

Implementation of Treatment Planning System Quality Assurance

By

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CERTIFICATE OF APPROVAL

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Abbreviations

- CPU: Central Processing Unit
- CT: Computed Tomography
- CT-Sim: Computed Tomography Simulation
- DICOM: Digital Imaging and Communications in Medicine
- DIR: Deformable Image Registration
- DVH: Dose Volume Histogram
- HU: Hounsfield Unit
- MC: Monte Carlo
- MR: Magnetic Resonance
- PDD: Percent Depth Dose
- PET: Positron Emission Tomography
- RIR: Rigid Image Registration
- TPS: Treatment Planning System
- PTV: Planned Treatment Volume
- QA: Quality Assurance

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Abstract:

Introduction: A treatment planning system is used as a step in the treatment planning process for radiation therapy. It provides computerized methods for creating beam arrangements and calculating dose distributions for patient specific anatomy. Before clinical use, the TPS goes through a commissioning process where beam measurements and parameters are entered into the system, and the commissioner confirms functionality and accuracy on all system components. Once in use, certain parameters, or data within the TPS may deviate from that established during commissioning, which may be due to vendor updates or user changes. To avoid errors in the treatment planning process, a review of any of these changes should be done through a routine quality assurance check.

Methods: Tests were created to assess the accuracy and functionality of the treatment planning system Eclipse as part of a quality assurance program. Specific pathways in the system were first analyzed, then tests were designed to cover each of these areas. Based on their coverage, the tests were grouped into one of the three categories of image input, contouring or beam modeling. An excel document was made to provide instructions for implementing these tests as well as objectives and baseline values to compare to. The document was stored in a quality assurance folder within the institution's drive for easy access.

Results: The tests created were found to cover a wide variety of processes and pathways within the treatment planning system including the assessment of image protocols, display, and dose calculations for protons. Not every aspect of the system was covered, however, and further creation of tests is recommended in order to have a more comprehensive quality assurance program. Some possible areas of expansions include the addition of different proton energies, the creation of electron treatment plans, and the assessment of more contouring tools.

Conclusion: The various tests provide a good start and outline for treatment planning system Quality assurance by assessing common functions used by the clinic. The format of the excel document gives users step by step instructions for performing the quality assurance tests and comparing the results. Future directions for the program would be to expand the tests to cover a larger variety of pathways within the treatment planning system.

1 Introduction

Radiation therapy has proven to be a popular and effective form of cancer treatment around the world as it utilizes megavoltage x-ray beams to target and kill tumor cells. The practice of patient treatment planning for radiation therapy is a complex process that requires expertise in many areas, and the proper handling of information from multiple sources. Great care is taken to ensure that each step in the process is consistent in both accuracy and efficiency to avoid errors that could potentially harm patients. [1]

The treatment planning system (TPS) is a major component in the treatment planning process. It is a computerized system used to plan beam arrangements with specific energies and field sizes for each patient treatment. Most also give insight into the expected dose distribution from these arrangements for specific anatomy by using dose calculation algorithms. There are a variety of TPSs that range from large commercial systems with a multitude of functions, to smaller, special purpose systems. The algorithms utilized also have a large variety with some implementing correction-based or collapsed cone methods, up to full Monte Carlo (MC) simulations.

A TPS requires a highly involved commissioning process before being deemed ready for clinical use. Physical measurements must be made for each treatment machine that will be planned on by the TPS, as well as for each beam energy and filter mode that will be clinically implemented. This information will be used to create beam models that the system software will utilize when calculating dose measurements. Comprehensive knowledge of the hardware and software of the TPS is necessary for the commissioning

process as the commissioner must verify both functionality and accuracy of every aspect of the system.

Throughout TPS use, the vendor will likely update parts of the system, and although these updates are intended to be beneficial, they can sometimes come with systematic errors. System users may also inadvertently change data or disrupt the TPS's functionality. These errors and changes can range from minor to major, and may or may not be obvious. To avoid inaccurate treatment planning, and promote patient safety, routine quality assurance (QA) is necessary for TPSs. QA should include a variety of tests that confirm many different aspects and pathways within the TPS, as well as those that confirm the communication between the system and other devices.

1.1 Aims

It is in this paper that the background knowledge of the treatment planning and commissioning process is discussed, as well as all aspects of the TPS including the hardware, software and known issues. From the aforementioned introduction, a QA program was written to test various aspects of the TPS Eclipse for photon treatment plans. These tests are described in detail along with future directions and recommendations for further tests that should be implemented to improve TPS QA.

1.2 Background

1.2.1 Treatment Planning Process

Before understanding the inner workings of the TPS, knowledge of the basic treatment planning workflow is helpful. The treatment process is known as radiation treatment planning, and consists of patient diagnosis, tumor staging, image acquisition, tumor localization, beam placement and treatment simulation. The workflow of this process is shown in **Error! Reference source not found.** and is comprised of multiple different people interacting with the TPS.

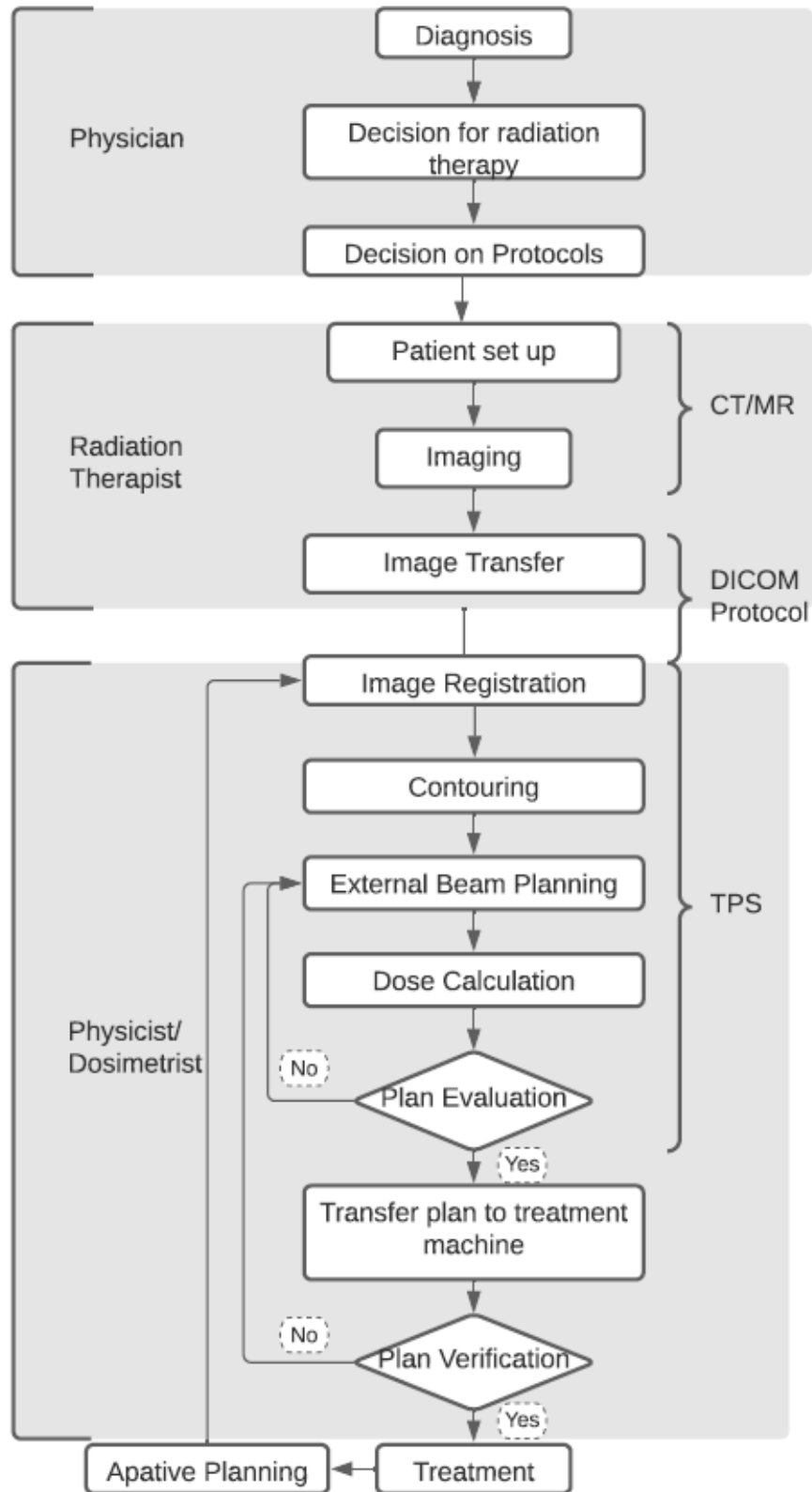


Figure 1. Flow chart of the process of radiation therapy treatment planning including who is involved and where steps take place.

