PRACTICAL LEARNING FOR EXTERNAL BEAM RADIOTHERAPY TREATMENT PLANNING USING OPEN SOURCE PLANNERS

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ABSTRACT

The therapeutic use of ionizing radiation in medicine is one of the main forms of treatment for patients with cancer and related diseases. In radiotherapy, a potentially lethal dose of radiation is administrated to patients. Thus, well-designed radiotherapy procedures must be adopted to avoid misadministration and exposure of non-patient individuals (medical staff, visitors or general public). One of the most important issues in radiation safety in radiotherapy is the optimization of the treatments, so one obtains the desired level of accuracy between the medical prescribed doses and the real doses during the treatment. The present work is focused on the practical learning of the treatment planning for External Beam Radiotherapy (EBRT) using open source and free planners. The learning methodology has been developed to teach future professionals in radioprotection in the medical field. The students learn the protocol and techniques with tools very similar to the real ones. They also learn basic concepts as isodose curves and the dose volume histogram, always from the point of view of the ALARA approach.

1. Introduction

The present work is focused on the practical learning of the treatment planning for External Beam Radiotherapy (EBRT) using open source and free planners. The learning methodology has been developed to teach future professionals in radioprotection in the medical field. The students learn the protocol and techniques with tools that are currently used in hospitals. They also learn basic concepts as isodose curves and the dose volume histogram, always from the point of view of the ALARA approach. This learning methodology is based in the case studies.

Case studies have long been used in business schools, law schools, medical schools and the social sciences, but they can be used in any discipline when instructors want students to explore how what they have learned applies to real world. Problems or cases come in many formats, from a simple “What would you do in this situation?” question to a detailed description of a situation with accompanying data to analyse. Whether to use a simple scenario-type case or a complex detailed one depends on the course objectives (1).

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.

Case studies can be used not only to teach concepts and content, but also process skills and critical thinking.

In this frame, the present work is focused on the practical learning of the treatment planning for External Beam Radiotherapy (EBRT) using open source and free planners. In particular, the case studies considered in this work is a prostate cancer patient.

The most crucial step in any form of radiation treatment planning is the accurate registration of the tumor volume. If this step is not correctly done, the radiation portals may include too much normal tissue, miss part of the tumor, or both. And once this error has been committed, no amount of treatment-planning sophistication can make up for it. This registration can be aided in various ways, for example, by placing opaque markers either internally, or on the patient's surface so as to identify areas of concern. Nevertheless, experience suggests that manual definition of the tumor on the simulation film is prone to error. For example, a review of an important national cooperative trial for the treatment of lung cancer revealed that the target volume was incompletely covered more than 20% of the time even though all of these patients had had preplanning diagnostic CT scans (2). Similar, or even higher error rates may occur in other anatomic locations.

2. Radiation Protection

The therapeutic use of ionizing radiation in medicine is one of the main forms of treatment for patients with cancer and related diseases. In radiotherapy, a potentially lethal dose of radiation is administrated to patients. Thus, it is fundamental to apply radiation protection principles to radiotherapy environment. There are two aims of radiation protection, one consists in the prevention of deterministic effects (not including those that are intentionally produced, but doing so with those which are not intended) and on the other hand, the reduction of the probability of stochastic effects.
According to the ICRP recommendations, the system of radiation protection is based upon 3 fundamental principles: Justification of practices, limitations of doses and optimization of protection and safety (3). Regarding to the first one, there is a basic need of evaluation of the benefits of the radiation, this is due to the fact that even the smallest exposure is potentially harmful, so the risk must be offset by the benefit. This fact is linked to the second principle; the dose must be limited.
The optimization in the context of the radiotherapy is focused in two main points of view, the optimization of the dose (in the sense of optimization) and the optimization of the protection of all the public (staff, patients and rest of public). The optimization of the protection is based on the ALARA (As Low As Reasonably Achievable) principle, and this concept links the optimization principle with the rest of the radiation protection system.
ALARA is an acronym used in radiation safety for "As Low As Reasonably Achievable." The ALARA radiation safety principle is based on the minimization of radiation doses and limiting the release of radioactive materials into the environment by employing all "reasonable methods. The ALARA concept is an integral part of all activities that involve the use of radiation or radioactive materials and can help prevent unnecessary exposure as well as overexposure. The three major principles to assist with maintaining doses "As Low As Reasonably Achievable" are:

