INTERNSHIP AT HOSPITAL CLÍNIC DE BARCELONA IN HOSPITAL RADIOPHYSICS

Student: **Hug Sala Oriol**

Degree: **Physics**

Company or institution: **Hospital Clínic de Barcelona, Hospital Radiophysics Service**

Tutor: **Cristian Candela Juan**

Period of time: **From September 2024 to December 2024**

Report delivery date: 28^{th} **January 2025**

I. Introduction

Hospital Clínic de Barcelona is a public consortium between the Catalan government and the University of Barcelona, specialised in a wide range of disciplines such as oncology, cardiology, neurology, among others, all of which are recognised worldwide. This recognition comes from the presence of this institution in multiple rankings both at state and world level based on indicators of efficiency, quality and reputation. Excellence is present in its three main areas of action: assistance, teaching and research.

As for care work, the Hospital rallies excellence through the quality of assistance, the well-being and satisfaction of the patient, innovative capacity, personalized attention and efficiency in the use of resources for the sustainability of a quality public health system.

The hospital's mission extends beyond patient care to include the training of future healthcare professionals. The educational work, linked to the Faculty of Medicine and Health Sciences of the University of Barcelona, involves not only the teaching of undergraduate and postgraduate degrees but also the training of residents and the organization of internal and external continuing education activities. It is one of the most state demanded centers by students to carry out their training.

In addition, the development of innovative techniques is a key element in the hospital's daily activity. It is recognized for its strong commitment to scientific research and innovation, being the center with the most scientific production in Spain and is among the top 25 worldwide. Supports cutting-edge studies in molecular biology, precision medicine, and advanced imaging technologies, contributing significantly to global medical advancements.

Among all the mentioned activities carried out by the hospital, those related to hospital radiophysics and radiotherapy stand out, of which it is a pioneer.

Hospital radiophysics is a branch of medicine that uses radiation for curative purposes, especially for diagnosis and treatment. This implies a variety of fields such as imaging technologies (CT and MRI), safety for both the staff and patients from radiation exposure, calibration and maintenance of the equipment, treatment plans optimization... The activity developed by the Radiophysics team of the Hospital Clínic de Barcelona strictly complies with these activities to maintain the institution's standards of excellence. This is achieved through the use of advanced technologies, such as stereotactic body radiotherapy (**SBRT**)[1], intensity-modulated radiotherapy (**IMRT**)[2], volumetric modulated arc therapy (**VMAT**)[3] and brachytherapy[4] to maximize treatment precision while minimizing side effects; combined with the guarantee that all equipment, such as linear accelerators (**LINAC**)[5] and imaging devices, is regularly calibrated and functions optimally.

They also conduct rigorous quality assurance (**QA**) programs to verify that treatment plans meet the highest safety standards for each patient before their treatment starts.

II. Objectives

The main internship objectives are:

- Accompany the specialists in hospital radiophysics and/or the specialists in training (residents) in their care tasks to know the work areas of their speciality, and getting to know the rest of the service professionals and their care tasks.
- Develop a project that consists of the prediction of collisions between the gantry, the part that contains the tube that emits X-rays and rotates around the patient, with the patient itself.

III. Details of activities performed

A. Gaining insight into clinical radiophysics activities carried out by specialists

The tasks carried out by the department are many and varied. The dosimetry team is responsible for outlining the organs at risk (OARs) and the support structures, which is very important for the development of the tool as will be seen in the next section, and is added to the contour of the PTV, CTV and GTV[6] outlined by the oncologist. In external beam planning, depending on the mass and its characteristics, the physicists choses the appropriate technique such as IMRT, VMAT, SBRT, among others; and the isocenter is defined taking into account the target volume. Once the treatment is planned, the position of the beams (usually coplanar) is configured. The procedure is different if IMRT is used, for example, where the number of beams, their orientations and their angles must be defined; or VMAT, where continuous arcs are configured around the patient. Among the multiple fixed angle configurations, we find the Parallel Opposed Beams, these being at 180º from each other and being an easy and effective plan for central and symmetrical tumour masses, or the Tree-Field technique, containing an anterior beam (0º) and two oblique beams (120º and 240º), allowing the reduction of dose (Gy) in the posterior part of the tissues. In addition, the positions of the multi-leaf collimator (MLC) and its shape must be defined so that it fits the shape of the tumour, blocking radiation that would not affect the region of interest.

