STEREOTACTIC RADIOSURGERY IMPLEMENTATION AT UTAH VALLEY HOSPITAL

By

Ryan D. Sharp

Bachelor of Science – Nuclear Engineering
University of New Mexico
2016

Master of Science – Medical Physics
University of Nevada, Las Vegas
2018

A doctoral project submitted in partial fulfillment
of the requirements for the

Doctor of Medical Physics

Department of Health Physics and Diagnostic Sciences
School of Integrated Health Science
The Graduate College

University of Nevada, Las Vegas
May 2020

ProQuest Number: 27995695

ProQuest 27995695

www.manaraa.com

Doctoral Project Approval

The Graduate College
The University of Nevada, Las Vegas
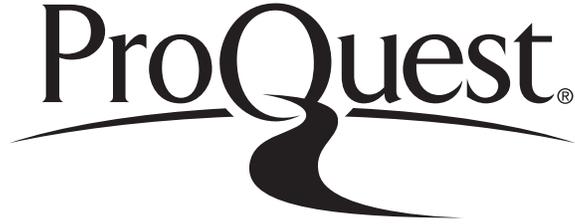
April 21, 2020

This doctoral project prepared by

Ryan D. Sharp

entitled

Stereotactic Radiosurgery Implementation at Utah Valley Hospital

is approved in partial fulfillment of the requirements for the degree of

Doctor of Medical Physics
Department of Health Physics and Diagnostic Sciences

Steen Madsen, Ph.D.   Kathryn Hausbeck Korgan, Ph.D.
Examination Committee Chair   *Graduate College Dean*

Yu Kuang, Ph.D.
Examination Committee Member

Cephas Mubata, Ph.D.
Examination Committee Member

Ryan Hecox, MS
Examination Committee Member

Graham McGinnis, Ph.D.
Graduate College Faculty Representative

Abstract

Utah Valley Hospital (UVH) implemented a stereotactic radiosurgery (SRS) program as an additional line of service. SRS as defined by the American College of Radiology is radiation therapy delivered via stereotactic guidance with approximately 1 mm targeting accuracy to intracranial targets in 1-5 fractions. Effectively implementing the SRS program at UVH requires the adoption and implementation of hardware and software technologies, a review of the clinical workflow with appropriate quality assurance tests, and the assessment of additional technologies that will further enhance the capabilities of the program. The scope of this work is to include a comprehensive writeup of the work that has been performed to implement the SRS program at Utah Valley Hospital.

Table of Contents

List of Tables

List of Figures

Introduction

Stereotactic radiosurgery (SRS) as defined by the American College of Radiology is radiation therapy delivered via stereotactic guidance with approximately 1 mm targeting accuracy to intracranial targets in 1-5 fractions.[1] This treatment technique was initially developed to treat arteriovenous malformations, meningiomas, and acoustic neuromas.[2] Over time the treatment technique was further expanded to include malignant tumors, such as gliomas & brain metastases; functional disorders, such as trigeminal neuralgia; and movement disorders, such as essential tremors.[2,3] Neurosurgeon Lars Leksell is considered the pioneer of radiosurgery treatment where he proposed using small fields of radiation to treat structures in the brain instead of the conventional stereotaxic treatment technique.[4] The conventional technique involves inserting a needle electrode into a targeted brain structure and performing electrolysis.[4] Leksell's proposal led to the development of the Gamma Knife, which is a noninvasive stereotaxic radiosurgery device that uses many beams of gamma radiation to accurately administer a high dose of radiation to a single spot.[5]

To this day, Gamma Knife is still considered the gold standard for SRS treatments, however, historically; there have been a variety of longstanding criticisms regarding the use of this device that are still prevalent. To ensure accurate delivery of the radiation, the absolute positioning of the patient must remain fixed starting from when the patient's planning images are acquired up to treatment delivery. This requirement is met by affixing a frame to the patient's cranium which has been reported as a traumatic experience by patients, in addition to the increased risks of bleeding and infection.[6] Head frames present additional challenges such

1

as requiring additional patient management from the nurse(s) & physician(s) involved, and the possibility of frame slippage occurring which may result in a compromised treatment.[6]

With the advent of new technology such as 3-D image guidance, a 6 degree of freedom (DOF) couch, & surface tracking, there has been a shift in frame-based SRS treatment techniques to frameless. Furthermore, there has been an increase in the utilization of LINAC based SRS treatments using either multi-leaf collimators or cones. Several vendors have incorporated frameless techniques in conjunction with their radiation therapy devices. For example, the Cyberknife from Accuray, the TrueBeam by Varian, and the Gamma Knife by Elekta have all incorporated frameless techniques.[5,7,8]

Utah Valley Hospital (UVH) in Provo, Utah has recently (as of 2017) acquired a TrueBeam equipped with flattening filter (FF) & flattening filter-free (FFF) beams, kV/MV image guidance, 120 leaf MLC, cones, the Encompass immobilization system,[9] a 6 DOF couch, and surface tracking. With the acquisition of the TrueBeam and supporting equipment, UVH has undertaken the task of incorporating the SRS treatment technique into their clinical practice.

SRS Clinical Workflow

Successfully delivering a radiotherapy plan, considering the numerous steps, numerous personnel, and the intricacies of each step, is a feat. Also, further challenges arise in the clinical workflow when considering that a diverse range of technologies are integrated together. Despite these factors, UVH successfully implemented a SRS clinical workflow, as presented in Figure 1.
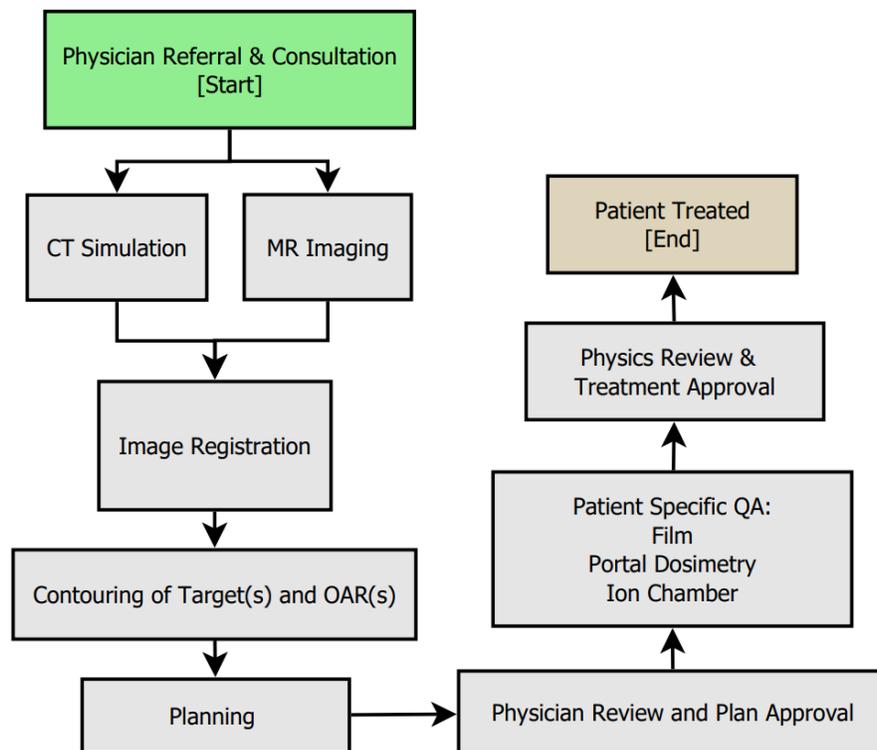
Figure 1 - SRS CLINICAL WORKFLOW