- Time: Reducing the time of exposure can directly reduce radiation dose. Dose rate is the total amount of radiation absorbed relative to its biological effect. Dose rate is the rate at which the radiation is absorbed. Limiting the time of radiation exposure will reduce the radiation dose.
- Distance: Increasing the distance with the radiation source the exposure will be reduced by the square of the distance
- Shielding: Lead or lead equivalent shielding for X-rays and gamma rays is an effective way to reduce radiation exposure. There are various types of shielding used in the

reduction of radiation exposure including lead aprons, mobile lead shields, lead glasses, and lead barriers. When working in radiation areas it is important to use shielding.

3. PLanUNC

Three-dimensional (3D) treatment planning is an integral step in the treatment of various cancers when radiation is prescribed as either the primary or adjunctive modality, especially when the gross tumor volume lies in a difficult to reach area or is near to critical bodily structures. 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. Over the past 15 years, these systems have evolved into complex tools that utilize powerful computational algorithms that offer diverse functional capabilities, while simultaneously attempting to maintain a user-friendly quality. 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. Despite this weakness, commercially available systems have become the norm because their commissioning time is significantly less and because many facilities do not have computer experts on-site.

PLanUNC, or PLUNC as it is known familiarly, is a portable, adaptable, and extensible set of software tools for 3D 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.

PLUNC, is an adaptable and extensible software system for RPT. Its features include graphical tools for contouring anatomical structures, virtual simulation, dose calculation and analysis, and Intensity Modulated Radiation Treatment (IMRT) planning. It is suitable for External Beam Photon/Electron therapy, but currently contains no LDL/HDL or Proton code (easy to add). PLUNC is built on the principles of fast, light programming -- complex solutions done simply by specific (non-general) but extensible code. In Figure 1 a screenshot from the treatment planning system is shown.

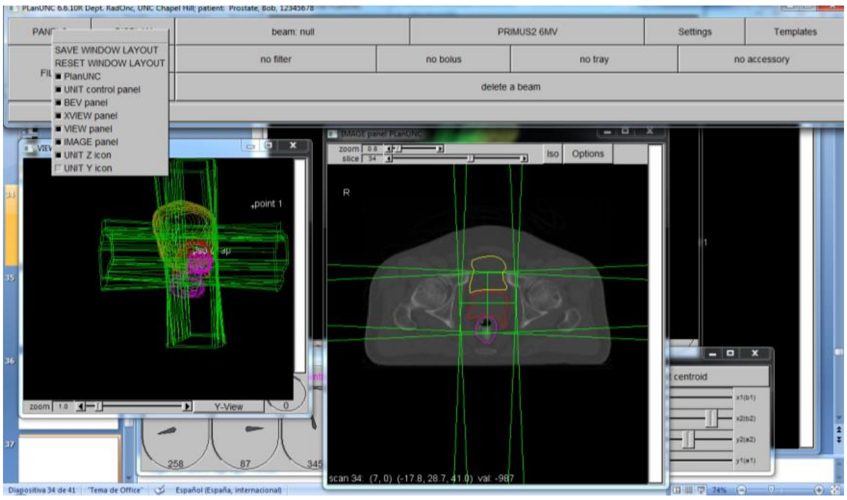

Fig 1. PLUNC screenshot from treatment planning system

The current UNC 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 qualified facilities to support research involving new methods for planning and delivering radiation therapy, and to support RTP training for dosimetrists, physicists, radiation therapists, and radiation oncology residents.
Today there are several commercialized planning system competitors used for extern beam radiotherapy. However, PLUNC is successfully used for the education and training purposes.

4. PRIMO

PRIMO is a computer software that simulates clinical linear accelerators (LinAc's) and estimates absorbed dose distributions in water phantoms and computerized tomographies (5). PRIMO is an adequate software to work with for students due to different reasons: First, it is a free software, so the students can install it in their computers and perform different simulations. Then, this engine is based on the Monte Carlo code PENELOPE (2), which is a software distributed by the OECD Nuclear Energy Agency (NEA). Thus, they work with a software based on an official code, using accurate physics but with a significantly computation time reduction due to variance-reduction techniques.
PRIMO can simulate Varian and Elekta linacs including multileaf simulations, and one can get absorbed dose distributions from a water phantoms or this can be provided in computerized tomographies in DICOM format. The user can store different fields in intermediate phase-space, and one can go through the set up case steps by working in a graphical interphase.

