# PLUNC 3D Radiation Treatment Planning System (TPS): An Educational Platform for Medical Physics Students

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## ABSTRACT

**Technological innovations with modern planning and treatment techniques have transformed the way of radiation treatment for cancer patients. A tremendous evolution in radiation treatment process occurred in recent years. This allowed the delivery of the desired radiation dose distribution to target tissue, while delivering an acceptable radia¬tion dose to the surrounding normal tissues with greater dose gradients and tighter margins. Evolution of the computers and computerized systems enabled the possibility to improve the basic two-dimensional (2D) radiotherapy treatment planning to a more accurate and more visualised three-dimensional (3D) treatment planning systems. Today there is now several commercialized planning system competitors used for external beam radiation therapy. PLUNC was one of the first operating 3D radiation treatment planning (RTP) systems'. This RTP system has been developed in the Department of Radiation Oncology at the University of North Carolina (UNC) since 1985 for research and educational purposes. PLUNC is freely distributed to the field of radiation oncology for research and educational use under special license agreement. In this study, PLUNC 3D treatment planning system has been installed and implemented for research and educational purpose in the field of medical physics. A 3D treatment plan has been created and analyzed in a typical patient CT image for educational demonstration purpose. Based on this analysis, it is concluded that the PLUNC 3D TPS could be successfully used for research and education purposes in M Sc/PhD thesis works of students from medical physics discipline.**

***Key words:*** **Radiation therapy, treatment planning, education, medical physics, PLUNC**

## INTRODUCTION

The therapeutic use of ionizing radiation in medicine is one of the main forms of treatment for patients with cancer and related diseases. For cancer treatment purposes, the radiation treatment planning process is complex and involves multiple steps and a number of technologies (1). The treatment planning system (TPS) is used to determine the dose distribution that will result in the body from selected incident radiation beams. The optimum radiation beam arrangement that will provide adequate coverage of the malignant tissues while minimizing the dose to critical normal tissues will be selected. Once the beam arrangement is selected, the radiation dose is calculated throughout the volume of interest by the TPS. The TPS also provides a permanent record of the dose delivered to the patient. This information is potentially needed in the event of further treatments or for retrospective or prospective clinical studies. As part of the implementation of sophisticated radiation therapy technology into clinical practice, it is important to recognize that such technology has inherent risks if not handled and administered properly. Recent reviews of accidental exposures in radiation therapy (2, 3) provide some clear lessons that should be learned by professionals involved in prescribing, calculating and delivering radiation treatments. The International Commission on Radiological Protection (ICRP) has produced a report on the prevention of accidental exposures to patients undergoing radiation therapy (4). This report describes a series of severe accidents for illustrative purposes, discusses the causes and contributory factors of these events, summarizes the sometimes devastating consequences and provides recommendations on the prevention of such events. For the accidents associated with TPSs, it was concluded that major contributory factors include:

1. lack of understanding of the TPS;
2. lack of appropriate commissioning (no comprehensive tests);
3. lack of independent calculation checks.

The major issues that relate to TPS errors can be summarized by four key words (4):

i. Education; ii. Verification; iii. Documentation; & iv. Communication.

Education is required both at the technical and/or professional level in terms of the use of the TPS and at the organizational level with respect to institutional policies and procedures. A very important component of education relates to understanding the software capabilities and limitations. Especially relevant are issues that relate to dose calculation normalization procedures, treatment set-up parameters as used by the computer compared with the actual treatment machine, time or monitor unit (MU) calculations, and in-homogeneity corrections. A misinterpretation of any of these calculation procedures can potentially lead to significant treatment errors. In order to reduce the significant TPS error, an interactive teaching methodology using TPS has been initiated. Using this methodology in teaching can provide opportunities for deep learning, as they:

- allow the application of theoretical concepts to be demonstrated, thus bridging the gap between theory and practice,
- encourage active learning,
- provides opportunities for the development of key skills such as communication, group working and problem solving.
- increase students' enjoyment of the topic and hence their desire to learn.

