in concert to reach the desired biological effect for the patient in the most optimal fashion. The aim of radiation therapy is to deliver a prescribed radiation dose to physician specified target volumes while minimizing the damage to tissue outside the target. Images of the patient's internal anatomy are essential to identify and quantify the target volume and its relationship to normal anatomy and verify the delivery of the intended therapy. The use of images has now become the basis for the design and optimization of radiation treatment plans.

Introduction

Major technological advances in medical imaging have had a profound influence on the planning and delivery of radiotherapy for the treatment of cancer. This revolution began in 1972 with the introduction of x-ray transmission computed tomography (CT) [Cormack, 1963; Hounsfield, 1973]. The ability to view anatomical structures of the patient without interference from overlying tissue made possible with CT scanning permitted the physicians to better delineate the extent of disease. The subsequent use of the CT, and later magnetic resonance imaging (MRI) scanners in radiation therapy was revolutionary in bringing large quantities of threedimensional anatomical information to the physician.

These technological advances provided images of the three dimensional spatial distribution of normal and abnormal tissue at a spatial resolution of a less than a millimeter and an acceptable contrast resolution. CT and MRI studies provide data for tumor staging and spatial localization of the tumor relative to adjacent normal structures. CT images also provide information concerning the electron density within small voxel elements, which is important for accurate dose distribution calculations. The three dimensional description of the target relative to normal tissues allows optimized radiation portals to be designed and evaluated.

Treatment planning based on imaging data from the patient plays a major role for all procedures in radiation therapy, including brachytherapy, hyperthermia, particle beam therapy, and radioimmunotherapy. Imaging is a core tool in the process of treatment planning and delivery of radiation, and is a key element in target delineation, dose computation, dose display and analysis, plan optimization and assessment of treatment delivery. Additional images acquired during the delivery of radiation therapy provide important quality assurance data on radiation field alignment and their reproducibility. Follow-up imaging studies provide quantitative measures of treatment efficacy.

Discussion

The modern radiation oncologist needs to view an enormous amount of images for both the treatment planning and throughout the course of treatment of each patient. The information the physician wishes to acquire from these images is used in two ways: (1) to determine the extent of the disease within the patient and to localize adjacent normal structures from multiple images of the area and image modalities and (2) verify delivery of the prescribed therapy.

Localizing the Disease and Surrounding Normal Tissue

Accurate radiotherapy treatment planning requires the precise identification of the targeted disease volume and the normal surrounding organs. Prior to the availability of CT images, these anatomical structures were outlined on a few projection radiographic images obtained on patients in the treatment position. However, the three dimensional extent of both the diseased volume and normal anatomy are often better visualized on multiple CT and MRI images.
The precise identification of the target volume and normal surrounding organs is made possible by examining the three-dimensional images obtained by CT and MRI. Using multiple CT images requires physician time to contour the structures of interest. Typically, 50-100 axial CT sections must be examined and anatomical structures within each section must be contoured to delineate the extent of the disease and surrounding normal organs. While the axial presentation of this three-dimensional information may be useful to identify the lateral extent of the tumor, identification of the superior and inferior borders of the tumor is difficult. This identification may be expedited by visualizing sagittal, coronal or oblique sections obtained by computationally resecting the volume of axial CT sections along these respective planes. Examination of MRI data collected along the sagittal or coronal plane may also be useful. Radiographs, CT and MRI provide basic anatomical information on the patient. New technologies, such as monoclonal antibody and PET/SPECT imaging, may provide additional physiological information concerning the tissue in an image format.

Full utilization of the images on a particular patient requires the quick access to all available imaging studies. A picture archival communication system, PACS, is almost certainly required. The radiation oncologist routinely reviews 150-200Mbytes of imaging information on a typical head/neck or chest patient. A patient's images are typically composed of diagnostic radiographs (20-30 films per patient, 6-7 MBytes per film), simulation and portal radiographs (30-50 films per patient, 6-7MBytes per film), and large CT/MRI datasets (50-100 slices of 512X512X16 bits or 25-50MBytes per study). Identification of anatomical and target structures is time consuming and represents a major bottleneck in three-dimensional treatment planning (Goitein and Abrams, 1983). Physicians are presently required to identify structures on 50-100 axial CT slices. Identification could be significantly expedited by presenting the same information in a customary planar radiographic view, sagittal or coronal sections and/or any arbitrary section through the patient. Registration of all these images is required. We are exploring two different approaches for presenting these multiple projections of the patient's anatomy.

In one approach, we acquire the information on the patient by obtaining MRI images in three projections: axial, sagittal, and coronal. The physician contours significant anatomical structures in any convenient view(s). From a small number of views used to identify structures, projection geometry is used to outline an estimate of the structure on the 50-100 axial views. The projection of the contours onto the axial CT data can be conveniently reviewed and edited by the physician. This approach is only in the exploring stage since (1) MRI imaging of the patient in the treatment position is not customary, since MRI exams of the patient are usually obtained prior to the decision that the patient will be receiving radiotherapy, (2) the basic data obtained in MR imaging are the regional distribution of mobile hydrogen density and proton relaxation times. For dosimetry, however, information on the regional distribution of electron density is required. The mapping of tissue hydrogen density to electron density has yet to be performed.