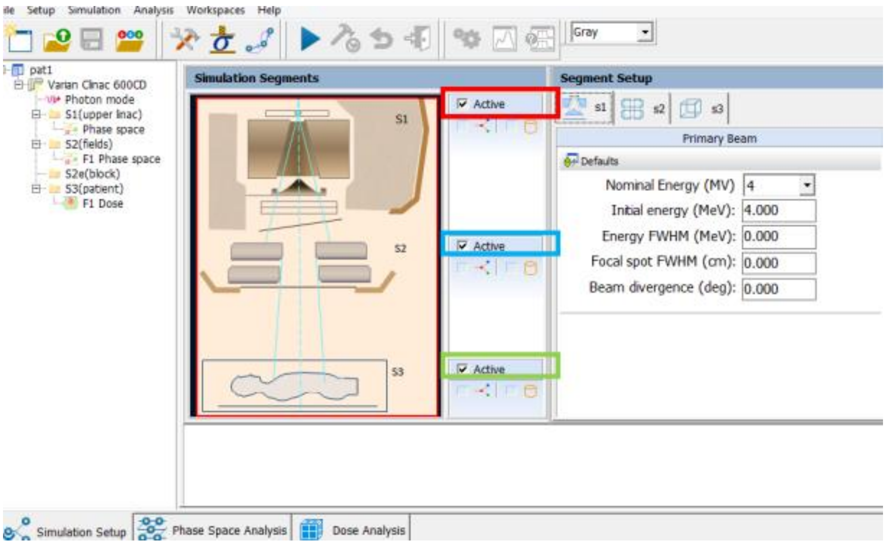

Fig 2: PRIMO software main window

By using these both codes, the students are working with a deterministic code and with a code based on Monte Carlo, learning also advantages and disadvantages of each code.

6 RESULTS

The treatment planning process consists of:

1. CT scans, volume definitions, localization of tumour and Organs-At-Risk (OARs) (critical structures).
2. Optimization of beam size effect, energy and placement.

3. Dose calculation/ treatment plan evaluation.
4. Preparation of treatment data.

Following sections present this process for both software. First, planning process simulated with PlunC is presented. In this section, a detailed description of the procedure followed by the students is presented. Hereafter, a brief presentation of the same performance but made with PRIMO is shown.

6.1 PLUNC

6.1.1. CT scans, volume definitions, localization of tumour and OARs

The definition of tumour and target volumes for radiotherapy is vital to its successful execution. This requires the best possible characterisation of the location and extent of tumour. Diagnostic imaging, including help and advice from diagnostic specialists, is therefore essential for radiotherapy planning. There are three main volumes in radiotherapy planning. The first is the position and extent of gross tumour, i.e. what can be seen, palpated or imaged; this is known as the gross tumour 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 3 shows the principal volumes related to 3D RPT, defined by the International Commission on Radiation Units (ICRU).

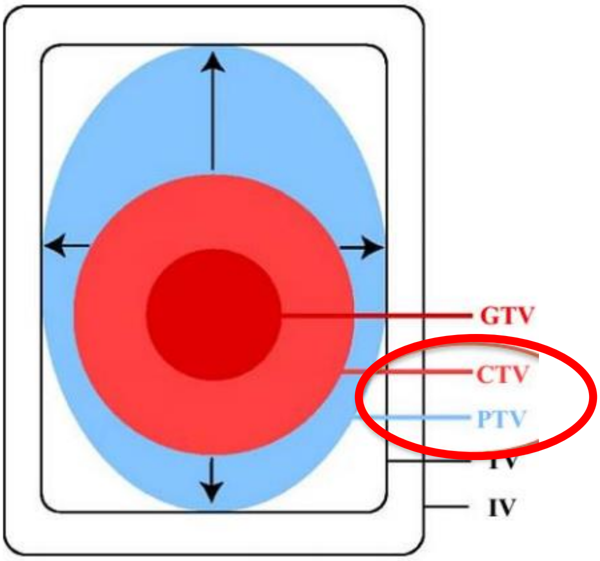

Fig 3. Regions of irradiated volume

Radiotherapy planning must always consider critical normal tissue structures, known as OAR. 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, tumour (PTV), rectum.