The oncologist will have previously prescribed the total dose that the patient will receive throughout the treatment and the number of days that will be in treatment. In addition, the doctor will impose restrictions on the dose received for those organs that, due to their location, may be affected and therefore considered at risk. Using advanced algorithms, Eclipse[7] calculates the distribution of the radiation dose within the patient's anatomy taking into account the configuration of the decided plan, the priority given to the restrictions and the dose of the PTV. With the suggested plan, the evaluation is carried out considering whether the entire PTV is irradiated, avoiding hot and cold spots (areas of excess or lack of dose), ensuring that the dose maximums are within the tumour, and checking that the affectation of healthy organs is minimal and within the limits established by the oncologist. This evaluation is carried out with the help of isodose curves and 3D dose distributions. In the first, checks are made to ensure that the dose in 95 % of the mass is not less than 95 % of the total dose delivered, and that in the organs at risk it does not exceed concentrations higher than those pre-established. In the 3D distributions, the position of the maxims and the isotropy of the dose received in each certain dose fraction (e.g. 45% and 105% of total dose) are checked. If these constraints are not met, the physicist may have to rerun the algorithms changing parameters such as the priority of the dose to certain organs or, in the worst case to reschedule the treatment or contact the oncologist to study a different one.

For example, in breast cancer treatments, depending on the particular shape and position of the breast, the two-beam plan irradiates the lungs and heart too much, exceeding the limits imposed. Therefore, it is necessary either to sacrifice a certain homogeneity of the dose received, or to exceed these limits for the organs at risk. If a readjustment of the beams and the MLC does not give better results, the oncologist is asked to choose between the two options described or to propose a new one. It may be necessary to suspend the treatment for lack of a solution if the case is extremely complex.

There is a technique for this type of cancer that allows the dose received by these two organs to be reduced without changing the configuration of the fields, known as Deep Inspiration Breath Hold (DIBH). In this technique, the radiation is delivered only at certain points during the patient's breathing cycle of inspiration and expiration allowing those organs to be less exposed to the radiation beam, or even move out of target.

Once approved, the plan undergoes QA to ensure safe and accurate delivery, checking for any mismatches between the calculated dose and the dose delivered to the detector. Irregularities in the patterns of the received dose are also sought, such as peaks or gaps in radiation at incorrect locations.

Furthermore, all kinds of problems with the equipment can arise before and during treatment. These include problems with the thermoplastic masks used to immobilise the head and neck in some treatments, collisions between the gantry and the patient or even with the equipment, for example the LINAC cooling system; as well as with the patient, for example if the situation were to arise where the treatment planning CT scan did not match the CT scan performed on-site or if the patient's positioning did not match the planning CT scan. It is also common for them to help all the technicians with problems that arise in the set of many procedures.

In addition to intervening in the treatment, the periodic calibration of the facilities and the implementation of new techniques are a responsibility of the physicist as well. The devices require extreme precision to perform their functions correctly, so periodically, with the help of mannequins and phantoms, adjustments are made so that they can continue to perform their tasks, for example, with laser systems for positioning or with the precision of the LINAC when delivering the dose at a specific point. As for new technologies, during the internship a new method called Identify, from Varian Medical Systems, has been tested. This software aims to replace the current system of positioning patients through lead markers, with a 3D surface imaging system that compares the patient's real-time surface contour with the reference image to ensure precise positioning. In addition, it performs all kinds of checks on the patient's clinical history, the coincidence of the planned treatment with the one carried out, the identity of the patient...

B. Elaboration of a tool for radiotherapy patient collision detection

At the beginning of the internship, the tutor explained a recurring problem during external radiotherapy treatments using linear accelerators. It is quite common that, depending on the area being treated, the gantry collides either with the patient or with the couch. In this situation, the treatment is interrupted instantly so neither the equipment nor the patient suffer damage; in fact, the instrument itself has a system enabled to avoid such collisions. The problem lies in the inconvenience of postponing the radiotherapy session, with all that this entails, but above all in the reprogramming of the entire treatment since it is often necessary to move the isocenter or attack the tumour with another configuration of the fields. All this complications could be avoided by simply analysing whether such a collision will occur before having the patient present. And although sometimes this already happens, since certain configurations of the couch and the patient denote a clear collision, there are many others that do not. This is the example of many breast or liver cancer treatments, which due to their location force the patient to have their arms raised, potentially leaving the elbow in the path of the gantry, or the need to use immobilizers or a wedge (placed on the patient's back to achieve a more inclined position). It is even more complicated to predict, by intuition, if the couch has a certain angle with respect to the perpendicular of the gantry's plane of rotation. To solve this problem, it was decided that a system had to be developed that could predict these collisions and allow the radiophysicist or dosimetrist in charge of configuring the treatment plan to be informed about those angles of the gantry trajectory that could potentially end in a collision. In this way, the professional could, in advance, study which fields to attack the tumour with and not rethink them after a collision once the appointment had been made and the installation reserved for the patient.