The process starts with patient diagnosis by a physician, and the decision to treat with radiation therapy. Depending on treatment site, certain protocols are chosen for patient setup. The protocols are followed by radiation therapists during computed tomography simulation (CT-Sim), where the patient is placed in a position that will be used as the model for treatment planning calculations. Certain immobilization devices may be used to ensure consistency and reduce patient movement during the delivery of each fraction of treatment. Computed tomography (CT) images are then acquired. Other imaging modalities may also be used, such as magnetic resonance (MR) or positron emission tomography (PET) in conjunction with the CT images. All images, acquisition parameters, and the patient identifiers are then transferred to the TPS.

Within the TPS, the patient images are imported, and, if additional functional/diagnostic images are available, they are fused with the CT images. These are fused and aligned using rigid image registration (RIR) or deformable image registration (DIR). RIR compares the images pixel by pixel, so the distance between all points within the image are the same. DIR locally registers the image sets and can be spatially variant with large number of degrees of freedom. This is done because the TPS can typically only calculate dose for CT images, but other imaging modalities may better help identify the tumor or other areas of interest.[2]

Contours can now be made on the image(s). The contours often localize the planned treatment volume (PTV), gross tumor volume, and other organs at risk. Beam configurations can then be made in an attempt to deliver a sufficient dose to the tumor, while sparing healthy tissue. This stage includes choice of beam direction, jaw size, MLCs and wedge use, as well as specifying the dose and the number of fractions the

patient will receive. Certain optimization parameters can also be specified such as upper and/or lower dose limits on structures, and normalizations. Once the planner is satisfied with the plan, a dose calculation is done using an algorithm. The algorithms use the beam arrangements and image data to estimate what the dose distribution within the patient will be. The plan can be evaluated by the user by analyzing the shown dose volume histograms (DVH) of specific structures and isodose lines.

There are two types of DVHs, absolute and cumulative, that both plot volume versus dose, but can give the planner slightly different insights into the dose distribution. An absolute DVH shows what percentage of a specific volume is receiving the indicated dose, giving insight into the dose variations within a structure. The plot for a PTV structure typically has a sharp increase in the volume percent at the prescribed dose. The cumulative DVH shows what percentage of the specific volume is receiving a dose greater than or equal to the indicated dose which gives the planner an idea of the maximum dose within the structure. A cumulative DVH plot for a PTV is likely to have a horizontal line around 100% volume, then a sudden drop off at higher doses. [4]

While both histograms give an overview of how consistent or inconsistent the dose is distributed within a volume, a major weakness with DVHs is that they do not describe exactly where these differences occur. From the plots, the maximum and minimum dose is not able to be located, which could be problematic depending on the type of structure. It is up to the planner to then use other tools like isodose lines, which visually display the dose distribution on the planned image, to determine what is acceptable.

The optimization process is usually iterative as the planner tunes the plan to find the most ideal situation. Once satisfied, the plan is transferred to the treatment machine for further dose confirmation, then the patient is ready to be treated.

Throughout the course of a patient's treatment, it is possible for the patient to have anatomical changes such as weight gain, weight loss or tumor shrinkage. In these instances, adaptive radiotherapy can be used to account for these changes by adjusting the patient's treatment plan or creating a completely new one. Imaging used in treatment, such as cone beam computed tomography (CBCT), can identify if changes have occurred. CBCT works by taking a cone beam x-ray of the patient right before treatment, this is then registered with the simulation images in the TPS. Regions of interest are compared in both images, with differences indicating either a setup error or an anatomical change. Depending on the issue, the patient will be readjusted, couch or gantry positions will be changed, or the plan will be revised. [14][4]

1.2.2 Commissioning

Before a TPS can become a part of the clinical workflow, it must go through a commissioning process. A qualified medical physicist is responsible for this process, and it requires comprehensive knowledge of how the TPS works. The definition of commissioning is to bring into working condition, so it is done by each institution before clinical use. The process involves testing system function, verifying dose calculation algorithms and setting specific clinical parameters. The idea is to tailor the TPS to the clinic's needs and enhance the QA of the treatment planning process by creating accurate

beam and anatomy models. The steps of the commissioning process are shown in **Error!**

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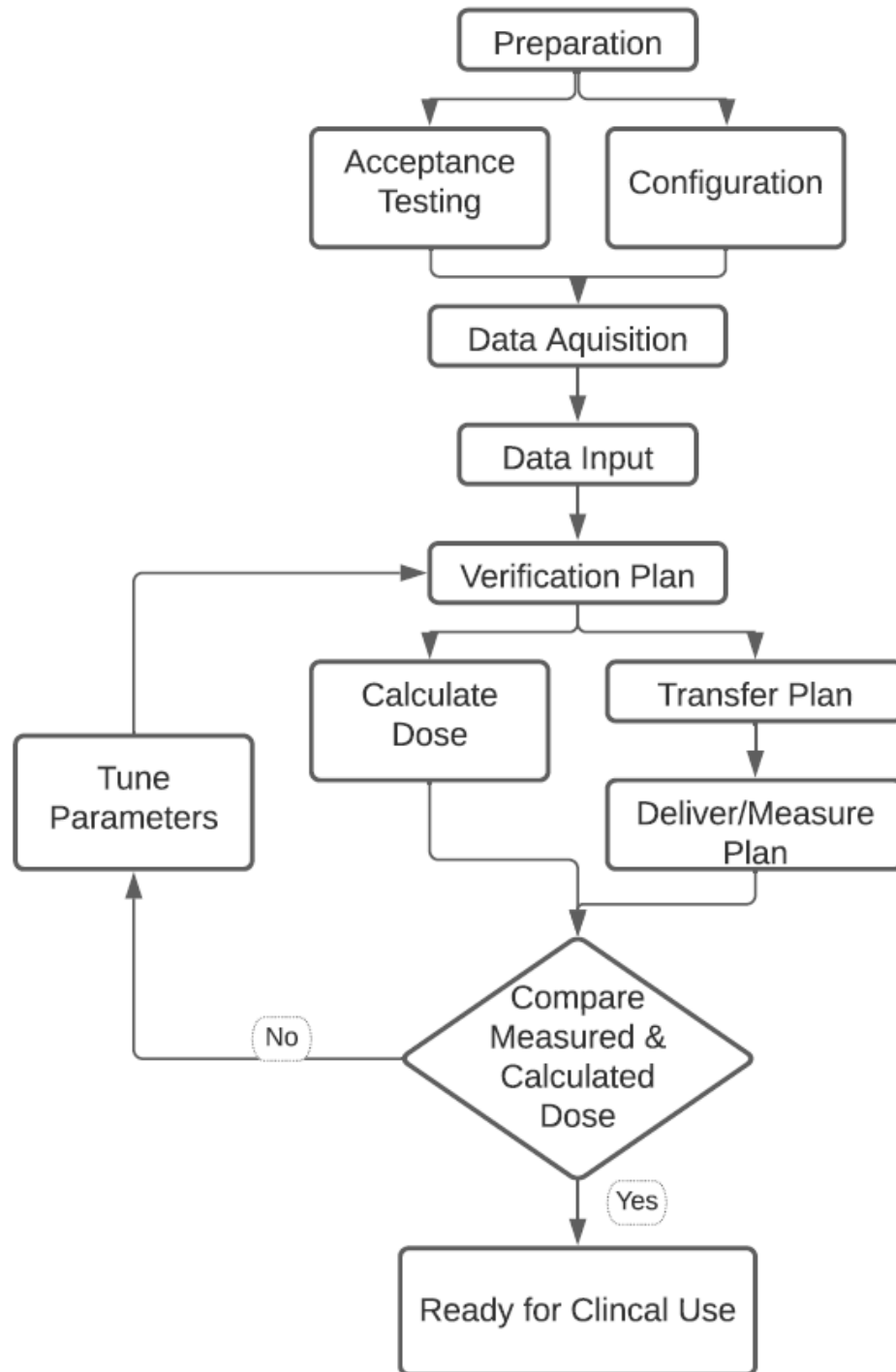


Figure 2. Workflow of the TPS commissioning process.

