Commentary (Herman/Wharam): Current Techniques in Three-Dimensional CT Simulation and Radiation Treatment Planning

November 01, 1995

By Michael G. Herman, PhD [1] and Moody D. Wharam, Jr, MD [2]

Stephenson and Wiley demonstrate that three-dimensional (3D) CT-based simulation is an improvement in the simulation process. The growing importance of CT in radiation oncology treatment planning has been discussed previously [1] and is further emphasized in this article. The advantages of geometric optimization in three dimensions for radiation therapy treatment planning also are described. These results are applicable to both 3D and two-dimensional (2D) dose planning, because the treatment team can visualize and delineate structures on axial or reconstructed CT planes in greater detail than is possible with conventional simulation projected radiographs.

Computed tomographic simulation represents the integration of highly accurate anatomic definition with the treatment field design of conventional simulation [2]. The patient is set up in treatment position, with immobilization and positioning devices in place. Modifications required for the limited geometry of the CT scanner opening are incorporated into the treatment set-up. The superior density and spatial resolution of CT data clearly differentiate internal anatomic structures, which allows the physician to more accurately define prescription volumes according to external-beam standards [3]. The gross tumor volume represents the visible extent of tumor. The CT simulator presents distinct anatomic boundaries for improved gross tumor volume delineation. Of equal significance is the ability of CT simulation to visualize structures for explicit interpretation of the clinical target volume. In conventional simulation, the probability of involvement and the location of anatomy to be included in the clinical target volume is usually referenced to bony landmarks on plain radiographs. The clinical target volume represents the demonstrated gross tumor volume plus direct local subclinical spread and suspected regional and distal areas of involvement, such as lymph nodes (and edema).

In conventional 2D simulation, the clinical target volume is typically defined as a fixed margin beyond the gross tumor volume, due to the lack of anatomic information in simulation films and the difficulty in reconciling other diagnostic data with these films. In CT simulation, the anatomy in which potential microscopic extensions or occult disease may reside is seen directly, equipping the physician with better tools to interpret the clinical target volume. This improves the ability to manage patients, especially in the treatment of occult disease, for which radiation therapy is very effective. In addition, software tools are available to expand or dilate the clinical target volume (not necessarily equally in all directions) into the planning target volume, which includes margins for patient set-up variation and target and organ motion.

Geometrically Optimal Treatment Plan

Once the gross tumor, clinical tumor, and planning target volumes and normal anatomic structures are drawn and the patient departs, the CT simulator allows the treatment team to select a geometrically optimal plan, in two or three dimensions, while visualizing defined volumes of interest (gross tumor volume, clinical target volume, and others) through virtual simulation. The authors refer to nonaxial planning as noncoplanar planning. This is also known as 2.5-dimensional (2.5D) treatment planning, or the ability to select and reconstruct an oblique anatomic plane that best conforms to the target volume and spares normal tissues. This can be contrasted with conventional 2D planning, which is done only in the axial anatomic plane, and with full 3D planning, in which
beams can enter the patient from any physically achievable direction. In nearly real-time, beams-eye-view digitally reconstructed radiographs (DRRs) are calculated as gantry angle, couch angle, and field size, and other parameters are manipulated. The target volumes and anatomy drawn by the physician are seen as projected contours in the DRR, making treatment field parameter selection more accurate and more efficient. In addition, as pointed out in this article, DRR views can be obtained for any beam and patient position, even when the projection plane is inside the patient (eg, brain vertex). The CT simulator also produces DRRs for use as reference images in special cases, such as repeat fixation stereotactic radiotherapy, for which conventional simulation films are not available.

After selection of the treatment parameters, the DRR serves as the therapy reference film. It is used to fabricate shielding devices and as a reference for verification of treatment set-up. The authors state that CT simulations with 2-mm thickness and 2-mm index provide the best DRR quality, but that acceptable DRRs can be obtained with larger settings.

A study of DRR image quality with both axial and spiral scanning techniques revealed that sufficient DRR quality is achieved even with spiral scans at 1.5 pitch and 3- or 4-mm thickness [4]. Technique selection not only decreased scan time but also allowed for simulation procedures utilizing timed contrast injections and anatomic maneuvers (eg, breath holding, swallowing). Scanning technique also affects the accuracy of anatomic and target contours, and thus, the accuracy of volumes generated in CT simulation for treatment planning. Volumes produced by contours from scans of varying axial parameters, as well as spiral techniques, were indistinguishable for typical-sized structures in radiation therapy.

**Digital Nature of Data Advantageous**

Another inherent advantage of CT simulation is the digital nature of the data, which facilitates direct and therefore accurate communication with treatment planning and calculation systems. This represents an improvement over the conventional contouring process, for which secondary data entry is necessary and therefore the probability of error is increased.

The authors describe the dose-volume histogram as one objective tool for comparing treatment plans. Whether planning in many-slice 2D, 2.5D, or 3D, scoring functions such as the dose-volume histogram are required to select the most appropriate solution. New tools based on radiation biology and tumor kinetics describe normal tissue complication probability and tumor control probability and provide guidance for dose prescription and dose escalation. The 3D anatomic information inherent in CT simulation is a prerequisite for calculation of any treatment plan scoring function.

**Other Applications in Oncology**

The CT simulator has been exploited primarily in external-beam radiation therapy but may have other important applications in oncology therapy and follow-up. It may be used to relate dose and 3D anatomy in brachytherapy [5]. The ability to visualize and analyze 3D anatomy and dose distributions is not typically available in conventional sealed-source brachytherapy planning. Computed tomographic simulation may also enhance combined-modality oncologic management, providing the means to define radiosensitive areas to be targeted or avoided. The ability to visualize medically or surgically treated volumes for radiation therapy planning could improve patient management in sequential or concomitant therapy. The CT simulator may be ideal for monitoring these and other volumetric and density characteristics throughout treatment. The ability to combine or correlate other diagnostic imaging information (eg, MRI, PET), although difficult, is being integrated into the CT simulation process, allowing more detailed characterization of target and normal tissue volumes.

**A Significant Step Forward**

Computed tomographic simulation brings the power of 3D anatomic information into the hands of the treatment planning team. Stephenson and Wiley show specific and graphic examples of how this represents a significant step forward in visualization, target delineation, and beam definition in radiation therapy treatment planning, which has the potential to improve quality of care. It is clear that CT-based virtual simulation represents an improved approach for any dose planning system, and that it may provide the oncology team with new methods for enhancing the therapeutic ratio.

**References:**


Source URL:

Links:
[1] http://www.diagnosticimaging.com/authors/michael-g-herman-phd