Although this tool has already been created by different commercial companies, the hospital did not have it. Therefore, after reading and analysing some papers on the subject with better or worse results and methodologies, the procedure to follow could already be intuited.

From the CT image of the patient obtained in the preparatory session and from which the entire treatment is planned, the dosimetry team contours and delimits the structures (the body and organs, the immobilizers and the couch) in order to begin the dose calculations on the PTV. From this task, a DICOM document is generated with the contoured structures that, when imported together with the CT image, serve as the basis of the developed tool. The image works as a canvas for the entire procedure, and although at first the pixel intensity was used, using the Houndsfield units, to detect if the trajectory was superimposed on areas of the image with the patient or other structures, in the final version it has no other function than to help understand the collision situation.

From the structures provided, masks are created by converting these structures into arrays of 2D coordinates indexed through the z coordinate. In this way, it is possible to classify all those parts of the image that would cause a collision and those that would not through a boolean operator assigning the value of 0 or 1. From the data entered by the user, these being the couch angle, the gantry radius and the collimator radius (the most prominent part and therefore the one causing the collision) the path of the gantry is configured in the form of a circle if the couch angle is 0º or 90º (negative if the rotation is clockwise), or an ellipse if it is between these values, and therefore is ruled by the following equation:

$$\frac{x - x_0}{a} + \frac{y - y_0}{b} = 1 \tag{1}$$

where x_0 and y_0 correspond to the displacement relative to the isocenter, and a and b are the semi-axes of the ellipse, related to the radius of the circumference through $a = rcos(\theta)$ and $b = r$

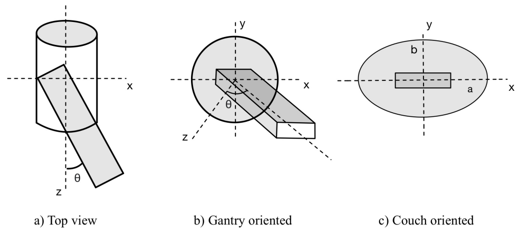

FIG. 1. Schematic of the relative position of the couch and gantry when θ is different than 0º or 90º, from three different perspectives.

From there, simply by superimposing the path on the masks over the image, the potential collision is detected, colouring the part of the path in red and returning the range of angles not accessible for the treatment.

The final execution is planned in three different approaches and it is intended that they are complementary. The first one deals with the collision analysis explained above for a mask configured by the sum of all the masks between a minimum z and a maximum z height specified by the user, and a step such as 1 cm. This allows to quickly determine if there will be a collision for the entire section to be treated. The second approach deals with the masks and analyses the collision for each of the masks between these two heights, giving rise to a layered analysis of the patient that is much less global but more specific. The third is reduced to the analysis of a single mask for a single z height, concentrating all attention on a specific layer of the patient.

From the synchronization of the three, a quick analysis can be obtained with the first method and, if positive, lead to layer by layer study using the second method to delimit the conflict zone. Finally, if user wanted to analyse a specific layer, the third method would allow to view the scene, confirming what had already been seen in the first but obtaining a much more specific image.

IV. General conclusions about accomplished work

The conclusions drawn from observing the activity of the hospital's radiophysics department and in particular of the radiophysicists, refer not only to the versatility of their work but also to its importance. Their work in the medical field and therefore for the patient is indisputable, as they are a key figure in the process of cancer treatment but also in radiodiagnosis. However, a large part of their merit is not so tangible and is in a certain way hidden from the eyes of anyone who has not been in the department. It is about the assistance and help offered to any specialist and technician, as the radiophysicist is a key part of the machinery of the department and without them there would be many more problems when carrying out medical functions normally and without delays.