Today, there are several commercialized TPSs used for extern radiation beam radiotherapy (5-7). However, PLUNC is successfully used for the education and training purposes (8-10). PLUNC has evolved over the years into a powerful planning tool that is comparable to any commercial available system, while providing the distinct advantage of being tremendously flexible, although proprietary dosimetry planning systems require much more time to design and implement than those commercially available. For more than 25 years, major efforts have been undertaken to develop and implement 3D treatment planning and delivery techniques in an effort to more effectively treat human cancers. The objectives of this study are to:

1. install and verify the PLUNC 3D TPS;
2. describe our initial experience with 3D TPS for educational purpose; and
3. discuss some of the challenges and issues of 3D planning.

## 3D RADIATION TREATMENT PLANNING SYTSTEMS

Treatment planning system (TPS) is the heart of radiation therapy (RT) systems and the key to improved patient outcomes. Once image datasets are loaded and the tumors are identified, the systems develop a complex plan for each radiation beam line route for how the therapy system will deliver radiation to the planning treatment volume (PTV). The software also computes the expected dose distribution in the patient's tissue, including variables such as tissue energy level penetration influences by the type of tissue the beam lines encounter (e.g., bone or lung vs. muscle). These systems also help navigate beam placement based on avoiding critical structures that are more sensitive to radiation in an effort to reduce collateral damage from the therapy. A brief description of different TPSs is highlighted in this section.

### Commercial 3D TPSs

The three major competitors in the field of 3D planning systems—Analytical Development Associates Corporation (ADAC), Computerized Medical Systems, Inc. (CMS), and Varian Medical Systems—are also attempting to provide increased user autonomy by offering customizable workspace layouts as well as hot-keys to expedite routing tasks (5-7).

#### Analytical development associates corporation (ADAC)

ADAC is a world leader in radiation therapy planning and nuclear medicine imaging. In 1996, ADAC acquired Geometrics, the producer of the Pinnacle 3D dosimetry planning system, thus spurring its radiation therapy planning business. ADAC was acquired by Royal Philips Electronics of Amsterdam in December 2000.The Pinnacle treatment planning system shares some common features with other commercial software.

**Computerized medical systems, inc. (CMS)**

CMS is headquartered in St. Louis, Missouri, and markets the most-used 3D planning system in the world (FOCUS), with over 1000 systems currently installed. Being a worldwide leader in radiation treatment planning (RTP) systems, CMS has recently developed XiO, a 3DRTP system that CMS claims offers advanced functionality and the highest rated user of any commercial system.

**Varian medical systems**

Eclipse is Varian's version of a 3D treatment planning system that offers many similarities as other commercially available systems, 8 including a distinct advantage of being able to be installed and functional in much less time than in-house platforms.

The following other commercial 3D software available on the treatment planning systems (5-7):

**Brainlab**

Brainlab's iPlan RT treatment planning offers efficient clinical work flows and provides more treatment options for clinicians to choose from. Its image features offer time-saving pre-planning steps, such as automatic image fusion and fast organ definition and contouring. The Brainlab Monte Carlo Dose Calculation software is a high-performance algorithm designed for fast, precise radiation therapy dose calculations.

**Elekta**

Elekta's Monaco system offers treatment planning for IMRT, volumetric modulated arc therapy (VMAT) and stereotactic body radiation therapy (SBRT). Monaco features innovative biological cost functions with multi-criteria constrained optimization, a leaf sequence optimizer and a robust Monte Carlo dose calculation algorithm.

**Philips**

Pinnacle is designed for small and mid-size centers as an affordable server-class system that provides access from virtually any location. The system is also scalable so it can grow with a center's needs. It can support centers with up to three linear accelerators (LINACs). Floating licenses allow a Pinnacle³ user to have unlimited number of access points.

**Prowess**

The Panther 3D Conformal Therapy system is designed to improve efficiency. It operates on the user-friendly Windows platform, allowing the fast generation of treatment plans due to the familiar Windows look and feel and the vendor's intuitive user interface. Panther supports Siemens virtual wedges, and photon and electron beams can be combined.