UVH's mission is to help people live the healthiest lives possible.[10] It was recognized that to ensure this goal, the department needed to incorporate many properties that indicate a workflow of high quality. Properties that were considered are the following: efficiency throughout the entire process, consistency at each step, more than 1 individual is trained at any

3

step in the clinical workflow, and the progress at every step is tracked. Significant efforts have been undertaken by the department to include these properties. For example, more than 1 therapist is capable of independently performing a CT simulation. An example of consistency is the physicists rely on a checklist when reviewing a plan that is ready for treatment approval. The benefit of having the checklist ensures that all SRS plans are subject to the same vetting process. An example of efficiency in the clinical workflow is the use of carepaths. Carepaths allow the department to track the status of the SRS treatment plan, and it notifies the appropriate individual(s) when their task or contribution is needed.

The workflow begins with the patient meeting with the physician for a consultation. During the consultation, the physician may review items such as the medical history, the current medical condition of the patient, prior imaging scans, the diagnosis, and other health related items. If the patient is determined to be a candidate for radiation therapy, the physician will discuss treatment options and what to expect during their course of treatment. Following the consultation, the patient is scheduled for a computed tomography (CT) simulation and to undergo a magnetic resonance imaging (MRI) exam.

Computed Tomography Simulation & Magnetic Resonance Imaging

To define targets and organs at risk (OARs) for a SRS radiotherapy treatment plan, CT and MR DICOM image sets are needed. Following the CT simulation, CT images are acquired of the patient. This process begins with the therapist working with the patient to create immobilization devices to limit the patient's movement during treatment and to provide support devices that ensure a comfortable, reproducible setup. First, the patient is asked to lay in a head first supine position on the Encompass system (See Figure 2) which is placed on the CT

table. Also, a head-cup rest, adjustable pegs for the hands, and a knee sponge are included to provide structural support.

Figure 2 - ENCOMPASS SRS IMMOBILIZATION SYSTEM

Next, a Qfix thermoplastic mask system is created.[9] The mask, as seen in Figure 3, consists of two components: an anterior and posterior piece.

Figure 3 - QFIX FIBREPLAST MASK

To create the mask, it is first heated in a water bath, and then it is molded to the surface of the patient's cranium. The mask is held in place until it cools and stiffens. The back piece is created first as it integrates into the Encompass immobilization system. This process is repeated for the anterior portion of the mask. The anterior portion of the mask also includes adjustable shims in 0.5 mm increments that can be loosened or tightened to account for slight changes in the patient's anatomy throughout their course of treatment. Additionally, the anterior mask component includes an open orbital region, which allows for surface tracking during treatment using the VisionRT system.[11] Once the mask is created, a CT scan of the patient's cranium is acquired. The SRS scan protocol consists of 0.8 mm thick slices with a scanning length from the most superior part of the Encompass structure to the inferior portion of the patient's cranium. This scan length ensures all the necessary anatomical and support structures are accounted for in the planning CT. Additionally, a high mAs of around 1300 per slice is used to improve the image quality, or more specifically, to reduce the mottle in the image. This increase in mAs results in an increase in the contrast to noise ratio.

Ideally, on the same day, a 3T MR is also acquired of the cephalic region. Scans from the MR provide superior tissue resolution when compared to the CT. Once both image sets are acquired, the medical physicist will perform an image registration which superimposes the anatomical information from the MR onto the CT. First the physicist will take advantage of the auto-matching feature to perform a registration between the two images and there may be a few fine, manual adjustments. This image registration allows the Radiation Oncologist and/or the Neurosurgeon to accurately contour high-resolution target(s) and OAR(s) onto the CT. Once

completed, the case is sent over to the dosimetrists to create a radiotherapy treatment plan using the CT images.

SRS Treatment Planning

In creating a radiotherapy plan, dosimetrists usually use a 6 MV flattening filter-free (6X FFF) beam due to its sufficient depth into the cranium, its high dose rate (1400 MU/min), its sharp dose fall-off, and low neutron production. To spare the normal tissue and to improve conformity the dosimetrists will include at least 500˚ of rotation in the gantry motion. This criterion is met by adding in 5 100˚ arcs or 1 360˚ arc with 3 oblique arcs. Avoidance sectors may be added to the arcs to avoid having radiation enter through the critical organs (e.g. the eyes). Adding in the avoidance sectors will result in less degrees of rotation. However, in such circumstances, additional degrees of rotation are added onto other arcs. The couch kicks are added in conjunction with the arcs. For example, if the dosimetrist adds in 1 360˚ coplanar arc with a couch kick of 0˚. Next, two noncoplanar partial arcs are added, one with a couch kick 30-40˚ clockwise, and the other counterclockwise. Finally, the 4th arc is added with the couch rotated normal to the 0˚ position with a vertex arc. The collimator for all arcs is rotated (e.g. 30˚) to reduce dose overlap from the multi-leaf collimator (MLC) interleaf leakage and tongue and groove effects. Upon adding the arcs, the dosimetrist will use an optimizer technique, as presented by the Radiation Oncology Department at the University of Alabama.[12] This technique involves radially expanding from the planning target volume (PTV) by a known distance and creating a spherical contour. Three spherical contours are created and assigned a priority to limit the dose in that structure which results in lower doses delivered to the normal tissue. Figure 4 showcases an example of the spherical contours generated.
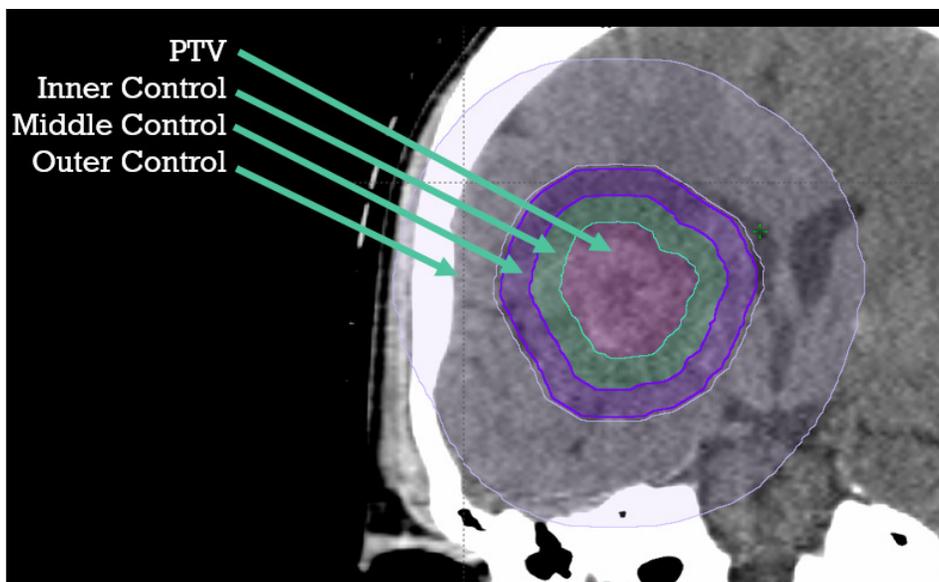
Figure 4 - SRS CONTROL SPHERES