The first step of commissioning, directly after the installation of the system, is deciding what needs to be tested, how it is to be tested, and the tools that are needed to test (documents, detectors, phantoms, etc...). Acceptance testing follows to confirm the functionality of the system. Tests at this stage do not necessarily confirm the accuracy of the system but identify any major performance errors. As acceptance tests are performed, the user also configures the system to match clinical needs. These customizations include system setup, such as what accessories are used in treatment, what display windows can be shown, such as beams eye view, CT number conversions and what algorithms can be chosen. Patient anatomy and contours will need to be verified through testing as well to confirm that images are acquired properly, imported correctly, and contorted accurately.

Beam outputs of the treatment machines are physically measured using water phantoms and are entered in the TPS for commissioning of the external beam. Examples of things that are measured are calibration data, output factors and percent depth doses (PDDs). Other machine parameters that are not physically measured, but also entered in the TPS at this time include dynamic leaf gaps and multi-leaf collimator transmission factors. This data will be used by the algorithms to create a beam model to calculate dose, so review is essential during this step. Any measurement errors or improper input can significantly affect the system's output, so confirming detector functionality and reviewing the data is necessary.

Once all the data is entered, and the functionality is tested, the TPS needs to be validated. For a simplistic explanation, a plan is created, and the dose is calculated by the TPS. The plan is then transferred to the machine and delivered to a detector array phantom. The calculated and measured plans are then digitally compared using a

software. The parameters that were not physically measured from the machine are then fine-tuned until there are minimal discrepancies between the calculated and the delivered dose distribution.

It is at this point, and under the discretion of the qualified medical physicist, that the created beam models are approved, and the TPS is considered ready for clinical use.[1][7][14]

1.2.3 TPS Hardware

Functionality of the TPS can be categorized as either a hardware or software component. The hardware is comprised of the network interface, central processing unit (CPU), hard disk, graphics processor, and text printer.

The network interface connects the TPS computer to the local network so information can be transferred to and from it. The CPU receives and processes information for the TPS. There can be one or multiple CPUs, and it requires sufficient memory to run the software associated with the TPS. A hard disk is used to store any and all data including images, patient details and beam parameters which requires the hard disk to have a large capacity.

A graphics processor works to visually display information on the computer monitor. This includes the visual representation of CT slices, patient name, beam data and more. When a plan or information needs to be printed, the txt printer and color plotter convert and summarize the data. These functions allow for the proper printing of text and graphics in a PDF format. [1][14]

1.2.4 TPS Software

Moving into the software, a TPS in its entirety is an application package driven by an operating system. The package contains a variety of software programs that facilitate information transfers, data storage and beam modelling, which allows the system to be a functioning and accurate component of the treatment planning process. [1]

1.2.4.1 DICOM

Network and interface software allows devices in an institution to sync and communicate with each other, with Digital imaging and communications in medicine (DICOM) being an important component in that process. DICOM is a standard for communication that specifies protocols for receiving and sending medical images and related information. The standard comprehensively covers formats used for information storage and protocols used for information transfers. The main purpose of DICOM is to allow the storage and transfer of medical information among different vendors and systems. DICOM interfaces are available for most types of medical equipment and are compatible with the Transmission Control protocol, so two DICOM compliant entities may communicate over internet.

Any medical device supporting and implementing the DICOM standard is considered a DICOM compliant device and must include a network interface in order to exchange data over the DICOM network. The DICOM network is a data network that connects these compliant devices to each other within the institution. Typically, this is a standard local area network with large amounts of patient data being transferred through.

Any vendor advertising a DICOM compliant device must provide a conformance statement which describes exactly which DICOM services the device implements.

The DICOM standard specifies several image related services including verification, storage, query and retrieve, print, modality worklist and modality performed service. The main services associated with the TPS is storage, and query and retrieval. The storage service saves incoming objects as DICOM media files. An example of this is archiving images on a hard drive after a CT scan. After image acquisition, the CT operator sends the images to an archive along with a storage request message. The message requests that the archive device verify all intended images have been received, and that the archive assume safe keeping of the images. The archive device returns either confirmation back to the user, which deletes the images from the local scanner, or sends back an error if not able to properly store the information.

The query and retrieve service is used to examine DICOM archives about its content, and eventually retrieve all or some portion of that content in another DICOM device. An example of this service is done when a user opens a list of patients then retrieves one in the TPS. The user implements a search function at a workstation, and the workstation software provides the archive with a query request. The request prompts the archive for image records that have a matching set of query keys. The archive then returns a list of matching images. The user can then further select from the lists by implementing a retrieve image command. Workstation software then sends a message to the archive, listing the specific image identification numbers, and the archive sends the images to the workstation. [12][5]

1.2.4.2 CT Number Conversion

CT images are used by the TPS for treatment planning because it provides information on anatomy density that other imaging modalities do not provide due to the way a CT acquires its images. CT uses x-rays, and these x-rays are absorbed and attenuated by the anatomy during imaging. The amount of this absorption and attenuation can be described by the linear attenuation coefficient:

$$\mu = \frac{1}{x} \ln \left(\frac{I_0}{I_x} \right)$$

The coefficient accounts for the ratio of the initial intensity (I_0) to the intensity (I_x) at a specific depth (x). This value is proportional to the physical density, so it is unique for different materials. A Hounsfield unit (HU) can then be calculated from the linear attenuation coefficient to give a baseline scale with water being 0HU and air being -1000HU:

$$HU = \frac{\mu_x - \mu_{water}}{\mu_{water} - \mu_{air}} \times 1000$$

CT uses the HU values to display different gray scales that make up the CT image with the range typically being from -1024 to 3071HU.

Certain utility software in a TPS facilitates the image transfer process and converts the CT data into relative electron densities that can be used for tissue inhomogeneity corrections and dose calculations.

When CT images are transferred to the TPS, the respective HU values are also transferred. The TPS software retrieves the value in each voxel of the image and converts it to a density using a tissue characterization relationship.

This relationship is established at time of commissioning by using a tissue characterization phantom that has inserts of a variety of materials with different densities. Images of this phantom are acquired and uploaded to the TPS. The HU value is then found for each insert and plotted against the insert's known density. This plot then serves as a baseline for converting all CT values into densities.[9][13]

1.2.4.3 Contouring and Beam Configuration

A contouring software is used to identify structures on the CT images. The program displays and allows user editing of body contours, internal structures, and other points of interest. The created structure contours are graphically displayed on the original contour set with options to choose what is displayed, as well as options to pan, zoom and rotate the images. Data, such as the density of the contours, can also be accessed through the software.

Beam configuration is another part of the TPS software which allows the user to position and shape beams, as well as display the configurations in different perspectives such as beams eye view or room view. Beam modifiers such as MLCs or wedges can also be displayed.

1.2.4.4 Algorithms

The dose calculation software is arguably the most important part of the TPS. A beam model is created from the measured beam data entered in the TPS during time of commissioning. An algorithm then applies an approved beam model to the specific

patient anatomy using its density, and the set geometry to calculate the dose. Any beam model that has been entered into the TPS, but not approved will not be used by the system as a safety measure.