**Ray Search**

Ray Station has created its own Ray Search proprietary system. The core of the system is the ORBIT software framework, which is currently used for optimization of IMRT, VMAT and 3-D conformal radiotherapy (3-DCRT). Ray Station has been designed for 4-D adaptive radiation therapy as a built-in generic feature and it incorporates the latest techniques for proton therapy.

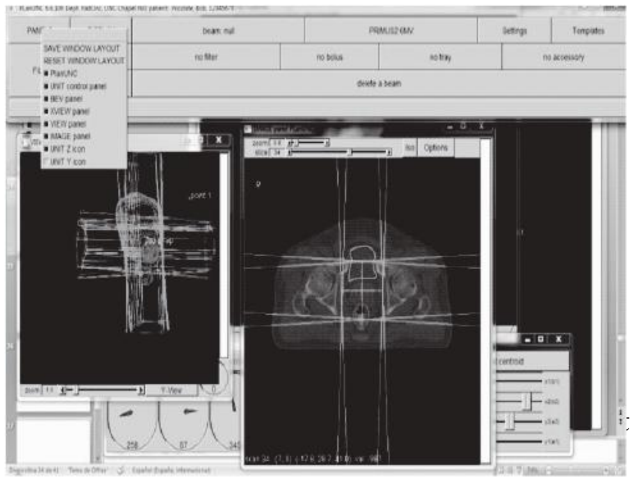
**Educational PLUNC 3D treatment planning system**

The University of North Carolina at Chapel Hill began developing the PLUNC system in 1985. PLUNC is also used at Duke University and the University of Chicago, and its longevity is mostly due to the system's flexibility. In its preliminary stages, PLUNC was a 2D planning system that had many limitations. Beginning in 1996, PLUNC became involved in clinical applications (10). PLUNC still exhibits many similarities with commercial systems because there are key functions that must be performed to accurately plan any radiation external beam treatment. Some of these mainstream features include a fully divergent beam's-eye-view (BEV) display that aids medical the best view of the target volume, and assists in the design of shielding blocks. Other generic features include being able to produce integrated DRRs, effective plan comparison tools, DVHs, and generation of volume and surface images in a wire-frame or smooth rendering format. Computer programming experts, medical physicists, and dosimetrists are able to continually add new features to modify the software's functionality to ensure optimal patient care. This is especially important in research and education institutions because their main goal is to discover more effective methods of radiation treatment, which often requires new or modified treatment planning methods (1). Commercially available, closed systems have features set by the manufacturer and make it difficult to fulfill research needs (5-7). A major disadvantage of commercial systems is that users do not have access to the programming source code, resulting in significantly limited clinical and technological flexibility. As an alternative, in-house systems such as Plan-UNC (PLUNC) (4) offer optimal flexibility that is vital to research institutions and important to treatment facilities.

## METHODOLOGY

### PLUNC 3D TPS installation

Plan UNC, or PLUNC as it is known familiarly, is a portable, adaptable, and extensible set of software tools for Radiotherapy Treatment Planning (RTP) that has been under active development in the Department of Radiation Oncology at the University of North Carolina (UNC) since 1985. Today, 3D systems have made it possible to more precisely localize tumors in order to treat a higher ratio of cancer cells to normal tissue. Its features include graphical tools for contouring anatomical structures, virtual simulation, dose calculation and analysis, and Intensity Modulated Radiation Treatment (IMRT) planning. PLUNC is built on the principles of fast, light programming -- complex solutions done simply by specific (non-general) but extensible code. The password protected website (10) and installed in the i7 core processor based personal computer for windows operating system. All necessary data and image files were installed and tested as per PLUNC operating manual. In Figure 1 a screen shot from the treatment planning system is shown.



The current PLUNC tools encompass the full range of RTP External Beam functions including image importing and processing, virtual simulation, dose calculation, plan evaluation, and planning for intensity modulated radiotherapy. PLUNC source code and related software are licensed without fee to support research involving new methods for planning and delivering radiation therapy, and to support RTP training for physicists, radiation therapists, and radiation oncology residents.