The radial distances used in generating each control sphere are listed in Table 1.

Table 1 – RADIAL DISTANCES USED TO GENERATE CONTROL TARGETS

Control	Inner Surface	Outer Surface
Inner	Edge of PTV_Total	5 mm from PTV_Total
Middle	5 mm from PTV_Total	10 mm from PTV_Total
Outer	10 mm from PTV_Total	30 mm from PTV_Total

The dose constraints and their corresponding priorities for each control sphere are listed in

Table 2.

Table 2 - OPTIMIZATION SETTINGS

Control	Dose constraint	Priority
Inner Control	Dmax < 98% of prescription dose	150
Middle Control	Dmax < 50% of prescription dose	100
Outer Control	Dmax < 40% of prescription dose	80

Although the guide for planning above represents the general SRS case, there can be variations in the planning process that will lead to deviations. The constraints and priorities may change depending on the treatment site, the treatment volume, the OARs, the OARS spatial location relative to the target(s), and other factors. Once a clinically acceptable plan is generated, the plan is evaluated for its PTV coverage and OAR sparring.

One OAR constraint that is included in every SRS plan, is the volume of brain receiving 12 Gy or more (V_{12Gy}). Numerous publications,[13–15] have reported on the complications following SRS treatment and one of those complications is radionecrosis. Symptoms associated with radionecrosis can include seizure, motor deficiency, cognitive deficits, and speech deficits.[14] V_{12Gy} is a dosimetric quality parameter that has been correlated to radionecrosis. Therefore, two planning objectives are added to the plan to track this parameter. The first planning objective reports on the V_{12Gy} present in the brain while the 2nd objective is a conservative estimate which only includes the normal brain tissue (i.e. Brain sub PTV).

In addition to the V_{12Gy} constraint, there are three parameters that are tracked that provide feedback on the quality of the plan. The three metrics are conformity index (CI), Paddick gradient index (GI), and homogeneity index (HI). The goal is for the CI to be equal to 1 which indicates the volume of the prescription isodose line is equal to the volume of the PTV. A value less than 1 indicates the PTV may be insufficiently covered by the prescribed dose. While a value greater than 1 indicates that the prescription isodose line volume is covering more than just the PTV but also nearby normal tissue. A visual scroll through is performed by the reviewing staff to ensure that the 100% isodose line volume is superimposed on the PTV volume. The equation used to calculate CI is presented by Equation 1.

$$CI = \frac{V_{Rx}}{V_{PTV}} \qquad \qquad [1]$$

V_{rx} − Volume of the prescription isodose line in ccs
V_{PTV} − Volume of the PTV in ccs

A high dose fall-off outside the PTV or in the normal tissue is highly sought after. The GI

is calculated to characterize this dose fall-off. The GI is calculated by taking the ratio of the

volume of the 50% isodose line to the volume of the 100% isodose line. The equation used to

calculate this metric is represented by Equation 2.

$$GI = \frac{V_{50\%, \ Rx}}{V_{100\%, \ Rx}} \qquad \qquad [2]$$

$V_{50\%, \ RX}$ − Volume of the 50% prescription isodose line in ccs
$V_{100\%, \ RX}$ − Volume of the 100% prescription isodose line in ccs

Homogeneity index, the final metric, is an additional metric to assess the dose fall-off and the

magnitude of the hot spot relative to the prescription dose. Equation 3 is used to calculate HI.

$$HI = \frac{D_{max}}{D_{Rx}} \qquad \qquad [3]$$

D_{max} − The maximum dose
D_{Rx} − The dose prescription for 1 fraction

With an ablative dose delivered, the hotspot inside of the PTV is of less concern. Instead a

greater hotspot can be advantageous as the dose fall-off outside the target can be greater than

a dose profile that is relatively flat. This concept is illustrated in Figure 5.
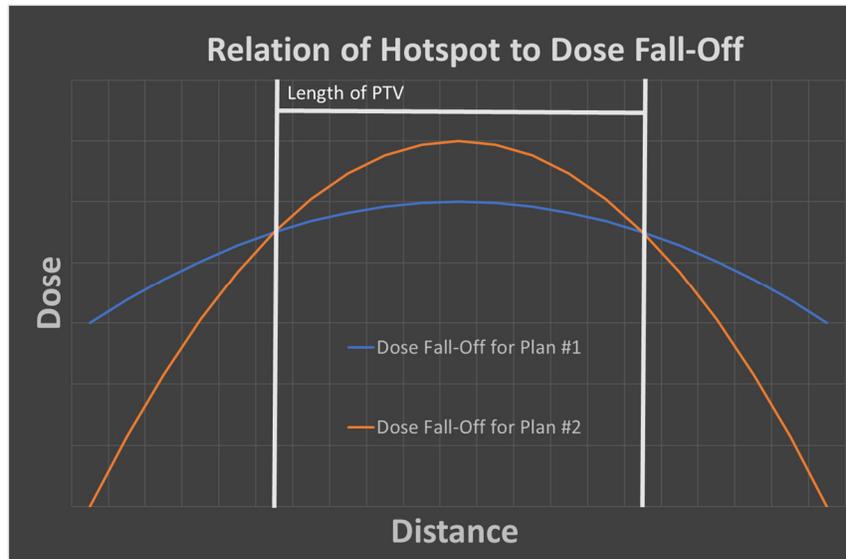
Figure 5 - HOTSPOT RELATION TO DOSE FALL-OFF

In Figure 5, the orange line represents a plan with a greater dose in the center of the target and is followed by a sharp fall-off. As compared to the blue line which has a relatively low dose in the center and has less of a dose fall-off. If the length of the PTV is the same distance as the intersection point between the two curves, as seen in Figure 5, and both curves encompass the target with 100% of the prescribed dose, the orange line is most beneficial in providing an ablative dose to the target while sparring the surrounding healthy tissue.

