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Medical Physics Contribution:

3D treatment planning system—Pinnacle system

Ping Xia, PhD, and Eric Murray, CMD

Department of Radiation Oncology, Cleveland Clinic, Cleveland, OH 44195, USA

A R T I C L E I N F O

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A B S T R A C T

The treatment planning system is key for the success of external beam radiotherapy, directly impacting the quality of treatment plans and accuracy of dose calculation in the plans. In this article, we provided an overview of the Pinnacle treatment planning system for external beam planning, including 3-dimensional (3D) conformal plans, step-shoot intensity modulated radiotherapy (IMRT) plans, and volumetric modulated arc therapy (VMAT) plans. We discussed dose calculation algorithm and other utilities, including image fusion, plan documentation, and adaptive planning. Based on our many years of clinical experience with the system, the aim of this article is to provide readers with a summary of this particular planning system.

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Introduction

The Pinnacle treatment planning system was initially called the "Analytical Development Associates Corporation" planning system. Its early version focused on conventional 3-dimensional (3D) plans for photon beams and electron beams with and without computed tomography (CT) images. Before CT simulators are equipped for every center, a simple module (named as "irregular calculation") can define blocked fields and calculate monitor units (MUs) for these fields without CT images. The MU calculation in this simple module is based on the following key parameters entered by users: field sizes, treatment depths, and source-to-distance or source-to-axis-distance treatment technique. In the advent of intensity modulated radiotherapy (IMRT), the IMRT module was introduced in version 6.0. In this version, the fluence maps of IMRT fields were optimized and then converted by a leaf sequencer to deliverable multileaf collimator (MLC) shapes or segments. During this conversion, the quality of the IMRT plan degraded, depending on the IMRT delivery modes, the maximum number of intensity levels, and the leaf sequencing algorithms along with other delivery parameters. In version 7.4, direct machine parameter optimization was introduced for step-shoot IMRT delivery such that the resultant IMRT plans are deliverable without further conversion and thus plan quality degradation. In version 9.0, volumetric modulated arc therapy (VMAT) module (named as SmartArc) was added. In version 9.10, the automatic planning (AP) module was added, allowing a progressive IMRT planning through 6 loops of optimization. The newest version of the Pinnacle system is P16, which has a new user interface, although most functionalities remain the same as in version 9.10.

In this review article, we will discuss the major functionality of the Pinnacle treatment system, primarily based on our clinical experience in version 9.10. As version P16 does not have any major function changes, except for user interface and enabling deformable image registration, we believe the materials presented in this article are still up-to-date.

Reprint requests to Ping Xia, PhD, Department of Radiation Oncology, Cleveland Clinic, 9500 Euclid Avenue CA-50, Cleveland, OH 44195, USA.

E-mail: xiap@ccf.org

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Methods and Materials

General description of the system

The Pinnacle system can create external beam treatment plans for C-arm linear accelerators manufactured by Varian, Elekta, and Siemens, supporting both photon (including flattening filter free beams) and electron beams. The major modules for external beam planning are listed in Fig. 1. The image fusion module allows users to coregister the planning CT images with other image sets, including CT images acquired at a different date and images from other modalities such as MRI and positron emission tomography/CT. Four-dimensional CT images are also supported. The other special modules for proton beam and brachytherapy are not widely used, and thus are not included in this review article. The basic 3D/electron, IMRT/SmartArc, and AP modules will be discussed in detail later. The dynamic planning module is to facilitate adaptive planning, allowing user to transfer all contours from one planning CT to another planning CT (or cone beam CT) through either deformable (only available in P16 version) or rigid image registration and to apply previous treatment beams (including IMRT/VMAT beams) to the new dataset such that the users can recalculate the resultant dose to the new dataset. Upon comparison of the initial plan and the plan with the current patient anatomy (reflected in the new CT), physicians can determine whether an adaptive plan is necessary. If so, based on the new CT and modified contours, the planner can use the same beam angles and the same planning objectives to generate a new adaptive plan.

Dose calculation algorithm

The dose calculation algorithm in Pinnacle includes a collapsed cone convolution (CCC) calculation and an adaptive CCC calculation.[1-3] The adaptive CCC is an approximation method of the CCC, calculating every fourth point in the total energy released per unit mass (TERMA) array while performing a gradient search on the TERMA array. If the TERMA has a low gradient, doses in between the calculation points are interpolated. If the TERMA has a high gradient, convolution calculation is performed in every point in this region. The calculation dose grid resolution can be set by users, typically at 4 mm but can be reduced to 1 mm for very small tumors. The calculation speed decreases as the dose grid resolution increases.

Most external photon beam plans are created with CT images with heterogeneity correction. The isocenter coordinates can be directly input from CT simulation, or placed manually at the center of 3 radiopaque markers on an axial image. If desirable, the users can use the point of interest automatic placement function to place the point in the center of the specified region of interest volume with an option of a box, sphere, or centroid of the volume. Upon input of the CT images, the system will prompt the user to select a proper CT density table if multiple CT density tables exist in the system. If not, a default CT density table is applied for heterogeneity correction in the dose calculation. For special clinical scenario, one can choose to use nonheterogeneity dose calculation for each beam, or to override the density of the body external contour while keeping the dose calculation with heterogeneity correction.

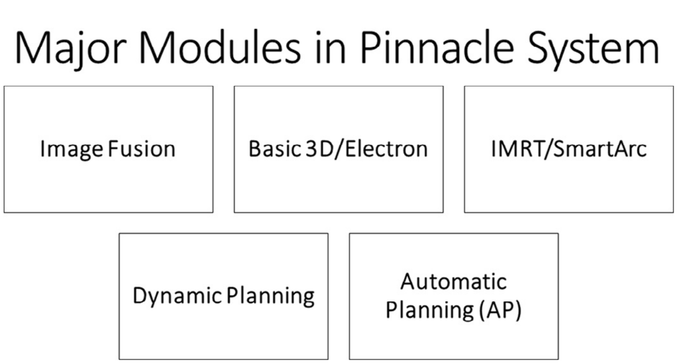

Fig. 1. A list of major modules in the Pinnacle system.

Contouring tools and dose prescription

The system supports various contouring tools, including manual drawing, model-based segmentation (in a separated module), threshold contour, and atlas-based contour (in a module called Spice). A plan can be normalized to a user-defined point, or the maximum dose point, or the mean dose of a user-selected volume. For 3D plans, a user-defined point (*e.g.*, isocenter, midline point, etc.) is typically used for the plan normalization. For IMRT plans, either the plan maximum point or the mean dose of a planning treatment volume (PTV) is typically used for plan normalization. For a 3D plan, the user can add many prescriptions, each normalized to a different point. For an IMRT plan, all IMRT fields under the optimization must be associated with the same prescription.

Users must manually define the dose calculation grid size, drawing directly in the axial, coronal, and sagittal images. Whereas the tissue outside of the grid size is accounted during the dose calculation, the dose-volume histogram (DVH) and the dose statistics for each structure do not take into account the issue outside of the dose grid. For example, if the entire lung is not included in the dose grid, the DVHs for the whole lung could be inaccurate. On the statistics page, the percentage of each structure volume outside of the dose grid is listed. Users need to pay attention to this information.

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