### Treatment Plan Analysis

In cancer treatment, external photon beam radiotherapy is usually carried out with multiple radiation beams in order to achieve a uniform dose distribution inside the planning target volume (PTV) and a dose as low as possible in healthy tissues surrounding the target, i.e. organ at risk (OAR).Recommendations regarding dose uniformity, prescribing, recording, and reporting photon beam therapy are set forth by the International Commission on Radiation Units and Measurements (ICRU). The ICRU report 50 (11) recommends a target dose uniformity within +7% and –5% relative to the dose delivered to a well-defined prescription point within the target.

When the radiation dose to a given volume is prescribed, the corresponding delivered dose should be as homogeneous as possible. Due to technical or anatomical reasons, some heterogeneity in the PTV has to be accepted. Parameters to characterize the dose distribution within a volume and to specify the dose are:

- Minimum target dose;
- Maximum target dose;
- Mean target dose; and
- Reference dose at a representative point within the volume.

The PLUNC 3D TPS was used to develop a radiation treatment plan typical prostate cancer patient to teach the medical physics students in the class room. The radiation treatment plan was then analyzed in the light of ICRU recommendations. The radiation treatment planning process consists of:

1. CT scans, volume definitions, localization of tumor and Organs-At-Risk (OARs).
2. Optimization of beam size effect, energy and placement.
3. Dose calculation/ treatment plan evaluation.

Three-dimensional treatment planning broadly refers to a variety of tools and procedures that facilitate the use of 3D data during the planning process. Different approaches to this process have been taken. A brief outline of the process is as follows:

1. Three-dimensional imaging (e.g. CT) is obtained with the patient in an immobilization device that is used throughout treatment. A reference coordinate system is defined and marked on the immobilization device (and, possibly, on the patient as well).
2. Structures of interest, targets, and normal tissues are identified on the images.
4. Treatment-planning software PLUNC is used to view the 3D relationship between structures of interest from any direction.
5. Beam orientations are selected and beams are shaped, based on the projection of the structures of interest as seen along the beam's-eye view.
6. Doses are calculated and adjustments in beam weights, wedges, blocks, and beam orientations are made as desired in an iterative fashion.
7. Digitally reconstructed radiographs (DRRs) of each beam are generated (including the block shape and desired structures) and can be used in lieu of physical simulator films.

## DISCUSSION

### CT scans, volume definitions, localization of tumor and OARs

The definition of tumor and target volumes for radiotherapy is vital to its successful execution. This requires the best possible characterization of the location and extent of tumor. There are three main volumes in radiotherapy planning. The first is the position and extent of gross tumor, i.e. what can be seen, palpated or imaged; this is known as the gross tumor volume (GTV). Developments in imaging have contributed to the definition of the GTV. The second volume contains the GTV, plus a margin for sub-clinical disease spread which therefore cannot be fully imaged; this is known as the clinical target volume (CTV). It is the most difficult because it cannot be accurately defined for an individual patient, but future developments in imaging, especially towards the molecular level, should allow more specific delineation of the CTV. The CTV is important because this volume must be adequately treated to achieve cure. The third volume, the planning target volume (PTV), allows for uncertainties in planning or treatment delivery. It is a geometric concept designed to ensure that the radiotherapy dose is actually delivered to the CTV. The PTV depends on the precision of such tools as: immobilization devices and patient positioning lasers. Figure 2 shows the principal volumes related to 3D RPT, defined by the International Commission on Radiation Units (ICRU)(11).Internal Target Volume(ITV) is the margin given around the CTV to compensate for all variations in the site, size and shapes of organs and tissues contained in or adjacent to CTV. Irradiated volume (IR) is the total irradiated volume adjacent to total volume (TV).