After creating a SRS plan, the dosimetrist will review the plan with the Radiation Oncologist for any final changes before having the plan approved. Once the plan is approved, the physics team will generate patient specific QA plans. The plans generated include: a portal dosimetry plan, a film measurement plan, and an ion chamber measurement plan.

Ion Chamber Measurement

Prior to patient treatment, the treatment delivery is simulated to verify the absolute dose to a point (small volume) and the corresponding MU. This is performed by using Standard Imaging's

11

stereotactic dose verification phantom with a cavity drilled for placement of the Exradin A26 ion chamber (IC).[16] A verification plan is generated where the beam parameters (MLC trajectories, energy, dose rate, etc.) from the clinical plan are computed on a CT dataset that includes the Standard Imaging phantom with the ion chamber. Upon calculating the dose in the phantom, the dose profile is evaluated on the axial scan in the anterior to posterior direction and in the left to right (lateral) directions. Ideally, the dose profile should be flat in all measured directions to avoid significant volume averaging effects. If the active volume is in a region of a high dose gradient, the isocenter of the treatment fields is shifted to a flatter dose region. Lastly, the plan is approved (planning approved) in Eclipse and scheduled as a QA plan which is to be delivered on the TrueBeam.

To prepare for the IC measurement, the phantom is placed on the treatment couch and set to isocenter. Then it is centered using the light field cross hairs with a set field size of 10x10 cm^2 and lasers. The A26 is placed in the cavity and connected to the electrometer by a triaxial cable. Figure 6 displays the phantom setup with the chamber in place.
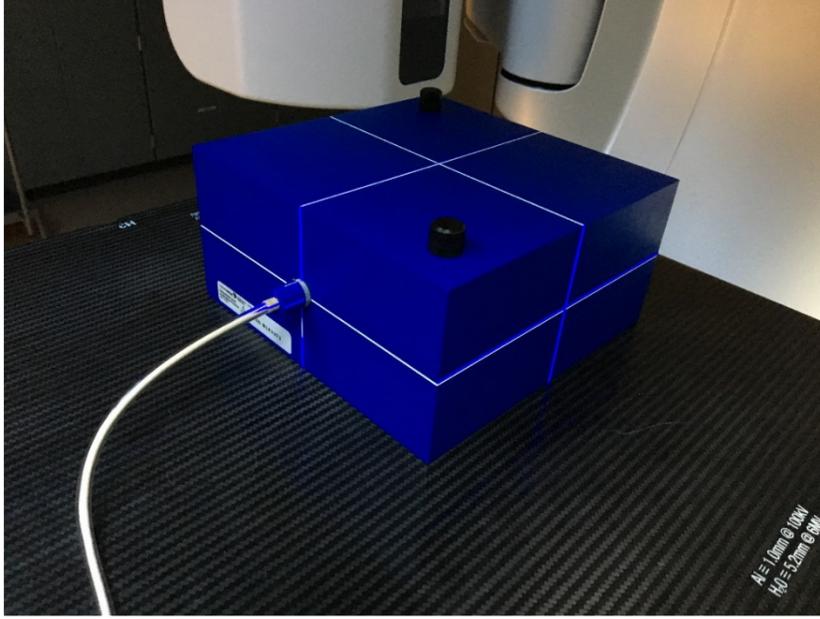
Figure 6 - STEREOTACTIC DOSE VERIFICATION PHANTOM WITH A26 CHAMBER

Next a reference MU of 100 is delivered to the phantom setup. This reference dose

measurement is recorded in units of nC or mR, depending upon the electrometer used. Then

the patient specific plan is loaded at the treatment console. Before beam delivery, a cone-beam

CT scan is acquired and registered with the planning CT dataset to minimize setup errors. Then

each arc is delivered to the phantom and the reading from the electrometer is recorded. The

reference dose measurement and the reading(s) acquired from the patient specific plan can be

used to calculate the dose measured in the active volume of the detector. Equation 4

represents the relation between the reference dose measurement to the plan dose

measurement.

$$D_P = TMR_{ref} * \frac{R_{plan}}{R_{ref}} \frac{1cGy}{MU} 100MU \qquad [4]$$

TMR_{ref} – The tissue maximum ratio for a 10x10 cm^2 field, for a known energy, depth 5 cm, set to 100 cm SAD
R_{plan} – The reading measured by the electrometer from running the patient specific planned field
R_{ref} – The reading measured by the electrometer from a 10x10cm^2, 100 MU, depth of 5 cm field
D_P – The calculated dose reading from the measured patient specific planned field

13

The TMR and reference reading, for the same setup, allows additional arc measurements to be calculated in units of cGy. The dose value (D_P) is compared to Eclipse's dose predicted value. UVH's ideal and acceptable agreement for each arc measurement and the cumulative sum is within 3% and 5%, respectively.

Performing the IC measurement presents a few advantages over other QA techniques. This technique allows for the determination of an absolute dose point comparison to the treatment planning system (TPS) whereas other QA techniques may only make relative dose comparisons. Additionally, temperature and pressure correction factors aren't required because the correction factor would cancel out due to R_{plan} and R_{ref} both needing the correction. Other advantages of this technique are the integration of the CT images and imaging aspect into the QA process. Also, this QA technique involves a relatively simple calculation only requiring the use of a TMR for a standard field size and depth. Therefore, it limits the introduction of additional uncertainties. For example, if R_{ref} was measured off-axis and for a different field size then additional correction factors would have to be introduced and thus increasing the total uncertainty. There are a few disadvantages to this technique, in that the physicist needs a to spend time setting up and aligning the phantom. Additionally, the QA process is quite involved which can lead to greater possibilities of operator error. For example, when loading the QA plan at the treatment console there are options to set the couch rotation option to 0° throughout the beam delivery process. If the operator selects this option, it will lead to erroneous results as the QA plan includes couch rotation.

