

3D Display of Treatment Planning and Anatomy Data: Initial Observation Using a Promising Technical Advance

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Abstract--

Purpose: To determine the feasibility of using a novel 3D display device for radiotherapy treatment planning and to provide guidelines for future development

Materials and Methods: The Perspecta display includes a 20-inch dome with a rotating flat screen, a projector and mirrors. The projector projects 6,000 images or frames per second through a group of relay mirrors onto a planar projection screen that rotates at 900 rpm. Thus, the system displays 3D volumes with a resolution of approximately 100 million voxels. In-house software was developed to transfer regions of interest (ROIs) and dose grids from the Pinnacle treatment planning system to the Perspecta system. A total of 74 ROIs from 8 patients were reviewed by 4 physicians for dose coverage and volume estimation. Reviewers also filled out questionnaires and commented on the plan evaluation process and suggested features required for future developments.

Results: Isodose clouds and ROIs from Pinnacle system were successfully displayed on the Perspecta system. Rather than relying on mental integration of 2D image slices, the volumetric display provided instant recognition of 3D relationships of anatomical and dose data. All reviewers felt that the device allowed better appreciation of these 3D relationships than images from a flat screen display. The locations and sizes of over- or under-dosed regions were also easier to identify on Perspecta. However, measuring tools and a mechanism to place and view treatment beams, such as 3D ruler/cursor, beam shaping and beam's eye view capabilities etc, are necessary for further Perspecta applications in treatment planning.

Conclusion: We implemented a novel 3D volumetric display in the radiation treatment plan evaluation process. Preliminarily, it appears that when treatment planning and anatomic data are displayed volumetrically in 3D, small and/or non-intuitive regions of inadequate coverage or excessive dose are more efficiently and readily appreciated. The data strongly suggest that, with further development, Perspecta has significant potential to become a valuable "true 3D" radiation therapy treatment planning tool.

*Keywords--*3D display, treatment planning, radiation therapy, volumetric estimation

I. INTRODUCTION

Ionizing radiation is an effective treatment modality to eradicate tumor cells when a sufficient amount of radiation dose is delivered to the target volume. A wide variety of radiation machines are now available to

provide safely and consistently the desired type of radiation (photons, electrons, or heavier particles) with sophisticated geometric positioning and rapidly variable collimation. Nevertheless, due to normal organ dose limitations, the amount of radiation that can be safely delivered to a particular patient is not always sufficient for tumor eradication. This is due to the fact that protecting critical normal structures along the path of radiation beams may limit the ability to deliver a curative dose of radiation. A set of beams that deliver high doses to the tumor, while intersecting little or no critical tissue, often lead to successful treatment outcome. Conversely, a treatment that requires the use of beams that irradiate significant amount of critical normal tissues may result in failures in tumor control or/and normal tissue complications [1].

Radiotherapy treatment planning, a process during which radiation beams are selected to avoid as much critical tissue as possible while delivering high doses to the tumor, is one of the critical steps toward a successful radiation treatment program. Large amounts of detailed patient image and anatomy data are acquired during the treatment planning process. These data may be from CT, MRI, PET, SPECT or other forms of imaging. Radiation oncologists, medical physicists, and dosimetrists use these data to determine radiation beam orientations and beam shapes for the patient's radiation treatment. Radiation dose distributions are calculated and then superimposed on patient's anatomical structures during evaluation of rival treatment plans. Sophisticated computer algorithms and technologies are used to help manipulate these image and dose data and provide users with the desired three dimensional perspective. Unfortunately, the optimal selection of a set of beams and the efficient choice of the best plan is not trivial even with those technologies. Among the problems impairing the process of beam selection and plan evaluation, one of the most vexing is the desire to visualize the beam and dose coverage three dimensionally while only 2D flat surfaces are used in most current display technologies.

A novel display device, Perspecta Spatial 3D, recently developed by Actuality Systems (Bedford, MA, USA) is a system that generates volumetric images within a 3D display volume rather than upon a planar surface [2,3,4]. The Perspecta images can be viewed from almost any angle without any viewing goggles. These features

provide great potential for enhancing radiation therapy treatment planning; specifically, selection of beam orientations, recognition of regions of excessive or inadequate dose deposition, and modification of dose distribution with beam adjustment iteratively. In this pilot study, we seek to determine the feasibility of displaying radiation dose distribution data on the Perspecta system and, if deemed feasible, study its potential usefulness in evaluation of treatment plans.