As far as the development of the tool is concerned, the main objective has been achieved, as it not only predicts collisions and marks them on the CT image, but also detects at what angles they occur. In addition, it has been tested with different real medical cases of patients and the result has been positive. The results when changing the main variables tolerated by the program are presented below prior to the analysis of the cases in Figures 2,3,4,5:

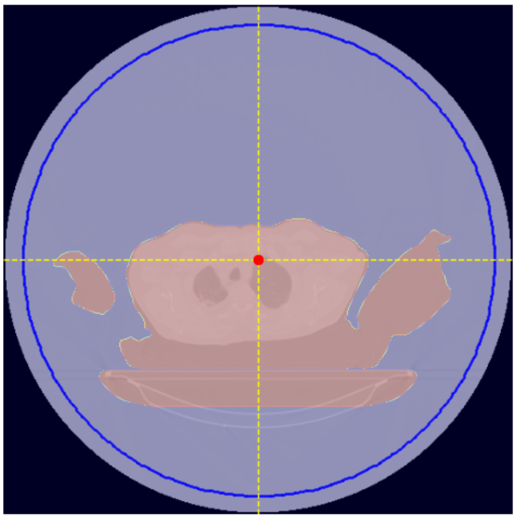

FIG. 2. CT image with mask applied, with the isocenter centered at the center and a couch angle of 0°.

Having presented the versatility of the tool in the face of the variation of its main variables, note that the same height $z = 150mm$ has been considered with respect to the origin defined by the dosimetrists when outlining the body, the results for the different patients can be displayed.

First, the cases are analysed as explained in previous sections, adding all the masks of the different z heights of interest and detecting if there is a collision in that sum. The same value for the parameters will be used for the first two cases (FIG. 6 and FIG. 7): displacement of (50, 100) mm and a couch angle of 0°, but the third is presented with different conditions (FIG. 8): displacement of (50, 20) mm and a couch angle of 30°. As it can be seen, the three results are wilfully different. For the third patient, the analysis would end here since there is no collision in the entire region of interest. For patients one and two, a collision has been detected. The second only presents it in the area of the couch and therefore with this configuration it would not be necessary to continue analysing since regardless of the z height, the angles detected cannot be accessed. However, in the first patient the situation is a little different, although it is true that there is also a collision with the couch, for certain z

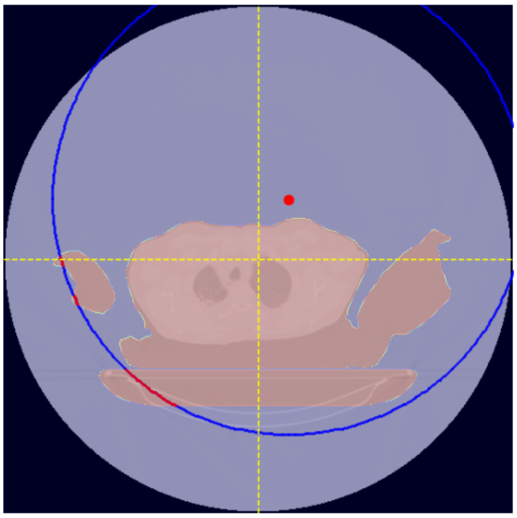

FIG. 3. CT image with mask applied, with the isocenter displaced from the center 50 mm to the right and 100 mm up, and a couch angle of 0°.

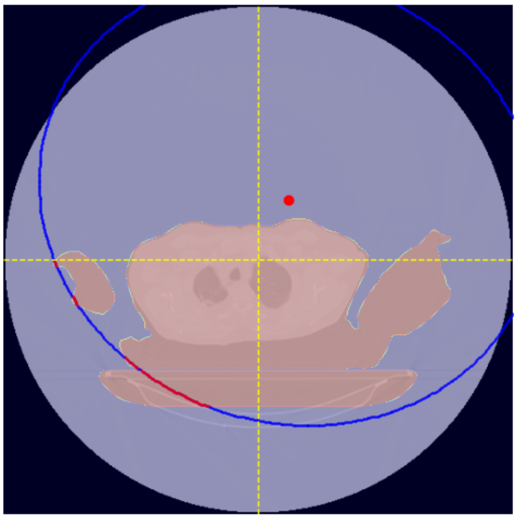

FIG. 4. CT image with mask applied, with the isocenter displaced from the center 50 mm to the right and 100 mm up, and a couch angle of 20°.