Portal Dosimetry

Portal Dosimetry,[17] supplied by Varian, is a software platform used to verify intensity modulated plans on the MV imaging panel. The panel, also known as the electronic portal imaging detector (EPID), is an amorphous silicon flat panel (aS1200) that extends from the base of the gantry to isocenter. The panel includes an active imaging area of 43.0 x 43.0 cm^2 with a pixel matrix of 1280 x 1280 and a spatial resolution of 0.035 cm (76 dpi).[18] This resolution is sufficient in making small field dose profile comparisons. For comparison, the UVH film analysis is performed at 96 dpi and this dpi can be greatly increased (e.g. 12,800); although there is diminishing returns as the dose gradient is already well characterized.

The radiation plan is delivered to the panel and the signal generated is recorded. During delivery, the couch remains at 0° and the gantry rotates with MLC/jaw motion, dose rate, energy, etc., as it would for the patient treatment delivery. This measurement method falls under the category of a perpendicular field-by-field analysis as classified by TG-218.[19] The recorded information (fluence) is represented in a matrix of pixels calibrated in units of calibration unit (CU). This matrix of CUs can be compared to a predicted dose distribution created in the software. The software component consists of a 2-D convolution portal dose image prediction (PDIP) algorithm that predicts the fluence delivered to the EPID. The measured and predicted fluences are compared in the Portal Dosimetry workspace using the gamma analysis test. This graphical user interface comparing the measured and predicted fluences is displayed in Figure 7.
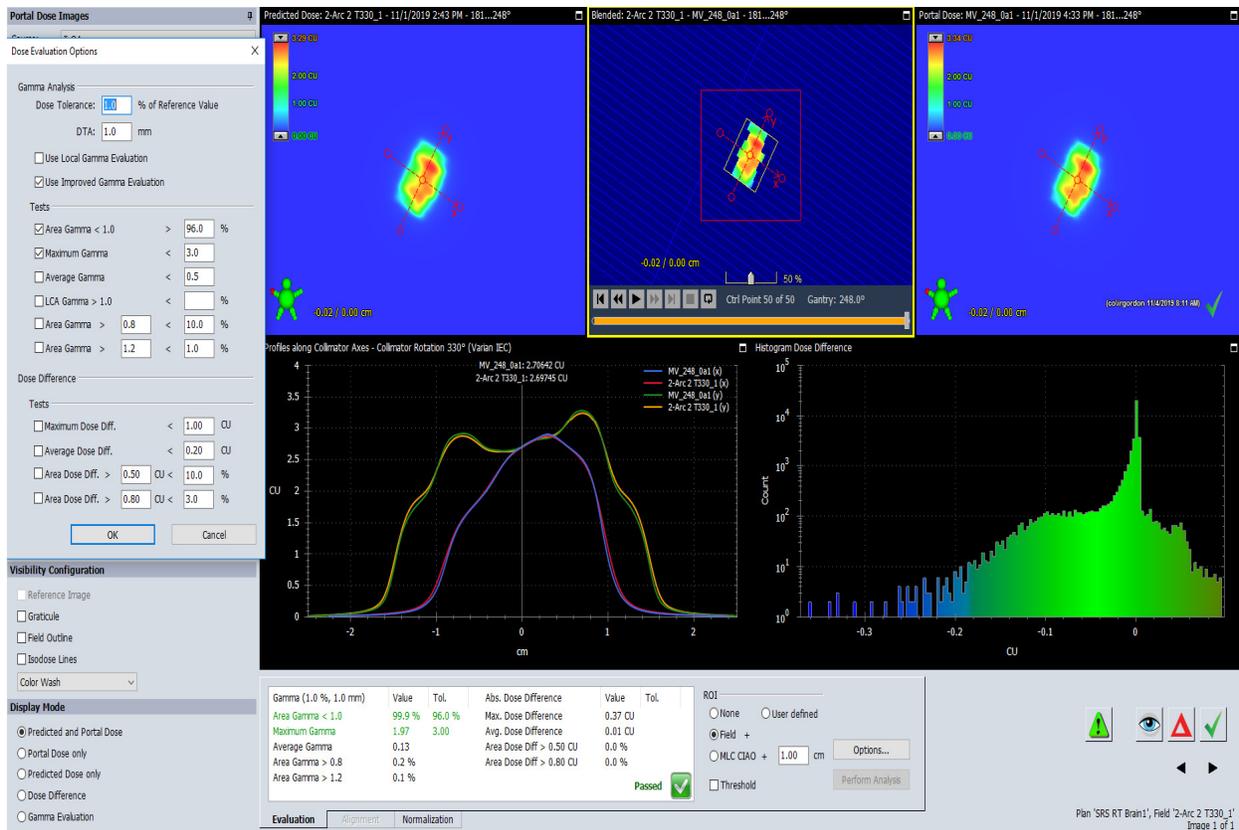
Figure 7 - PORTAL DOSIMETRY WORKSPACE: GRAPHICAL USER INTERFACE

The gamma analysis criteria consisted of a dose difference and distance-to-agreement of 1% and 1mm, respectively. This gamma analysis showcases that 99.9% of the points compared have a gamma value less than 1. It should be noted that for the analysis of each arc, it is split into multiple subarcs. The arcs are split to avoid masking potential dose delivery errors in a composite dose analysis.

The advantages of performing the PD QA is it is integrated into the software of the department's TPS and LINAC. For example, the PD plan can quickly be computed in the Eclipse workspace within a few mintutes. Then if the therapists have a ~5-10 minute open timeslot, they can perform the QA as it only requires the MV imaging panel to extend and doesn't

require the setup of a phantom. The disadvantage to using this QA technique is it isn't exactly independent from the LINAC system and it doesn't include the couch rotations in the QA plan.

Setting up a Portal Dosimetry QA program requires commissioning the PDIP algorithm and calibrating the MV panel. The following is required to calibrate the hardware: a dark field calibration, a flood field calibration, and an imager dosimetry calibration.[17] The dark field calibration consists of measuring the response of each detector without the beam turned on and setting this value to 0. Then a flood field calibration is acquired where the gain of each pixel is adjusted to produce a uniform image intensity. These two calibrations must be done for each energy and dose rate combination. Afterwards, a dosimetric calibration is performed consisting of a beam profile correction and a dose normalization. The beam profile correction is applied by introducing a diagonal profile that reintroduces the non-flatness of the beam. For the dose normalization, a CU is assigned for a 100 MU 10x10 cm^2 field. Lastly, configuration of the PDIP algorithm requires intensity profiles, fluences, absolute calibration parameters, and output factors.[17]

Film Calibration

In addition to portal dosimetry, film is also able to verify the accuracy of the relative dose plane with the added benefit of being an end to end (E2E) test. Film QA is categorized as an E2E test as it includes processes from start to finish (e.g. CT simulation to plan delivery). Film has additional advantages over other available QA tools in clinic which includes the films near tissue equivalence, its self-developing property, the affordable pricing, the range of dose response, and most importantly, its micrometer resolution. The delivery of the film in the phantom allows for a true composite method (dose measurement method).[19] All beam delivery and machine

parameters are kept the same as the original patient plan when irradiating the phantom except for the total MU due to the limited dose range of the film. Therefore, the total MU delivered to the film is scaled down.