A second approach is to use the axial CT information of the patient and computationally generate planar projection radiographic views, as well as sagittal, coronal and other arbitrary sections through the CT volume of the patient. These digital reconstructed images can then be used to assist in the identification and contouring of anatomical structures. For example, delineation of the spinal cord from serial axial sections requires examination of 50-100 sections. Resectioning the CT data along the coronal or sagittal plane reveals the 3D position of the spinal cord in a few rapidly viewed images, thus significantly reducing the time required to delineate its anatomical location. Resectioning the CT data also improves the precise delineation of the inferior and superior borders of organs in the abdomen, e.g. pancreas, liver, kidneys etc. In addition, resectioned coronal or sagittal views from axial CT data are useful for correlating with MRI data obtained in coronal or sagittal planes. MRI images often useful to better understand the extent of the disease in the patient.

The spatial resolution of the computed gray-scale computed prospective image is determined by the axial CT slice separation and slice thickness. A large number of finely spaced slices is desirable for high quality reconstructed digital images. In addition, the tissue contrast in the computed projection image is somewhat enhanced due to the reduction in quantum noise owing to summation along the projected rays.

The information contained in MRI and CT images is clearly complementary. While CT provides important electron density information necessary for 3D dosimetry calculations, MRI provides more information on the extent of disease and high resolution images required in any arbitrary plane. To make use of this complementary information, registration of the imaging modalities is required.
Comparison of CT, MRI and planar radiographs taken at different time points, different patient positions and different imaging modalities is an essential process in understanding the information present in the images. The physician mentally performs a qualitative comparison of images, viewing them in sequence. It is common for the CT and MRI images to be of different sizes, different orientations of acquisition, spacing, and section thickness. When comparing 3D images obtained from different modalities, features seen in one modality may be difficult to discern or seen with different contrast in another modality.

Images to be compared must be brought to a common spatial framework to allow for geometric alignment. Anamorphic scaling, rotation and translation can be performed using reference landmarks common between the two sets of images. In images of the head, external features such as the eyes, nose and teeth can be used to bring the volumes into a basic congruence. Internal landmarks, such as the mandibular fossa or the outline of the third ventricle can also be used. A simple visual alignment often produces a good start.

Assuming the two 3D volumes (CT/CT or CT/MRI) are rigid and undeformed between measurements, alignment of 3D rendering on the basis of external features such as the eyes, nose and teeth can be used to bring the volumes into a basic congruence. Internal landmarks, such as the mandibular fossa or the outline of the third ventricle can also be used. A simple visual alignment often produces a good start.

Landmarks can also be obtained by obliquely sectioning one volume and comparing the oblique sections with the sections from the reference volume. Each landmark on the reference image is cross-correlated with the corresponding landmark from the other image. Because of differences in sampling as well as other reasons, landmarks common to both 3D volumes is often difficult to identify with great accuracy.

Chen et al. (1985) have devised a surface fitting scheme to parameterize the tiled surfaces from 3D contours, minimizing the volume between the two comparable surfaces. This method is based on contouring structures in each axial section of the first data set and forming a tiled surface. This surface is then transformed to the coordinate system of the second dataset. Transform contours are generated based on the intersection of the tiled surface from the first data with the primary sections composing the second dataset. While this method has found some success in aligning intracranial lesions from CT data, it is unclear how successful this method will be for alignment of different anatomical structures.

Other schemes take surfaces from the sample data and elastically deform it relative to the reference surface until a minimum of the potential energy is found. Schwartz et al. (1985) matches brain ventricles in the CT data of the head with those in the brain atlas, using an initial alignment based on first and second moments, followed by an iterative local matching. These techniques imply the ability to find distinct surfaces.

Procedures using elastic deformation appear to be useful in addressing the correlation of deformations. Correlation of images taken in different patient positions or changes due to local tissue growth and atrophy must be addressed. Fortunately, elements such as the skeleton change position in a conservative fashion and thus are useful for long-term landmarks. Correlation of soft tissue between imaging studies is currently under exploration.

Verify Delivery of Prescribed Therapy

To confirm the radiotherapy treatment is delivered as planned, portal radiographs are acquired with the high energy photons used for treatment. The image quality and tissue contrast in these radiographs is much poorer than those obtained with lower energy x-rays employed in diagnostic radiology. However, these portal images can be significantly enhanced by digital techniques using simple thresholding and windowing of the dynamic range (Seshadri, 1986; Bloch et al., 1987, 1988) as well as spatial frequency corrections (Meertens et al., 1988). In addition, new technologies are being introduced in radiotherapy where electronic portal images are acquired in near real time during the course of therapy (Meertens et al., 1985; Wong et al., 1989). The large number of images acquired and their registration to other images presents a new dimension to verification of treatment.

CT data can also be used to generate a gray-scale projection radiographic images in the direction of the treatment beam. This computed prospective image can be used for direct comparison with the radiographic images obtained with diagnostic x-ray energies during treatment simulation as well as the portal images obtained with the high energy photons used in treatment. Verification of the planned and delivered radiation portal is made more precise by correlating the computed projection images with the radiographic portal images.

Summary

Radiotherapy treatment planning involves extensive visualization of the patient anatomy during both planning and delivery of therapy. The identification of the normal and diseased anatomy is normal for the precise delivery of this therapy. Visualization and correlation of CT and
MRI volumes greatly facilitate this process of identification and segmentation. Computed prospective projections of CT volumes can be rapidly and accurately generated to verify both the patient setup during both simulation of therapy and the actual delivery of radiation. This application of biomedical visualization has enormous potential for revolutionizing the delivery of radiotherapy to the patient.

References


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