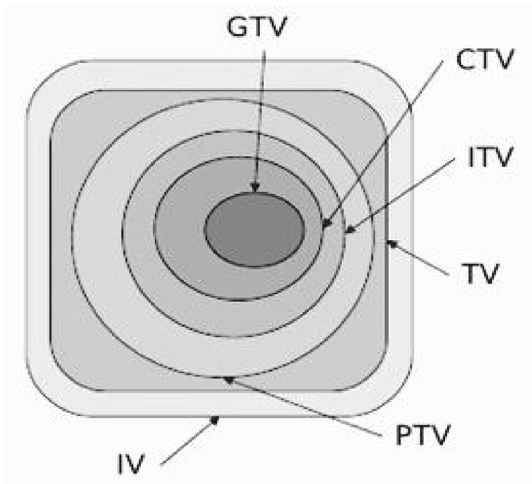



**Figure 2. Regions of irradiated volume.**

**Dose calculation/ treatment plan evaluation**

Radiotherapy planning must always consider critical normal tissue structures, known as OAR (1). It is an organ whose sensitivity to radiation is such that the dose received forma a treatment plan may be significant compared to its tolerance, possibly requiring a change in the beam arrangement or a change in the dose. Figure 3 shows a 2D view of computed tomography image for prostate cancer patient: the main anatomical structures are: bladder, tumor (PTV), rectum (12). External photon beam radiotherapy is usually carried out with multiple radiation beams (Figure 4) in order to achieve a uniform dose distribution inside the target volume (PTV) and a dose as low as possible in healthy tissues surrounding the target.

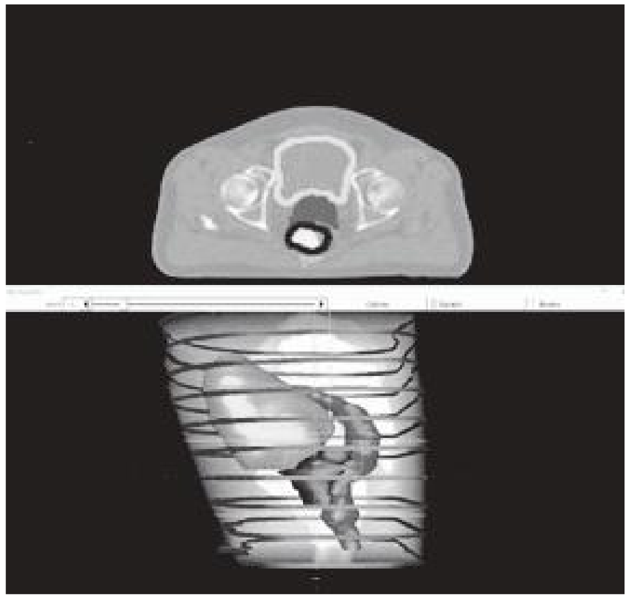


**Figure 3. 2D view of computed tomography image for prostate cancer patient: the main anatomical structures: bladder, tumor (PTV), rectum.**

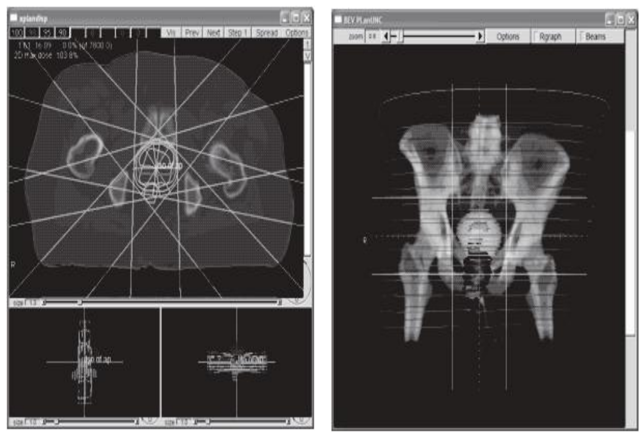


**Figure 4. Multiple radiation beams with PLUNC 3D TPS.**

Evaluating the radiation treatment planning results the students learn to use a plot of a cumulative dose-volume frequency distribution, known as a dose-volume histogram (DVH) (1, 13-16). DVH results for the students' shows graphically summarized the simulated radiation distribution within a volume of interest (PTV or OAR) of a patient, which would result planned radiation treatment plan. Also using DVH students have a possibility to compare treatment plans for the same patient by clearly presenting the possible uniformity of the dose distribution in the target volume and any hot spots for normal organs or healthy tissues.