The film used in performing the pretreatment quality assurance is Gafchromic RTQA2 film.[20] It is advertised for the use of LINAC QA (e.g. light/radiation field coincidence, starshots, etc.) and has been adopted into the clinic due to its ample abundance. The Gafchromic film consists of 4 layers, first a yellow polyester, a pressure sensitive adhesive, an active layer, and a white polyester. The active layer displays a significant change in optical density (OD) following irradiation, which can be correlated to a known dose.

To compare a measured axial plane of dose to the TPS, a sensiometric curve is required to convert OD to dose. This curve is generated using the fragment calibration method which involves irradiating film pieces with a known dose varying from 0 to 400 cGy. This dose range was selected to operate in the region to be more sensitive to the change in OD per change in dose. Following irradiation, the film pieces are scanned, and the OD is measured using ImageJ.[21] Then a 4th order polynomial trendline is fitted to the measured OD to establish the correlation to dose. The sensiometric curve generated from the fragment calibration method is shown in Figure 8.
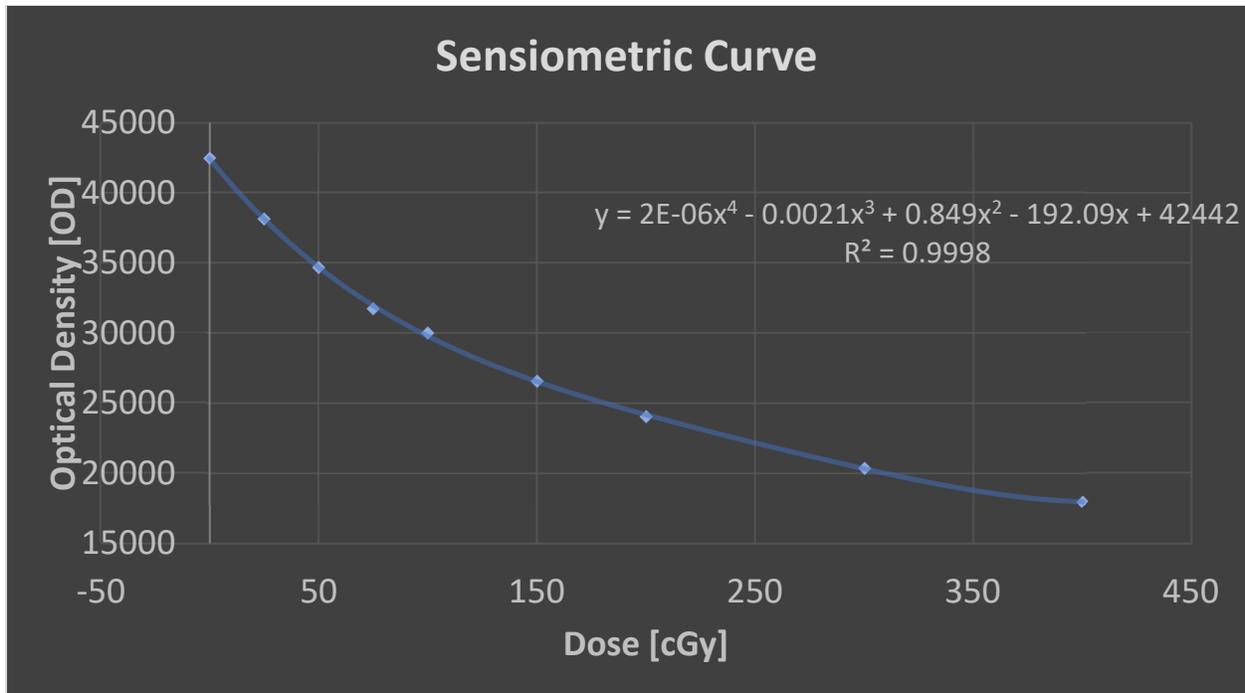
Figure 8 - SENSIOMETRIC CURVE

An axial dose plane from the patient plan is measured on film by creating a verification plan in Eclipse that takes the field parameters and recalculates the dose onto stereotactic dose verification phantom with a film slab instead of the ion chamber slab. Figure 9 displays the film being positioned onto the blue slab (a piece of the stereotactic dose verification phantom) and then with the top plate screwed into place.

19

Figure 9 - LOADING THE FILM INTO THE STEREOTACTIC DOSE VERIFICATION PHANTOM

This phantom, with the embedded film, is set up in the treatment room and a CBCT scan is taken to further align the phantom to the expected treatment position. Once in position, the phantom is irradiated using the same treatment parameters in the clinical plan except with the MU scaled to the dose range of the film. Afterwards, a square film (~6.35 cm x 6.35 cm) is placed on a 5 cm thick solid water block. The film is aligned to the light field crosshair and an additional 5 cm solid water block is placed on top. The SSD is then set to 95 cm which places the film at isocenter. This film fragment is irradiated to a known dose, and it used to scale the sensiometric curve when calibrating the axial plane of dose film.

The three pieces of film scanned on the Epson 10000 XL scanner include: the axial dose plane, film fragment(s), and a background film. Since, multiple films are to be scanned, they are centered on the scanner and placed in a vertical fashion where the aggregate of films form a straight line that is parallel to the scan direction.[22] As previously reported,[23–25] lateral scan effects (LSE) can be created due to the scan field being ununiform, which can lead to significant discrepancies between the expected OD of the film and the measured OD. This effect was

www.manaraa.com

investigated by taking two scans of the same irradiated film at the center and at the edge of the scanner. It was found the LSE is negligible for all films scanned at the center.