Different algorithms calculate this dose differently, and range in time and accuracy. One calculation algorithm is Monte Carlo (MC) which follows each particle throughout the accelerator and into the anatomy. It uses interaction probabilities to determine the path, and final dose deposition of each particle. Other newer algorithms, like AcurosXB, analytically solve the Boltzmann transport equation to determine the dose. Kernel based methods, such as AAA, have also been used, but have shown a much lower accuracy, especially in inhomogeneous mediums when compared to MC and AcurosXB. Both AcurosXB and MC have shown high accuracy in their calculation, but each excel in different ways. MC is very time consuming but has an overall more accurate dose calculation especially in the presence of materials with a high atomic number. AcurosXB has been shown to have slightly less accuracy but can compute a dose distribution much faster, with still high accuracy, which makes for a much more efficient workflow. [9]

Once the dose calculation is complete, the program interpolates the calculated points to visually display isodose lines. These displays are user interactive, so specific isodose lines can be selected, deselected, and changed from dose to percent. Other display tools that can be used to inspect the validity of the patient plan include DVH's of structures and the dose at specific points within the anatomy. [4]

1.3 Quality Assurance

Although the TPS will be ready for clinical use after commissioning, it is necessary to continue verifying the system's integrity throughout its life. A TPS is a human made product distributed by a vendor, thus it is prone to imperfections. No coding environment is immune to bugs, and updates to the TPS are released to continuously fix known issues. The vendor Varian publishes customer release notes on a routine basis that include issues that have been found in their TPS Eclipse, and ways for the user to avoid or fix them.[5][11]

One issue released was that specific contouring functions in the Eclipse TPS have been recognized to lose functionality or be inaccurate in certain situations. For example, there are reported cases of copied structures being flipped when the patient's image orientation is something other than Head-First Supine. This was due to DICOM orientation vector components not matching, and could lead to, if not caught, a patient receiving treatment in wrong locations. Instances of the segmentation wizard being inaccurate and structures outside the body contour getting no dose have also been reported. [5]

TPSs such as Eclipse do have a few safety locks in place when dealing with beam models and data. This includes the dose calculation algorithms not using any measured data that has not been officially approved. Also, if any tuned parameters have been changed, the user will get a warning when logging into the system, and the plan printout will indicate there is an error. It is possible, however, for the system to miss some of these changes, or inaccurately flag data changes, so additional tests to confirm the safety checks is needed.

With the complexities and various parts of the TPS, it is necessary to establish a comprehensive QA routine to ensure each aspect of the system is producing the same results as when first commissioned. Confirming functionality of specific treatment planning devices is a necessary first step in assessing the quality of the system. This includes testing the contouring tools and image displays. More involved tests can be done to ensure the dose algorithms are consistently producing the same results. Testing image transfers and DICOM protocols is another aspect of QA that should be considered.

It is not possible to test every aspect and pathway of a system, but a Swiss cheese method should be considered when designing tests. The idea is to create a series of barriers that are not necessarily perfect, but when put in sequence, the probability of errors getting through is very low. A visual representation of this idea can be seen in

Figure 3.

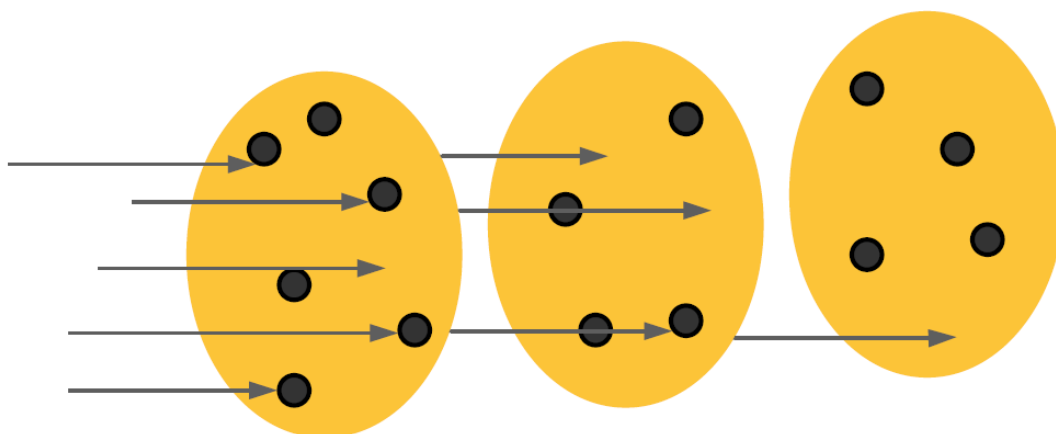


Figure 3. Diagram of the Swiss Cheese Method. The arrows represent errors going through the TPS. The yellow ovals represent tests designed to stop the errors. Although one test cannot stop all the errors, if enough tests are put in sequence and look at different areas of the TPS, the more errors are able to be caught without having to test every aspect of the system.

Figure 3 can be transformed to fit the actual treatment process with each person having a series of roles and responsibilities that involve the TPS, with the designed tests covering specific aspects of those roles as shown in **Figure 4**.

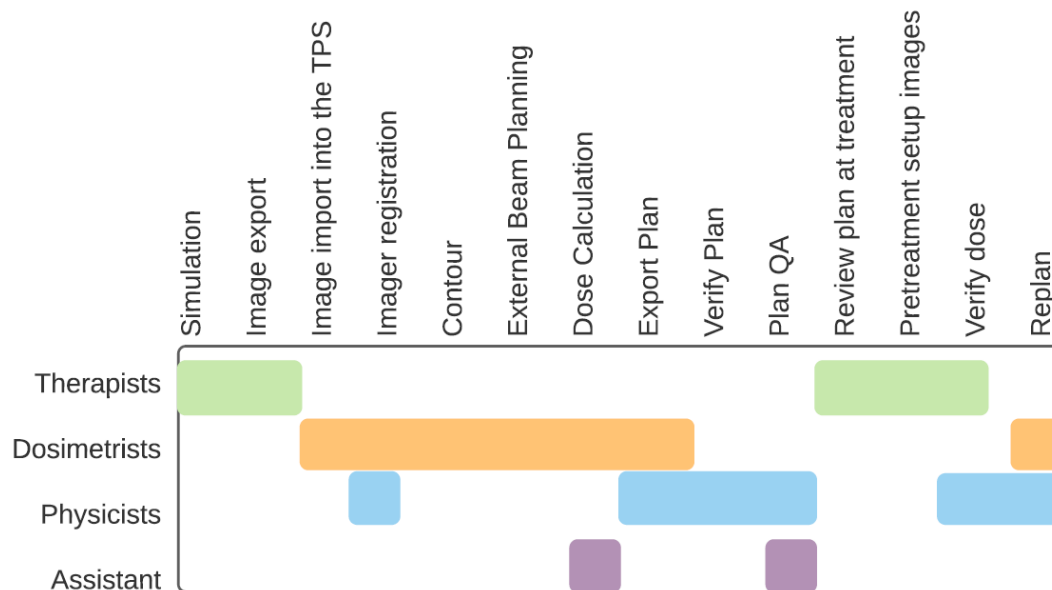


Figure 4. The different parts of treatment planning system and the treatment planning process along with those who are responsible for and facilitate the activity.

Along with testing the TPS, a set of tolerances should also be established to guide the tester. A piece of knowledge to consider when developing tolerances is the unavoidable uncertainty of the system. Uncertainty is found in all aspects of the treatment planning process, and knowledge of the sources is important when determining realistic tolerances and criteria for clinical QA. Uncertainties related to the TPS include beam measurements such as detector size and accuracy, phantom composition, and data input. PTV and normal tissue localization, and dose calculation limitations are other areas that may affect the PTVs accuracy. [16]

2 Methods

A series of system tests were developed to look at the functionality and consistency of the TPS Eclipse for proton plans, with the idea of providing QA. The tests followed the broad recommendations given by the American Association of Physicists In Medicine and the International Atomic Energy Agency on TPS QA [1][7][14] An outline of how to perform each test along with what the expected outcomes should be were documented in an excel file. The file is saved as TPS QA and is stored within Oregon Health and Science University's network folder. This can be accessed through the folder featured in [Appendices](#).