DVHs can be compared, scaled, and viewed in differential or cumulative modes (Figure 5).

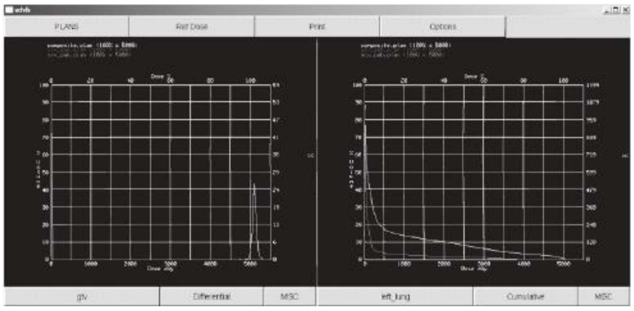



**Figure 5. Differential and cumulative DVH of a treatment plan.**

When the dose to a given volume is prescribed, the corresponding delivered dose should be as homogeneous as possible. Due to technical or anatomical reasons, some heterogeneity in the PTV has to be accepted. Parameters to characterize the dose distribution within a volume and to specify the dose are: Minimum target dose; Maximum target dose; Mean target dose; Reference dose at a representative point within the volume. Recommendations regarding dose uniformity, prescribing, recording, and reporting photon beam therapy are set forth by the International Commission on Radiation Units and Measurements (ICRU). The ICRU report 50 recommends target dose uniformity within +7% and -5% relative to the dose delivered to a well-defined prescription point within the target. For deeper lesions, a combination of two or more photon beams is usually required, if it is needed to concentrate the dose in the target volume and spare the tissues surrounding the target as much as possible. The Figure 6 shows the geometry of the fields and the wedges selected by the student (12). Dose distributions for multiple beams can be normalized to 100 % at $z_{max}$ for each beam or at isocenter for each beam. It allows that each beam can be equally weighted.

PLUNC's flexible dose modules are also important and offer distinct advantages over closed systems. Although commercially available systems are costly, they can be quite appealing because they require substantially less time to implement than systems developed in-house. However, they are severely limited in terms of providing flexibility to accommodate advancements in treatment methodology and technology. Among the most notable deficiency is the fact that commercial systems are not capable of having their computer code altered and hence pose a problem when changes are necessary to satisfy clinician requests and technological progression. Conversely, proprietary systems (such as PLUNC) offer a dynamic alternative and satisfy the adaptability dilemmas mentioned above. Source code can be relatively easily manipulated to produce real-time changes in system function to meet user demands. If new algorithms emerge, PLUNC will be able to accommodate them by adding, deleting, or changing source code relevant to the dose modules. In house systems are especially recommended for research institutions where these capabilities are paramount to progress the field of medical dosimetry. Today there is now several commercialized planning system competitors used for external beam radiation therapy. Despite this today PLUNC is successfully used for the education and training purposes (8-10, 12) and successfully use PLUNC as 3D TPS for educational purposes. The introduction of 3D planning presents new challenges to existing quality assurance systems. These need to be addressed to maintain patient safety. Based on others experience, the benefits, challenges, and hazards of routine 3D treatment planning should be considered (15).

## CONCLUSION

PLUNC 3D TPS has been installed and implemented successfully for research and education purpose in the field of medical physics. PLUNC 3D TPS has been used for practical demonstration for medical physics students and students get an idea about planning and dosimetry evaluation process. PLUNC is an open source in-house treatment planning system from the University of North Carolina. PLUNC is freely distributed to the field of radiation oncology for research and educational use. Advantages for having a non-commercialized treatment planning system for education purposes means safe, and realistic education process; also students do not need to use clinical equipment used in a daily clinical environment. Moreover, it is needed less time to spent learning daily clinical skills after graduation starting to work in real clinical environment. However, compared to the commercialized planning systems, PLUNC today is useful for students' education and training, for its flexibility, this system does not require any annual contracts; it means that PLUNC 3D TPS is available to other institutions for research and educational purposes under special license agreement. It is also expected that the PLUNC 3D TPS could be used for M Sc/Ph D thesis works of students from Medical Physics discipline.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