The film fragment irradiated after the axial dose plane film is loaded into ImageJ. The OD from the film fragment is measured and compared to the expected OD from the sensiometric curve of the same dose. The ratio of these two values is taken and used to scale the entire sensiometric curve, which is then used to calibrate the film with the axial dose plane from OD to cGy. Once the dose plane film is scanned in, it is also loaded into ImageJ. The film is cropped and split into the three-color channels (RGB) where the red channel is selected and edited for the remainder of the film analysis. The red film channel is shown to have a greater change in OD per unit of dose than the other two channels.[22] This effect is desirable as the film displays the greatest sensitivity to changes in dose. This effect is preferable when compared to the extremes. The first extreme is that the film is highly insensitive to the delivered dose, thus resulting in the noise drowning out the sensitivity of the delivered dose. Additionally, the scanner may be limited by its color bit depth where it would be unable to detect a slight change in the OD. The other extreme would be that the film is highly sensitive to ionizing radiation where other ambient radiation can add additional noise to the film. The dose plane films matrix of OD is then calibrated (units from OD to cGy) using the newly created sensiometric curve. Next, a 3D median smoothing filter with a radius of 3 pixels is applied to smooth out any existing film defects and any scanner and scanner bed artifacts that may be the result of imperfections in the glass or dust particulate.

Then, the matrix of dose from the film QA is exported and it is formatted before it can be imported into Portal Dosimetry (PD). Additionally, the axial dose plane corresponding to the

center of the film from the verification plane (from the QA plan) is also exported from ImageJ and formatted before importing into PD. PD was originally designed with the intent of comparing the measured dose from the EPID to the PDIP algorithm. However, in its simplest form, PD is just comparing two matrices of data via a gamma analysis. Therefore, the film is formatted in a manner that allows for the PD software to read the file information and to allow comparisons of the film to an axial plane of dose. A drawing exchange format (.dxf) file is required to successfully import the file. There are a few items that must be specified in the header of the file. Those items include the matrix size (image dimensions, e.g. 512 x 512) and the resolution of the image. Extra information that isn't required to import the file, but it is important from an accuracy standpoint, includes the patient's name, id, the field size, the energy, and other miscellaneous details. The complete file header is included in Appendix A. After the file has been appropriately formatted, it can then be imported into the PD workspace. Finally, a gamma and visual profile analysis is performed by comparing the measured dose distribution to the TPS calculated dose distribution. Figure 10 displays an example of this comparison.
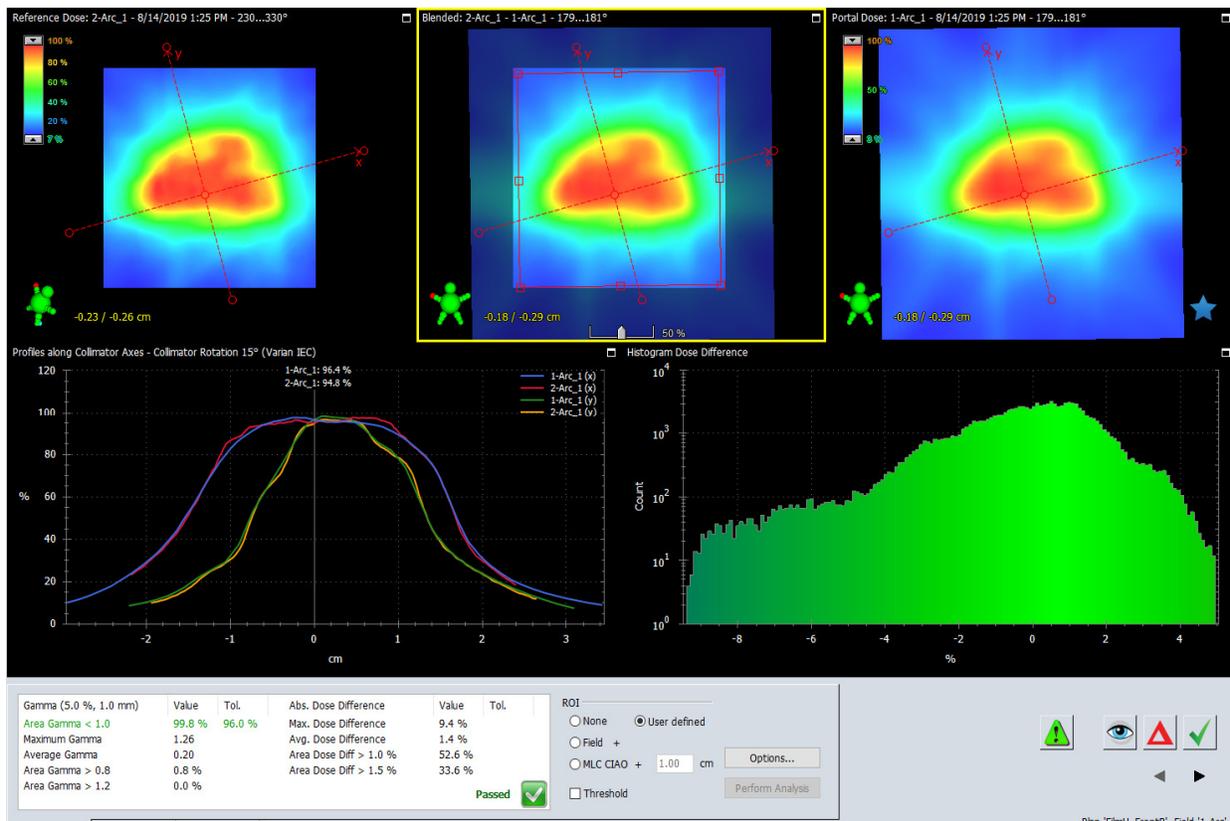
Figure 10 - PORTAL DOSIMETRY: FILM COMPARISON

For this gamma analysis (in Figure 10), a distance-to-agreement and dose difference tolerances of 1 mm and 5%, respectively are used. A normalization mode of relative was set with the option of minimizing the difference between the two datasets. In this comparison, one of the most important parameters, is ensuring the dose fall-off agrees. The Portal Dosimetry analysis can also assess dose fall-off. However, the film workflow includes components that are more representative of a SRS case. For example, this film analysis involves delivering the patient's plan onto a CT dataset that includes the phantom and film, while the PD QA doesn't include a CT dataset. Additionally, couch walkout uncertainties are included in this test. Lastly, the comprehensive writeup regarding the entirety of the film QA process is included in Appendix A.

IMSure

IMSure[16] is a secondary independent calculation software that compared its calculated MU and dose to a point against the TPS. After the planning approval step, the dosimetrist will export the plan information and CT dataset into this software to make the comparisons. This is done for every SRS case prior to treatment. This software is a 3-source model developed at Stanford University that models scatter from the main photon source, the scatter from the flattening filter, and the scatter created by the main collimators. Once the plan has been planning approved, the QA has been performed, and the IMSure check has been calculated, the case is sent over to the physicist for review.