The first step in this process was identifying what aspects of the TPS we wanted to test. The test categories identified were image transfer, contouring and external beam.

In order to test that images are being imported into the treatment planning correctly, CT images were first acquired. CatPhantom images were taken on a Phillips CT-Sim during routine monthly QA of the imaging system with the acquisition parameters listed below [**Table 1**]. The CatPhantom was chosen for its features of having a variety of densities. Once the images were acquired, they were saved under the patient's name "ZZZCatPhantom QA, CT" and image slice "2015_1_15", then transferred to Eclipse using DICOM protocols.

Table 1. CT-Sim image acquisition parameters for the CatPhantom

Setting	Resolution	Tilt	Rotation time	FOV	Filter	Matrix
Head>Axial	Standard	none	.75s	250mm	Standard Edge	1024
Length	Thickness	Increment	kV	mAs	Cycle Time	Cycles
60cm	.75mm	Continuous (3mm)	120kV	375mAs	2s	20

In the TPS, the images were loaded in the contouring tab. The density feature of the phantom was found in the transversal view. The physical properties tool was then used to retrieve the CT values and relative electron densities for each of the seven different materials within the phantom. The values were recorded in an excel document. Using the properties tool, the size, resolution, slice distance and number of slices were also found for the image and recorded [Figure 5]. An image of the phantom within the TPS on the density slice was taken and stored for future reference [Figure 6 (A)].

The contours were made on the phantom using the brush, 2D adaptive tool. These were made for the air, Teflon, and polystyrene areas for all 15 slices [Figure 6 (B)]. This was done for window and level set parameters of bone, liver, and abdomen. Images of the contours, as well as notes on any inconsistencies were taken. The measuring tool was then used to measure the diameter of the body contour as well as the air circle in the transversal view [Figure 7]. This image is used as reference in the QA Excel document when testing contour tool functionality.

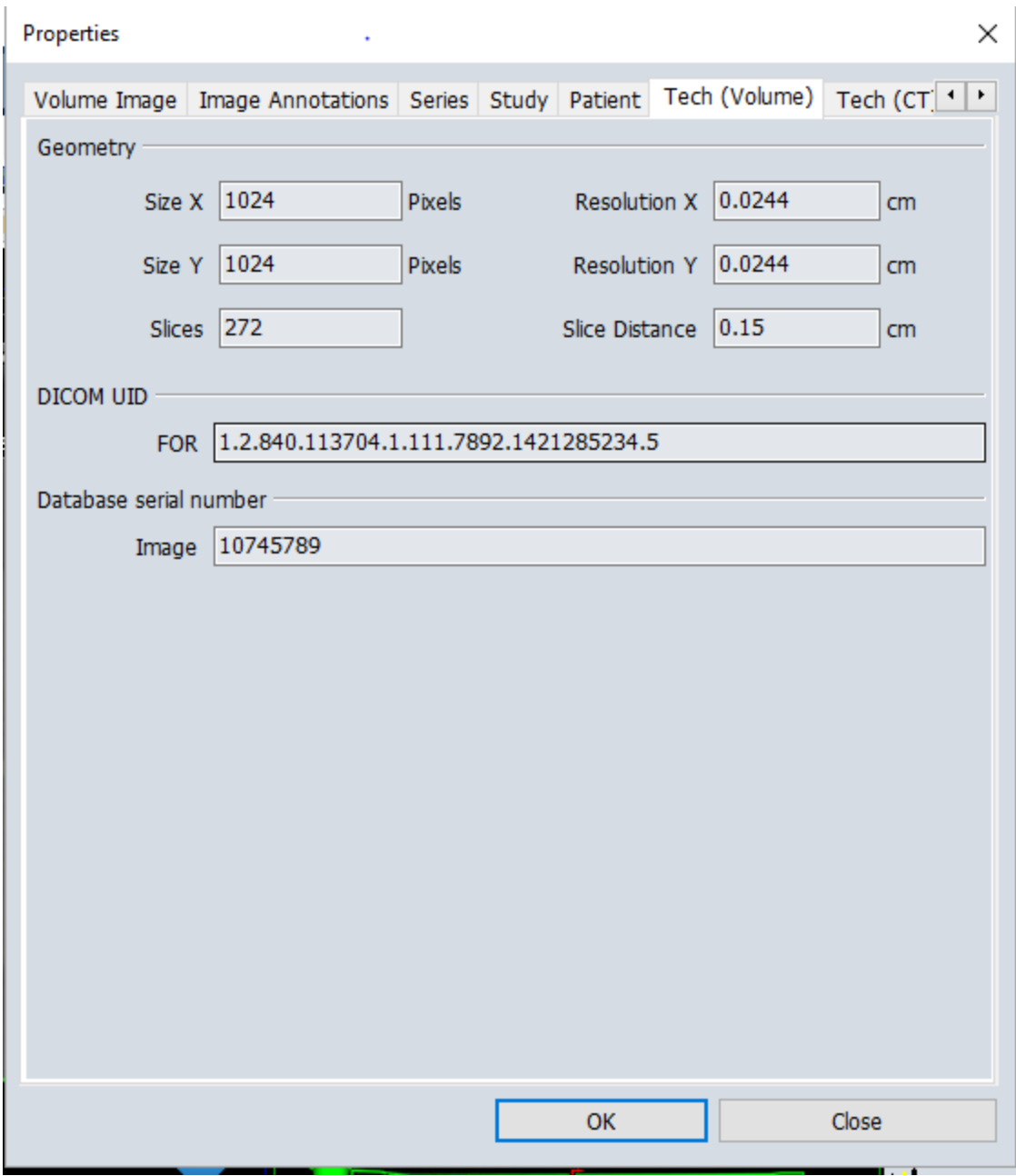


Figure 5. Tech Properties tab used to find specific imaging parameters.