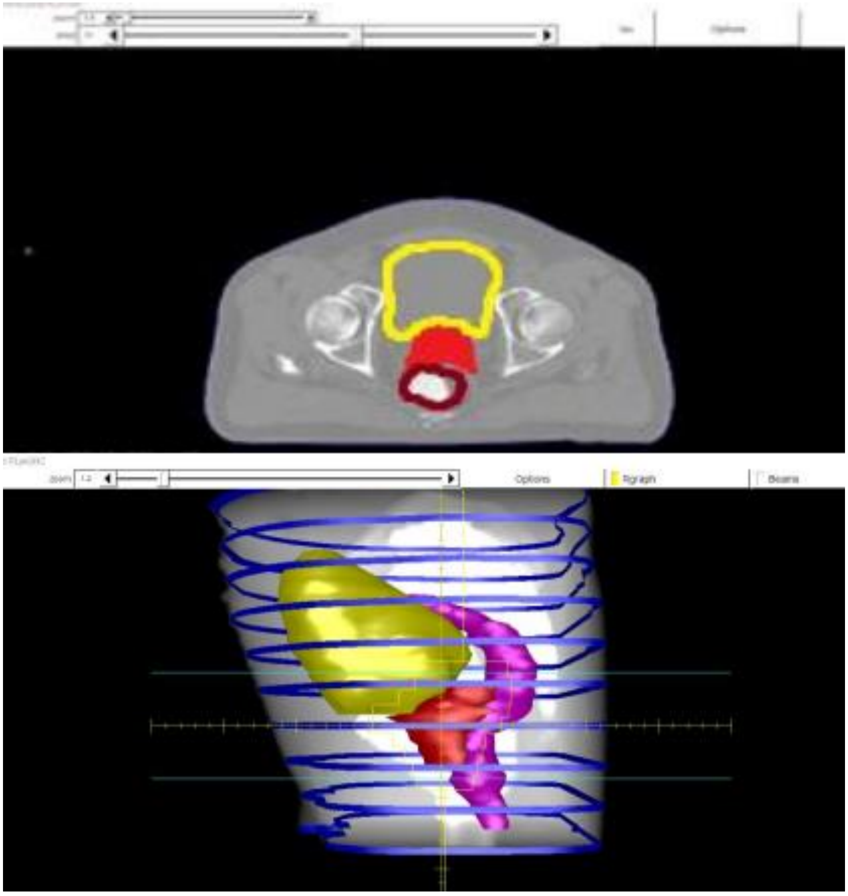

Fig 4. 2D view of computed tomography image for prostate cancer patient.

6.1.2 Optimization of beam size effect, energy and placement.

External photon beam radiotherapy is usually carried out with multiple radiation beams 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.

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 a 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 5 shows the geometry of the fields and the wedges selected by the student.

Weighting and normalization: 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.

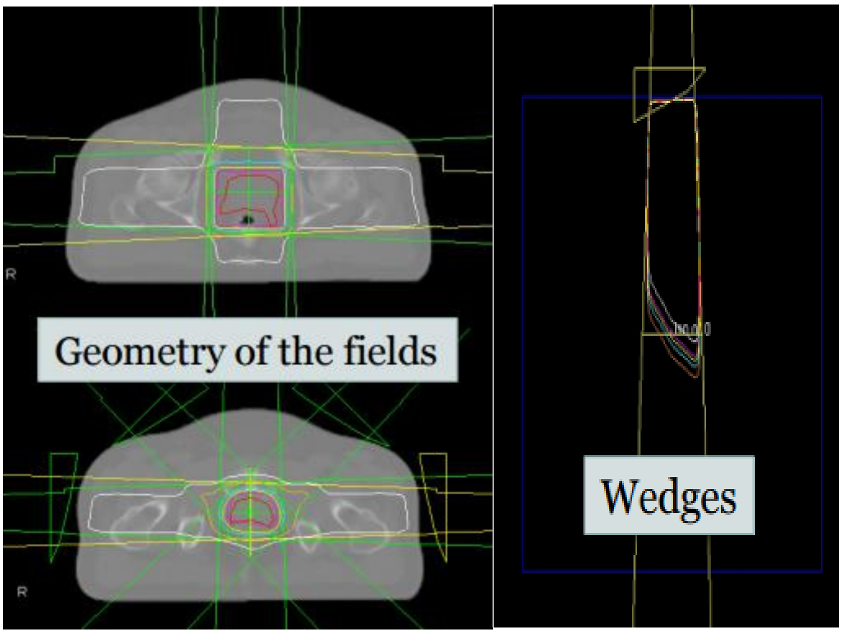

Fig 5. Geometry of the fields and the wedges selected by the student

6.1.3 Dose calculation/ treatment plan evaluation.

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.