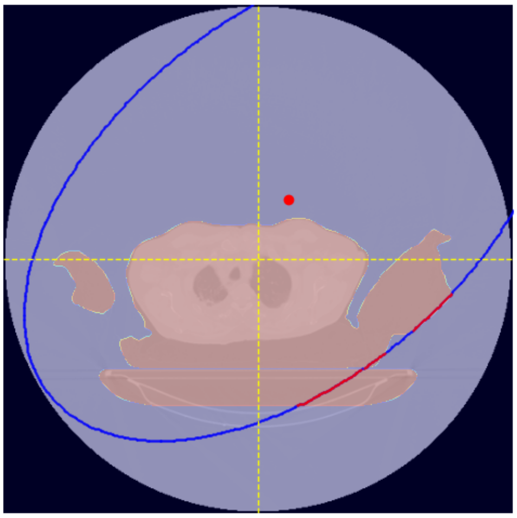

FIG. 5. CT image with mask applied, with the isocenter displaced from the center 50 mm to the right and 100 mm up, and a couch angle of $-40°$.

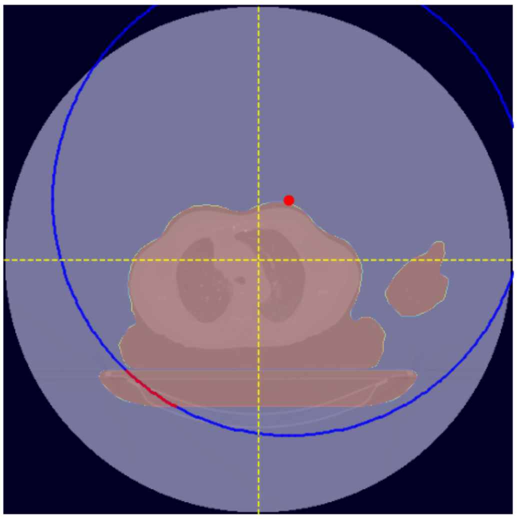

FIG. 6. Patient 1 analysed from $z = 95mm$ to $z = 150mm$ with a spacing of $10mm$. A total of 6 slices were analysed and collision was detected for angles between 195.3° and 269.7°

heights there is also a collision with the arm immobilizer. For this case, the technician could decide whether to use the option provided by the tool and perform a layer-by-layer analysis or, otherwise, change the conditions of the isocenter or the couch angle to avoid such a collision. For academic purposes, the layer-by-layer analysis has been performed and it has been determined that, among the range of z heights analysed, there is a collision with the immobilizer for heights greater than $z = 145mm$.

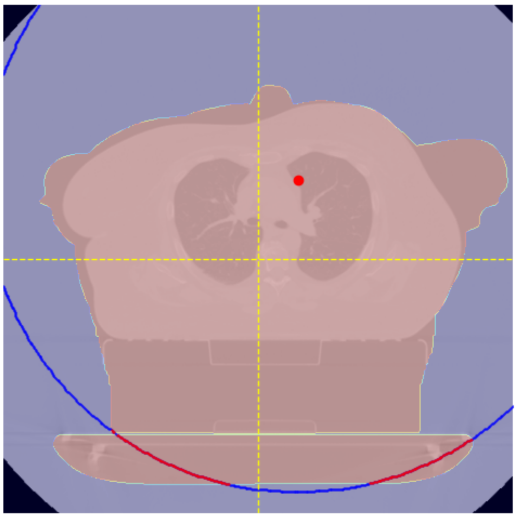

FIG. 7. Patient 2 analysed from $z = -150mm$ to $z = 150mm$ with a spacing of $10mm$. A total of 11 slices were analysed and collision was detected for angles between 132.3° and 229.7°. This is an exemple case of a breast cancer with a wedge used during the treatment

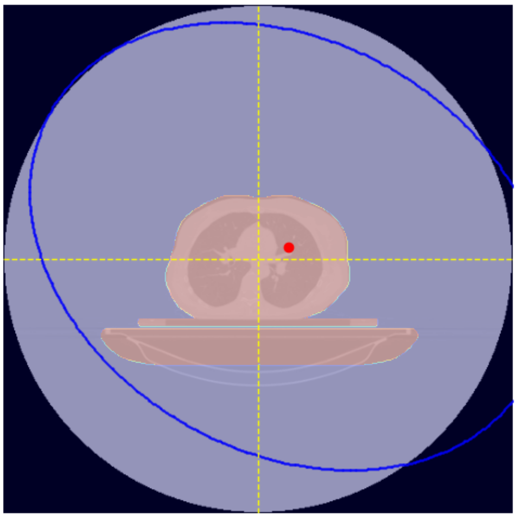

FIG. 8. Patient 3 analysed from $z = 95mm$ to $z = 150mm$ with a spacing of $10mm$. A total of 2 slices were analysed and collision was avoided.