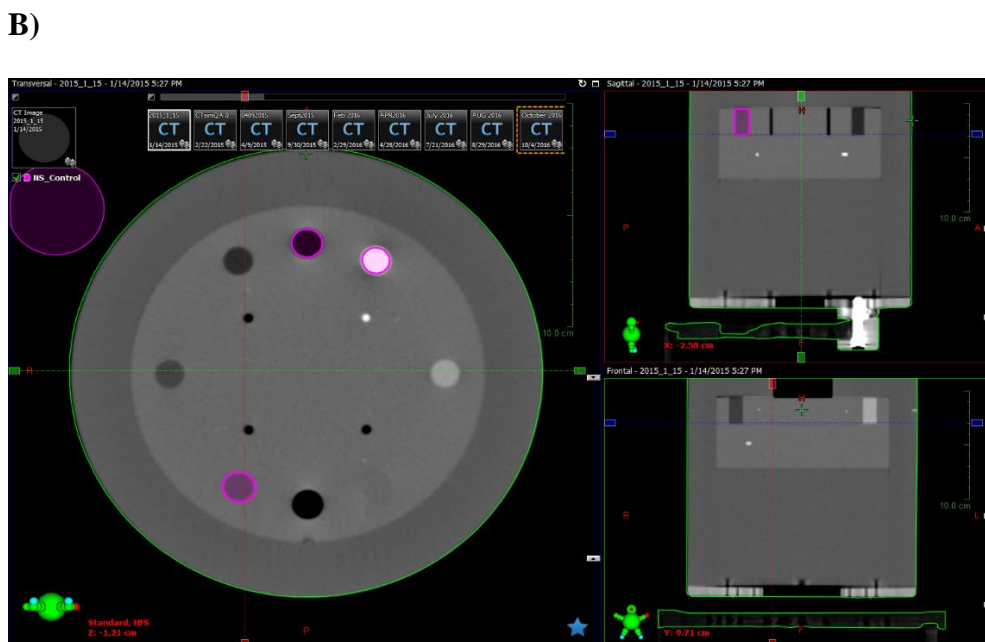
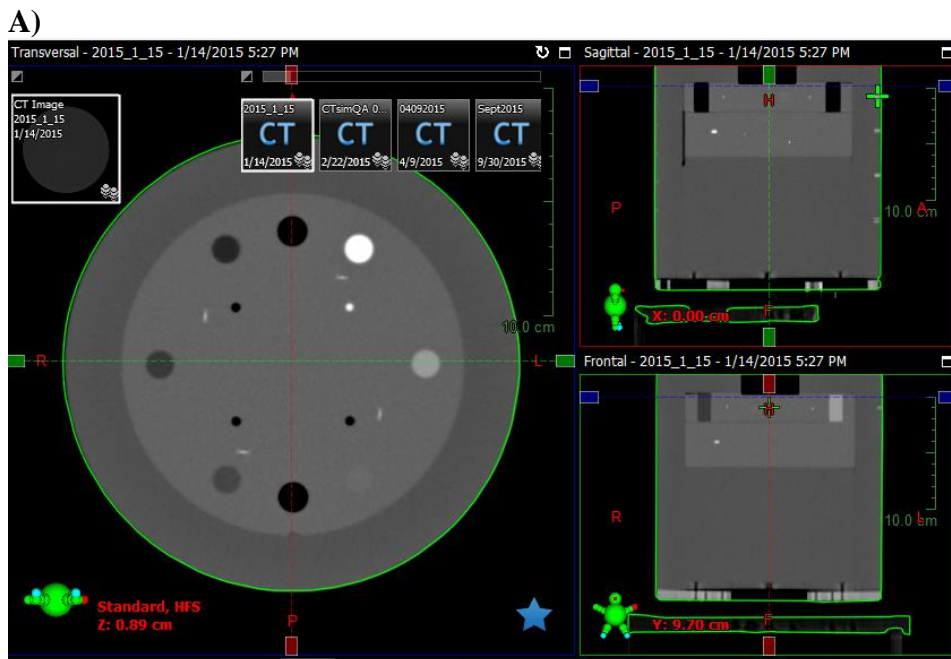


Figure 6. CatPhantom in the contouring tab of Eclipse. Transversal, sagittal, and frontal windows are shown with the density region of the phantom being viewed in the transversal plane. (A) This image is used to verify that the CT images are oriented properly when displayed in the TPS. (B) The pink circles represent contours made of the air, Teflon, and polystyrene features of the phantom.

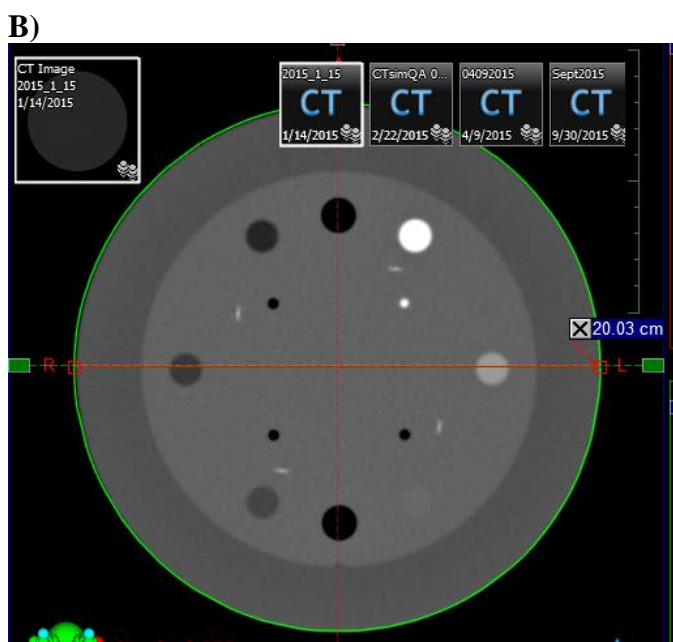
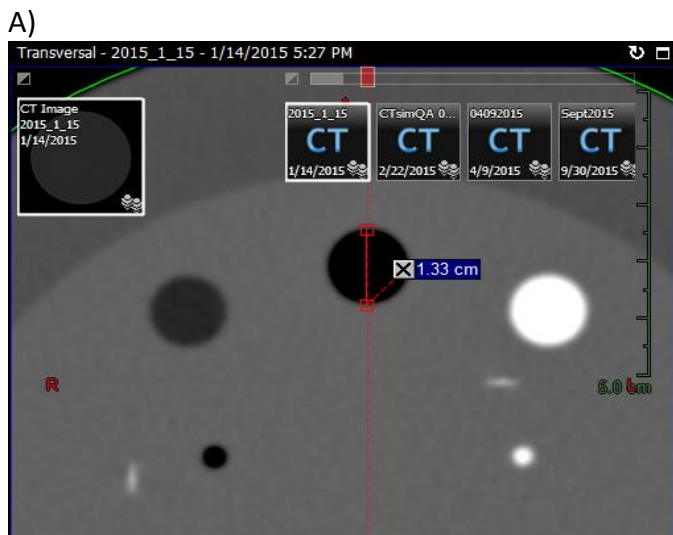


Figure 7. CatPhantom in the contouring tab of Eclipse being shown in the transversal view. (A) The measuring tool is being used to measure the air region of the phantom. (B) The measuring tool is being used to measure the diameter of the phantom’s body.

A cylindrical phantom was created and saved in the TPS during time of commissioning. The name of the phantom was saved under “TPS QA, ZZZ”, and had multiple contours, including a PTV, created [Figure 8]. A course under the name

“TG119” was then made for the phantom with multiple plans that tested different aspects of the TPS during time of commissioning. Four of the plans and the phantom were duplicated twice and saved under the courses “QA_Test6X” and “QA_Test10X”. The fields for each plan for the first course “QA_Test6X” were all set to the beam energy 6MV. The fields for each plan for the second course “QA_Test10X” were set to the beam energy of 10MV. Each plan was then calculated using the Acuros_XB algorithm. Instructions for how to access these courses and duplicate the plans were described in the TPS QA excel sheet along with images of the duplicated plans.

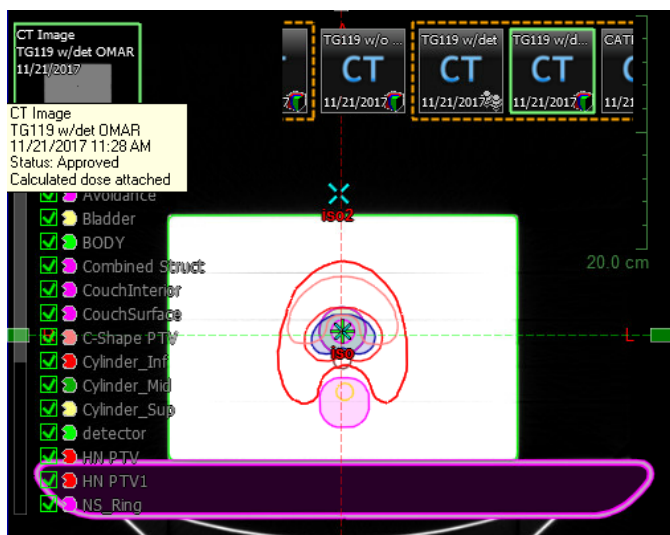


Figure 8. Phantom created during time of commissioning along with the created contours.

3 Results

The tests created were designed to assess a multitude of TPS functions through a workflow process. These tests included verifying accuracy and functionality of image transfers, display and dose calculations. The excel sheet containing the tests provide an

easy-to-use template for running the QA. Not only does it provide detailed directions, but it contains the baseline data and areas for the user to note any errors they may encounter. This process could be followed by multiple people from multiple backgrounds including physicists, physics assistant and dosimetrists.