Evaluating the radiation treatment planning results the students also learn to use a plot of a cumulative dose-volume frequency distribution, known as a Dose-Volume Histogram (DVH). 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 (5).

The DVH data can be analysed with a TPS for the same "patient", with evaluation of the single plan or even comparative dose distributions for few different plans (Figure 6).

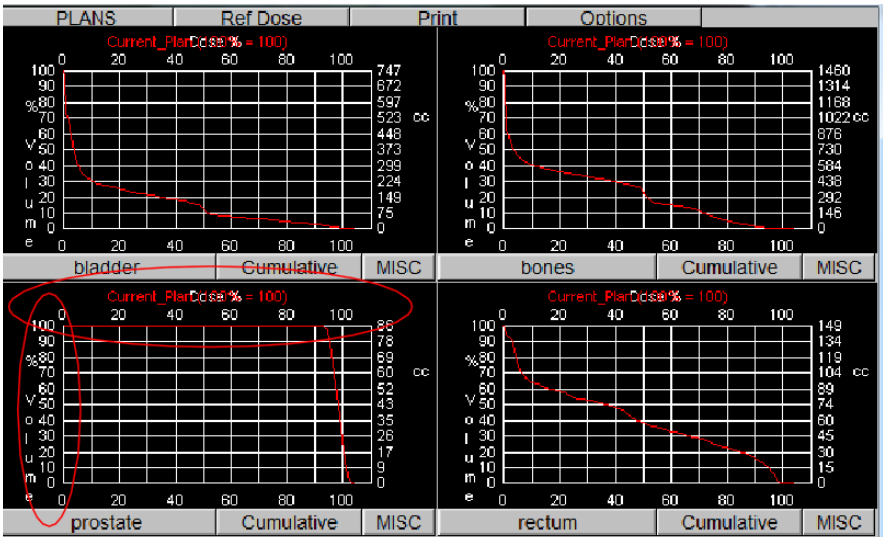

Fig 6. Results obtained by the students.

The DVH is an important tool that specifies each dose value, the fraction of a structure that receives a certain amount of the dose, dose distribution of irradiated volumes, ensuring the better protection of critical structures.

6.1 PRIMO

6.1.1. CT scans, volume definitions, localization of tumour and OARs

First, they need to import the CTA images. Then, they will be able to see a reconstructed voxelized geometry for the estimation of the dose. It is also necessary to convert to mass densities from Hounsfield number calibration curve and to associate each voxel to one material.

In order to define the planning target volume (PTV), the students can delineate in the 2-D views, reproducing the same process explained in the previous section.

Fig 7: 2D views of computed tomography image for prostate cancer patient in PRIMO

6.1.2 Optimization of beam size effect, energy and placement.

Once the students know the main volumes taken into account in radiotherapy planning and they know how to define the critical tissues (OAR's), now they also have to set up the accelerator, the beam and the collimator.

This software allows the students to define different accelerators from Varian and Elekta. Then, they have to select also the operation mode, where they can choose between photon or electron. Once the linac has been selected, the nominal energy has to be specified, along with the positioning of the jaws, multileaf collimators or electron applications.