II. MATERIALS AND METHODS

A. Display System:

The Perspecta system produces 3D images by projecting multiple cross-sectional images onto a diffuse screen rotating at about 900 rpm (Fig 1). 198 slices of

images are displayed over 180° during rotation. The projector, at about 6,000 frames per second, consists of three digital mirror devices (DMDs) based on Digital Light Processing (DLP™) technology from Texas Instruments, Inc. At a volume refresh rate of 30 per second and a resolution of 768 x 768 pixels/slice, the system displays about 3,500 million voxels per second (bandwidth more than 3 GBytes/sec). The 3D images appear floating in space within a 24 inch dome due to visual persistence. Proprietary optics and software are used to stabilize and maintain focus of the image. The 50/50 reflectance and transmission property of the diffuse screen also makes the images appear to be semi-transparent. This feature is particularly useful for this study as structures enclosed by a particular isodose surface are still visible during treatment plan evaluation. More detailed descriptions of the Perspecta system were presented previously [2,3,4].

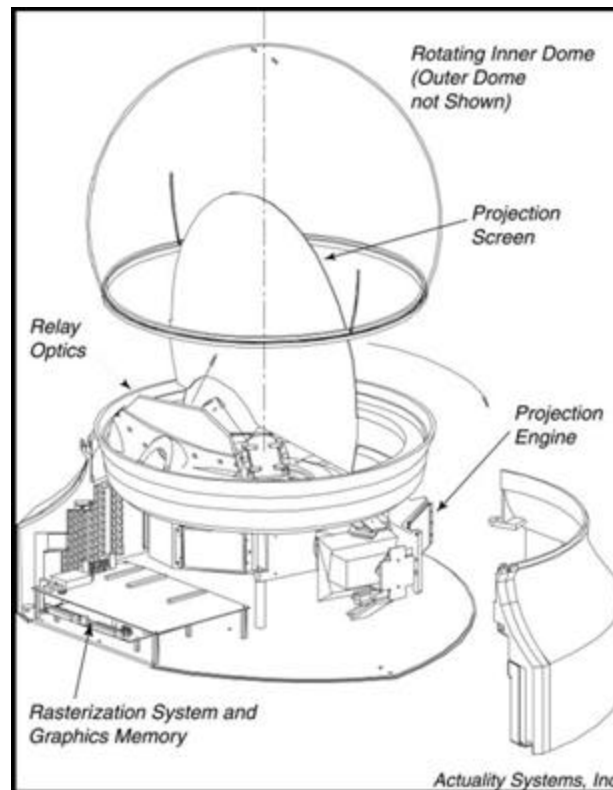


Fig. 1 The Perspecta 3D display system projects 6,000 images per second on a fast spinning screen through a series of mirrors. This system allows visualization of 3D volumetric objects without goggles.

Table 1
Frequency of more accurate volume coverage estimation by Pinnacle or Perspecta system

ROI Volume cm ³	550-2000	15-550	0-15	ALL
No. of ROIs	14	50	10	74
*Pinnacle more accurate	17 (46%)	53 (31%)	13 (39%)	83 (34%)
#Perspecta more accurate	9 (24%)	80 (47%)	6 (18%)	95 (40%)
Tie	11 (30%)	37 (22%)	14 (43%)	62 (26%)

*Pinnacle: a modern treatment planning system by Philips Medical Systems, Inc.

#Perspecta: a 3D display system by Actuality Systems, Inc.