With additions to **Figure 4**, **Figure 9** visually marks where within the treatment planning process the created QA tests cover. This mostly includes areas where dosimetrists and physicist are involved, including image import, contouring, external beam planning and dose calculations.

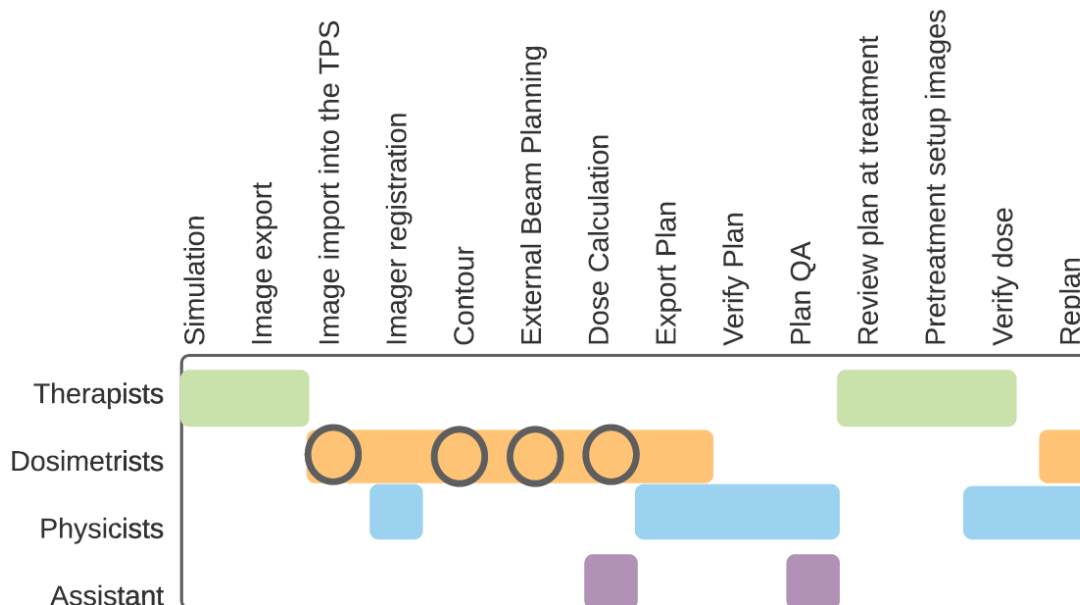


Figure 9. Display of the different parts and professional involvement of the treatment planning process, with the grey circles indicating what areas of the process the TPS QA tests covered.

3.1 Image Input

The image input tests are mostly focused on image storage and retrieval, but also confirm that the CPU and memory are functioning. Four tests were made in this category:

“Properties”, “Geometric Location”, “Txt Information”, and “CT Number & Electron Density”. An overview of the QA Excel sheet for the Image Input Tests is pictured in **Figure 10**.

Image Input Test	Date							
Before performing the quality assurance procedures, reimport the CT images "2015_1_15" for "ZZZCatPhantom QA, CT" into the TPS system.		*Refer to "Image Reference" section for direction visuals						
Test	Directions	Objective	Baseline	Results	tolerance	Pass/Flag	Comments	
Properties	1. Open "ZZZCatPhantom QA, CT" in Eclipse 2. Go to the contour tab 3. Open Image slice 2015_1_15 4. Select Tools->Properties->Tech 5. Record the following:	Size X	1024		0			
		Size Y	1024		0			
		Resolution X	0.0244		0			
		Resolution Y	0.0244		0			
		Slice Dsitance	0.15		0			
Geometric location and orientation	1. Confirm the correct orientation in each of the three windows	Slices	272		0			
		X:						
		Y:						
Txt Information	1. Select tools->properties->Patient confirm patient name and ID are correct 2. Select Volume Image tab confirm slice name is accurate	Patient Name	ZZZ CatPhantom QA, CT					
		Patient ID	1142015					
		Image Slice	2015_1_15					
CT Number & Electron Density	1. Select Measure Physical properties tool 2. click on the image (a 1x1 box should appear) 3. Move the box to each of the areas indicated by the image 3. Record the HU value and electron density		HU	e- Density		HU_Density		
		Air	-1000	0		15, 5		
		PNP	-215	0.9		15, 5		
		LDPE	-113	0.9		15, 5		
		Polystyrene	-47	0.7		15, 5		
		acrylic	130	1.6		15, 5		
Delrin	395	1.2		15, 5				
Teflon	1064	1		15, 5				

Figure 10. Image of the QA Excel Image Input tab used to explain the steps in performing the quality assurance tests.

3.1.1 Properties Test

“Properties” confirms that the CT image size, resolution, slice distance, and number of slices are the same as the baseline data. This confirms that specific CT data parameters have been successfully imported into the TPS. The data has a tolerance of zero because any deviations from the baselines for this test could indicate a change or error in DICOM protocols, causing some information to not be retrieved, or the wrong information to be retrieved. [Table 2]

Table 2. Directions for performing the Properties TPS QA test

Directions	Objective	Baseline
1. Open "ZZZCatPhantom QA, CT" in Eclipse 2. Go to the contour tab 3. Open Image slice 2015_1_15 4. Select Tools->Properties->Tech 5. Record the following:	Size X	1024
	Size Y	1024
	Resolution X	0.0244
	Resolution Y	0.0244
	Slice Distance	0.15
	Slices	272

3.1.2 Txt Information Test

“Txt Information” tests something similar. It confirms that the correct patient information is being associated and displayed with its corresponding images. This not only tests the DICOM protocols of image transfers, but it confirms the TPS is able to properly display retrieved information. Directions on how to perform these tests are featured in **Table 3**.

Table 3. Directions for performing the Txt Information TPS QA test.

Directions	Objective	Baseline
1. Select tools->properties->Patient confirm patient name and ID are correct 2. Select Volume Image tab confirm slice name is accurate	Patient Name	ZZZ CatPhantom QA, CT
	Patient ID	1142015
	Image Slice	2015_1_15

3.1.3 Geometric Location Test

“Geometric Location” tests more of the TPS’s display and contouring software. Errors found in this test could mean that the TPS is decoding the CT information

inaccurately. When anatomy is displayed flipped or in wrong viewing windows, the rest of the software may not account for this, which could lead to displaced contours and inaccurate dose calculations. [Table 4]

Table 4. Directions for performing the Geometric Location TPS QA test.

Directions	Objective
1. Confirm the correct orientation in each of the three windows	X: Sagittal
	Y: Frontal
	Z: Transversal

3.1.4 CT Number and Electron Density test

“CT number and electron density” assesses CT number transfers and the tissue characterization relationship curve. Differences from baseline for this test could mean many things depending on exactly what they are. If the CT value and the density value have changed from baseline, this could mean the value was not transferred properly, indicating an error somewhere in the image transfer process. If the HU value is inaccurate, but the density is not, that means there is an issue with the local retrieval and display. The system has the correct HU value, since it is needed to find the correct density, but it is inaccurately displaying the value.

If the electron density is different, but the HU value is the same, then there is a similar issue as the before mentioned scenario, or there is an issue with the tissue characterization curve. The latter could mean inaccurate conversions within the software, or there has been a change to the data. [8]

A list of the seven materials along with their corresponding CT number and electron density are shown in **Table 5**.

Table 5. Directions for performing the CT and Electron Density TPS QA test.

Directions	Objective	Baseline	
		HU	e-Density
1. Select Measure Physical properties tool 2. click on the image (a 1x1 box should appear) 3. Move the box to each of the areas indicated by the image 3. Record the HU value and electron density	Air	-1000	0
	PNP	-215	0.9
	LDPE	-113	0.9
	Polystyrene	-47	0.7
	acrylic	130	1.6
	Delrin	395	1.2
	Teflon	1064	1

3.2 Contouring

Two tests were made for the contouring category: “Tools” and “Measuring”.

Figure 11 displays part of the contouring tab from the TPS QA excel sheet.