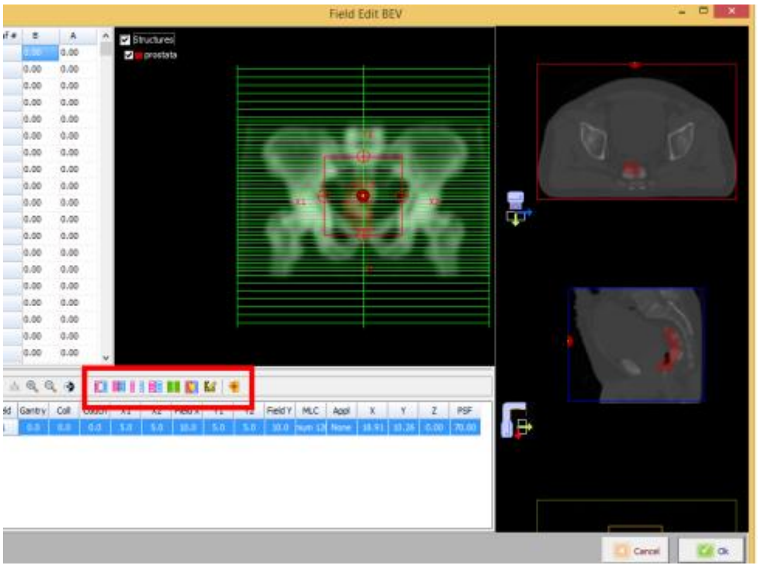

Fig 8: Selection of the collimator in PRIMO

6.1.3 Dose calculation/ treatment plan evaluation.

One of the advantages of PRIMO is that it allows to analyse not only dose distributions but also the spatial distribution of particles of the energy spectrum in 2-D planes called phase—space planes. In this work a phase-space has been defined immediately at the exit of the collimator. Dose distributions are seen by superimposing the results to the computerized tomography. The DVH is also plotted so that the students can check if their treatment plan.

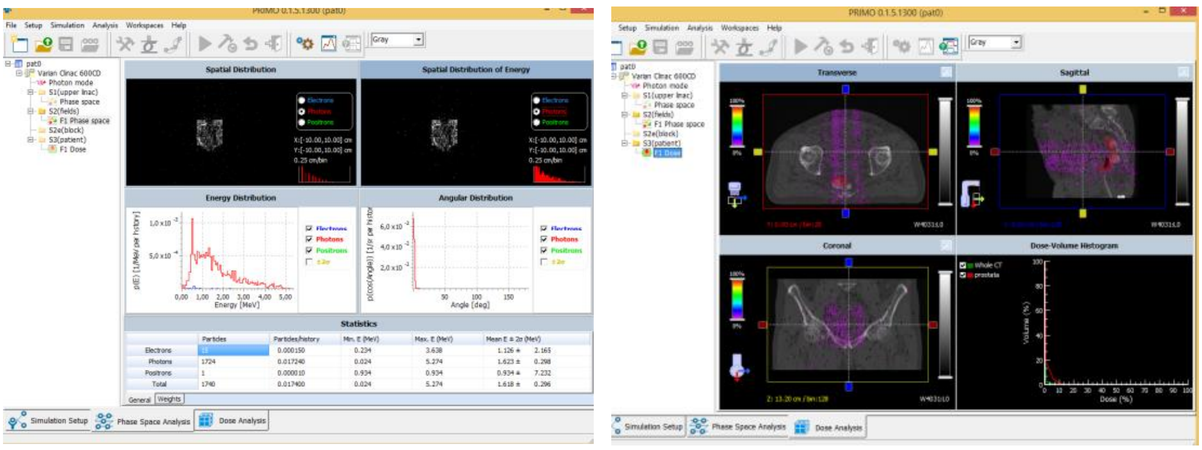

Fig 9: Phase –space view (left) and dose distribution view (right)

The main advantages using PLUNC and PRIMO with students are:

- Safe, and realistic education process;
- The clinical equipment, which is used in a daily clinical environment, is not necessary;
- Before starting work in a hospital it helps for future professionals and demo “patients” to find and discuss the most proper and optimized radiation treatment plan and irradiation method/technique.
- With such knowledge and practice it is easier to integrate the new practitioner in real clinical environment after graduation;
- it is needed less time to spent learning clinical skills like standard radiotherapy techniques used for patient radiation treatment planning.

7. CONCLUSSIONS

- ✓ Students get an understanding about planning process.
- ✓ 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 treatment planning software is available to other institutions as mentioned for research and educational purposes.
- ✓ Advantages for having a non-commercialized treatment planning system for education purposes means safe, and realistic education process; also you do not need to use clinical equipment used in a daily clinical environment; it is needed less time to spent learning daily clinical skills after graduation starting to work in real clinical environment.

8. References

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