B. Study Design:

Treatment plans from eight patients with cancers of head and neck, lung and prostate treated with external beam radiotherapy and three patients with cancers of breast and base of tongue treated with brahytherapy were used for this study. As these treatment planning data were not initially compatible with the Perspecta display software, we developed in-house software to display pertinent planning data on Perspecta. Our MATLAB based software also allowed selection of colors associated with particular regions of interest (ROI) and various dose surfaces. Four physicians then reviewed the plans using either a flat surface display from a modern planning system (Pinnacle version 7, Philips Medical Systems, The Netherlands) or Perspecta display. They also filled out a survey sheet when completing the review of each plan. The survey included estimates of percent volume coverage at particular dose levels for various ROIs; it also asked if the 3D image confirmed the physician's mental impression, if additional insight was gained, and if additional planning would be needed. The physician's estimates of volume coverage were compared with the dose volume histogram (DVH) calculations from the Pinnacle system. Seventy-four ROIs in three volume ranges were reviewed by each physician (Table 1). The smaller volume ROIs are mainly from the head and neck cases; the larger volume ROIs are mainly from the lung cases. The majority of

ROIs are in the 15-550 cm³ range (including sternum, heart, spinal cord, rectum, bladder, femoral head, prostate etc).

III. RESULTS

All treatment plans and ROIs were successfully displayed on Perspecta using our in-house software. Figure 2 shows two dose surfaces and 7 ROIs for a lung cancer patient. The higher dose surface (yellow) covers only part of the target volume (green) while the prescription dose surface (orange) covers both the target volume and involved lymph nodes (purple). The adequacy of target coverage is easily confirmed from different viewing angles by tilting the head during evaluation. The ability to see through the dose and ROI surfaces is valuable for plan evaluation.

Figure 3 shows the dose distribution for a breast cancer patient receiving interstitial brachytherapy. The patient was treated with 10 catheters loaded with Ir-192 radioactive seeds. The Perspecta display indicates that the prescription dose surface (red) adequately encloses the target volume (green). The dose surface also exhibits a ripple pattern reflecting the non-uniform distribution of radioactivity along each catheter. This type of display is potentially useful for real time brachytherapy, in which the effect of particular source positions on the overall plan is immediately observed and easily recognized.

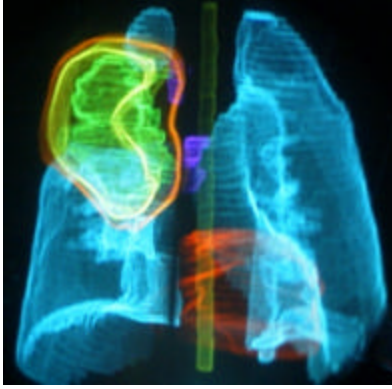


Fig. 2 Perspecta display of a treatment plan for lung cancer. Structures displayed are lung (blue), heart (red), lymph nodes (purple), spinal cord (light green tube) and tumor (green). Two dose surfaces are shown in yellow and orange.

Comparison of the ROI volume coverage estimations with that calculated by DVH is summarized in Table 1. The physicians' estimation of the volume coverage was more accurate using the Pinnacles system for large and small ROIs. However, for 71% of all ROIs, with volume ranging from 15 to 550 cm³, the physicians achieved better estimation more frequently with Perspecta. These differences, nevertheless, did not reach statistical significance.

On analysis of physician surveys, physicians reported that the Perspecta display confirmed their "mental image" of the volumes in 32/33 (97%) of evaluated cases, and that the Perspecta resulted in "additional insight" in 24/33 (73%) of evaluated cases. Physicians also felt 3/33 cases to be inadequate and would need additional work.

IV. DISCUSSION AND CONCLUSION

A "true 3D" display has the potential of improving operation efficiency and outcome in certain 3D tasks, such as ultrasound guided catheter manipulation [5] and collision avoidance in air traffic control [6]. As volume determination is one of the difficult tasks in radiotherapy planning [7], we implemented Perspecta display during plan evaluation. Additional tools, such as 3D ruler and interactive volumetric calculation [8], would be desirable to facilitate the plan evaluation process. The volumetric display provides users complex, 3D information in a more efficient and natural way. The preliminary data demonstrate that, with further development, Perspecta has significant potential to become a valuable tool in radiation therapy treatment planning.

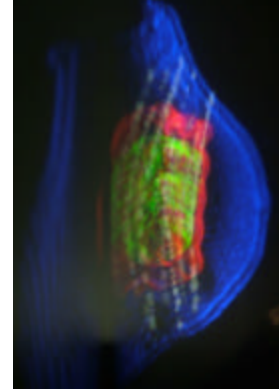


Fig. 3 Perspecta display of a breast brachytherapy implant. It demonstrates that the tumor (green) is adequately covered by the prescription dose surface (red).

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