Contouring			
Test	Directions	Objective	Bone
Tools	1. Scroll to Catphan region one 2. Set Window an level to Bone 3. Use Brush, 2D, Adaptive to create contour of air, teflon and polysterne areas for all 15 slices 4. Confirm the objectives are accurate 5. Delete the contour from all slices 6. Repeat with window and level set to Liver and abdomen	Contour is correct color	
		Contour is shown in all slices	
		Contour is shown in all windows	
		No gaps in contour	
		Contour was deleted	
Measuring	1. Choose the measuring tool 2. Use the tool to measure the diamter of the phantom in the transversal window. Use the L/R lables as guides for the tue diameter 3. Use the tool to measure the diameter of the air sphere of the phantom in transversal view 4. Record the values and compare to baselines	Distance is correct	Baseline
		Diamter of Body	20cm
		Diamter of Air portion	1.3cm

Figure 11. Image of the QA Excel Contouring tab.

3.2.1 Tools Test

“Tools” confirms that the features in the contouring section are functioning and displaying properly with multiple window and level parameters. Window and leveling changes the midpoint of the range that CT numbers that are displayed, so changing these will give a better visualization of what pixels are actually incorporated in a contour. The act of contouring and deleting verifies that the tools are functioning properly. **Table 6** shows the directions on how to perform this test.

Table 6. Directions for performing the Tools TPS QA test.

Directions	Objective
1. Scroll to Catphan density region 2. Set Window and level to Bone 3. Use Brush, 2D, Adaptive to create contour of air, Teflon and polystyrene areas for all 15 slices 4. Confirm the objectives are accurate 5. Delete the contour from all slices 6. Repeat with window and level set to Liver and abdomen	Contour is correct color
	Contour is shown in all slices
	Contour is shown in all windows
	No gaps in contour
	Contour was deleted

3.2.2 Measuring Test

The digitizer scale accuracy is assessed in the “Measuring” test. This makes sure that the TPS is registering and displaying the image properly, and that the measuring tool is to scale. Deviations in this test could mean the tool needs to be recalibrated.

Table 7. Directions for performing the Measuring TPS QA test.

Directions	Objective	
1. Choose the measuring tool 2. Use the tool to measure the diameter of the phantom in the transversal window. Use the L/R labels as guides for the true diameter 3. Use the tool to measure the diameter of the air sphere of the phantom in transversal view 4. Record the values and compare to baselines	Distance is correct	Baseline
	Diameter of Body	20cm
	Diameter of Air portion	1.3cm

3.4 External Beam

External beam tests were designed to test that the dose calculation algorithms are yielding consistent results when calculating the same plan. Parameters changed were the beam energy, field size, gantry, and collimator angles. These were changed to cover a wide range of the software and give a more confident result. [7][2] Directions on how to perform this test, including how to copy and recalculate plans, are shown in **Table 8**.

Areas kept consistent throughout the plans included using a static over and arc technique and using the algorithm AcurosXB over AAA. Parameters that were changed included gantry angle and field size. A more complete look at all of these parameters is outlined in **Table 9** and **Table 10**.

Table 8. Directions for performing the External Beam TPS QA test.

Directions	Objective
1. Go to external beam planning	DVH Comparison
2. Open patient "TPS QA, ZZZ" 010232017	
3. Open "QA_Test 6X"	
4. Insert-->New Course	
5. ID: "QA Date"	
6. Right click (RC) on plan "APPA"-->Copy Plan	MU Comparison
7. RC on the new course-->Paste plan-->OK	
8. Calculate the pasted plan	
9. Compare the pasted plan to the original. Compare structures in DVH Window and the calculated MUs. Record and describe any differences	
10. Repeat steps 5-8 for each plan. (Bands, Head and Neck, Prostate)	
11. Repeat steps 3-9 for course QA_Test 10X	

Table 9. Parameters held constant for the Beam test plans

Technique	Linear Accelerator	Source to Surface Distance	Flattening Filter	Collimator Rotation
Static	Linac 2-Varian Truebeam	82-90cm	Flattening Filter Free	0 degrees

Collimator Rotation	Dose	Algorithm	Beam Type
0 degrees	200cGy	AcurosXB_156MR3	Photon

Table 10. Parameters changed for the Bam test plans.

Gantry Angle [deg]	Field size [cm]	MLC	Energy [MV]
0	3	Dynamic	6
40	7	None	10
50	8		
80	10		
100	12	Normalization	Target Volume
120	14		
150	18	100% covers 90% of Target Volume	HN PTV
160	20		
180		100% in Reference Point Iso	Body
200			
210		Plan Normalization Volume: 15.14%	Body
240			
260		100% covers 95% of Target Volume	Prostate PTV
280			
310			
320			

4 Discussion

The Image Input tests confirmed the accuracy of image and data transfers from the CT-Sim into Eclipse. DICOM protocols can be confirmed to be the same by cross referencing specific aspects of the image to what is considered the baseline. These tests also confirm that the TPS is able to properly retrieve and display information.

The Contouring steps verify that tools often used within Eclipse are working and being displayed properly. This gives assurance that pieces of anatomy are shown with the correct dimensions and are receiving the proper label when being contoured.

The plans chosen to test the calculation algorithm's consistency encompasses a wide variety of beam modeling parameters that are often used within the department. Eclipse

does have interlocks to prevent parameter changes, but these tests ensure that those interlocks are flagging areas that need to be flagged.

4.1 Future Directions

Although the written tests covered many pathways within the TPS, there are still more areas that should receive attention. This includes a more systematic approach to analyzing checksums. This would not only test but verify that data files have not been changed on top of the safety measures the system currently has in place. Data is grouped and encoded with a specific key at the end. If anything within that data is altered, the key is drastically changed. A test that was able to document and automatically compare these keys for multiple files would be a great addition to the QA in confirming data consistency.

A wider range of test plans could also be a potential area of improvement. The plans created cover the basic and most common treatment parameters, but an extension into more variations would lead to a more comprehensive QA of the algorithms. This could include developing plans with more beam energies or dose calculation algorithms. Delivery of these plans could be performed to ensure that plans are being transferred appropriately. Another area for expansion could be in the transfer tests. Changing patient orientation at the CT console and transferring it to the TPS would provide more detailed information on the accuracy of transferring, receiving, and displaying software.

Expanding into adaptive therapy could also be done. This would include using the image input tests to look at all types of images. Tests to look at the RIR and DIR algorithms and accuracy of alignment would help avoid planning errors.

A larger variety of contouring tools could also be explored, but it is important to note the time constraints of QA. It should not and does not need to be too long or too involved. The idea is to test a variety of pathways that can be done routinely and consistently. There are too many variations within the TPS to test them all, and the likelihood of a problem arising in multiple untested areas is not likely.

5 Conclusions

TPSs undoubtedly play a large role in the radiation therapy treatment planning process as they provide the means to create unique beam arrangements and dose distributions for every patient. The intricacies of a TPS's software and hardware requires an in-depth commissioning process before clinical use. Due to vendor updates and user error, continuous monitoring of the system is essential in ensuring the accuracy of the product. A series of QA tests can be created for each specific TPS to catch any mistakes that may happen.

The tests developed and described in this paper were done so with the intention of providing QA to the TPS Eclipse. Areas assessed were memory, data transfer, display, tool functionality, and dose calculation consistency. The tests were organized in a excel sheet under tabs indicating three categories of assessment which were Image Input, Contouring, and External Beam. Step by step instructions, as well objectives for the tests were included. This layout created an easy way to routinely test and assess the TPS. There are still areas of the TPS that the aforementioned tests do not completely cover, and the development of subsequent tests are recommended in order to have a more comprehensive QA program. This paper, however, provides the layout and examples of tests that can be used as a starting point when verifying a TPS

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7 Appendices

TPS QA Excel Sheet:

X:\Hospital\RAD\RAD_Share\Physics\TPS (keep)\TPS QA\Thesis Project\QA Procedures\TPS QA