V. Personal conclusions

Every physics student enters the degree with a set goal, for some is to specialize in astrophysics, for others in particle physics, others lean more towards a more applied and less theoretical branch such as conductors, meteorology or energy. However, throughout the four years of my degree I have not met anyone who entered considering hospital radiophysics, or even knowing about this professional path. I am proud to say that now I not only know this field but that for three months I

have been able to immerse myself in the day to day and tasks that these specialists perform. Having been in contact with residents, I have also been able to learn about the process from leaving university to joining the team, from the competitive examinations to the three years of residency. Another important element, although less serious or professional, is being able to talk with physicists and hear them talk about the conditions of their work or the research they are carrying out. From all this, one can see that despite the hard process to get to work at the hospital, both the work, the environment, and the impact that you see that your work has are worth it, and it is a good professional direction to take. Three months are enough to answer the question that everyone asks: "what does it have to do with physics? Is it necessary to have studied quantum mechanics or electrodynamics to dedicate oneself to this?" The answer is yes. Hospital radiophysics is steeped in physics and the department breathes physics. In fact, the common element of physicists, that ability to relate the most mundane facts with what was studied at the faculty, is a constant in the team.
At the same time, being able to have helped the hospital and the team to solve a problem that can help reduce time and effort, and have a positive impact on all those people who suffer from this disease that is cancer has fulfilled me completely. Developing this tool has been a personal challenge and I am pleased to have been able to finish at least this first version and to have collaborated with the team and the hospital.

VI. References

- Miao, J., Niu, C., Liu, Z., Tian, Y., and Dai, J. (2020). *"A practical method for predicting patient-specific collision in radiotherapy"*. Journal of Applied Clinical Medical Physics, 21(8), 65-72. Available at: [`https://doi.org/10.1002/acm2.12915`] (https://doi.org/10.1002/acm2.12915).
- Clínic Barcelona. 2024. Servei d'Oncologia Radioteràpica. Hospital Clínic de Barcelona. Available at: [`https://www.https://www.clinicbarcelona.org/cat`].
- Clínic Barcelona. 2024. Sobre el Clínic. Hospital Clínic de Barcelona. Available at: [`https://www.clinicbarcelona.org/ca/asistencia/sobre-el-clinic`].
- Varian Medical Systems, Inc. 2024. Eclipse. Varian, Siemens. Available at: [`https://www.varian.com/products/radiotherapy/treatment-planning/eclipse`].

---

[1] A highly precise form of external radiotherapy, with margins of error of only one or two millimetres, which irradiates the affected area with maximum doses while minimizing the irradiation of healthy tissue. Used for treating small and well-defined tumours, through a short course of treatment.

[2] With similar procedures as SBRT but intended for larger and complex-shaped tumours and a longer period of treatment.

[3] A more efficient and faster treatment as consists in a continuous modulation of the dose, speed and shape through an arc-based delivery, instead of the fixed angle treatment of IMRT.

[4] A form of internal radiotherapy that achieves through invasive treatment, normally intended for prostate or cervical cancers, a more localized dose, avoiding damage to other organs and healthy tissue.

[5] The LINAC accelerates electrons through electromagnetic waves in phase and makes them collide against a metallic target, releasing photon beams shaped using collimators and multi-leaf collimators (**MLCs**) to match the tumour's size and shape.

[6] GTV corresponds to the visible tumour identified by the doctor in the scans. CTV to the GTV plus any microscopic tumour spread regions. PTV accounts for CTV plus uncertainties such as patient movement and setup errors.

[7] Eclipse is a treatment planning software system (**TPS**) in radiation therapy developed by Varian Medical Systems, which designs, optimizes and simulates radiotherapy treatments.