Physicist Plan and Contour Review

Prior to treatment delivery, the physicist will perform an initial chart check of the patient's plan. This check is performed to, "ensure compliance with the prescription, no clinically significant deviations are present, and that all information necessary for the therapists to deliver the treatment has been provided".[26] When OAR contours are completed, the physicist will review those structures. Items that are reviewed include: if density overrides were used (if applicable), the use of high-resolution segments, verifying the body contour, if the user origin is set correctly, and the contour accuracy. Checking the contours ensures the plan is most representative of the patient anatomy, and to prevent undesirable consequences. For example, if there is discontinuity between the brain stem axial slices, the fluence optimizer may try to put some amount of dose through that axial slice to aid in covering the PTV. After contour review, the physicist will perform an additional review but of the treatment plan once it has been approved by the physician. During this check, the physicist will perform a comprehensive

evaluation of the plan and available documentation. The physicist will review the physician's prescription and if the plan follows it. There is review of the documentation such as diagnostic scans/reports, pathology findings, previous radiation treatment (if applicable), and if the patient has consented to the treatment. Next the plan quality and pretreatment QA is evaluated. The physicist will review the PTV coverage, OAR sparring, the SRS plan metrics (e.g. CI), isodose lines, if the appropriate imaging is added, and reasonable MUs for the dose prescribed.

Lastly, the physicist will review the pre-treatment QA tests and the 2nd independent check to determine if there are any items that require further investigation prior to treatment. For example, in the film analysis, the relative dose fall-off measured from the film is compared to the TPS dose fall-off via gamma analysis. If for example, there was a considerable discrepancy in the two dose fall-offs, this would serve as an alert to the physicist to investigate this finding. One cause of this discrepancy, for example, might be due to a MLC positioning error. Once the plan is deemed acceptable and all potential items of concern have been addressed, the physicist will approve the treatment plan.

Treatment Procedures

Once the physicist has reviewed the patient treatment plan along with the results of the QA and if the plan is deemed clinically acceptable, the plan is ready for treatment delivery. On treatment day, the Encompass SRS Immobilization System is placed onto the 6 DOF couch using the lock bars. Then the patient is asked to lay on the system in a headfirst supine position mimicking the setup during the CT simulation. The ancillary devices used during the CT simulation are also included, such as a plastic headrest, toeband, and/or a knee cushion. The

QFix Encompass mask, created during CT simulation, is placed onto the patient's head with a shim setting of 2 (the default setting). If the mask is too tight or too loose, the shims are adjusted until a very snug but tolerable fit is achieved. The therapists in the room will make the appropriate marked isocenter shifts in the vertical, longitudinal, and lateral directions to the planned isocenter. Additionally, the therapists will simultaneously interface with the VisionRT system to assess if any residual shifts remain and if there are any rotational shifts that need to be addressed. The VisionRT system is continuously left on to achieve a steady thermal state which results in improved sub-millimeter stability while monitoring treatment delivery.

After the patient has been setup on the couch and VisionRT agrees with the spatial location of the patient, the therapists will exit the vault to perform imaging. At this point, the physicist is called into the console area to oversee the imaging. First, a CBCT scan is acquired to perform an image registration between the planning CT and the current patient setup. An auto-matching tool in the image registration software is used to easily address any remaining translational and rotational misalignments. After the registration is reviewed by the therapists and the physicist, the shifts are made and a 2nd CBCT scan is taken with the physician present. An advantage to taking a 2nd CBCT other than confirming the shifts, is to also verify the clearance between the gantry and the patient and support structures while the couch is at 0°. At the same time, a reference surface is captured on the VisionRT system to record the current spatial location of the patient and to monitor for any deviations from the CBCT based alignment throughout the course of the treatment. The physician and physicist will jointly review the overlaid CBCT images to verify the alignment of the patient. If the images agree, an AP MV image is taken using the EPID panel to confirm alignment of the skull as a final, independent

26

verification before delivering the beam. The use of the MV panel allows for verification of the

CBCT imaging alignment system, thus confirming the patient is in the correct setup position.

The AP MV image is most sensitive to misalignments in the lateral and superior/inferior

directions. Vertical misalignments may manifest as a magnification error between the two

image comparisons. It could be argued that a lateral (orthogonal to the AP image) MV image

would highlight possible vertical alignment discrepancies. However, with the verification of the

spatial alignment of the patient with the MV image and the initial feedback from VisionRT, it is

deemed that the lateral MV image would provide little benefit. Once these images are

determined to also match, the treatment delivery begins. Throughout the course of treatment,

the VisionRT shift readouts are closely monitored. In the event there was a sustained shift

greater than 1mm, the beam is immediately turned off, and the patient is reimaged with a CBCT

scan at a couch angle of 0° to verify the accuracy of the patient's spatial alignment. Additionally,

to expedite the time of treatment, the couch and gantry angles are ordered in a sequence that

reduces the total rotational time. For example, if there are 4 couch angles, 0°, 45°, 90°, and

315°, the first couch angle will be 0°, since it is easiest to acquire a CBCT scan. The remaining

couch angles will then occur in the following order, a 45°, 90°, and 315°.

Commissioning

The Acuros External Beam Algorithm[27] (Acuros XB 15.6.05) is used in calculating dose distributions for stereotactic cases. The algorithm deterministically solves the linear Boltzman transport equation. This algorithm is known for its quick, accurate dose calculation, especially with GPU acceleration. Uncertainties in the XB algorithm arise from the discretization of solution variables in space, angle and energy.[27] Additional uncertainties exist in how the algorithm handles charged particle coulombic interactions. An overview of the calculation steps, as provided by Varian,[27] is included below.

1. Creating a physical map material

2. Transporting the components of the photon beam source model (primary and secondary photon source, and electron contamination source) into the patient

3. Transporting the scattered photon fluence in the patient

4. Transporting the electron fluence in the patient

5. Calculating the desired dose mode (dose to medium or dose to water)

As seen in the first calculation step, Acuros requires the mass density and material for each voxel which is supplied by Eclipse through a conversion of HU values.

Before any radiation transport in the patient medium, the radiation from the head of the linear accelerator must be characterized. As outlined in the Eclipse Photon and Electron algorithms reference guide, [27] there exists an accurate parameterized model of the radiation output from the linear accelerator. The parameters of the model are modified by parameters inputted by the user to construct a customized phase-space specific to the treatment machine. For each LINAC energy, the phase space file defines the fluence and energy spectrum.

28

To commission this algorithm there are a variety of measurements that need to be inputted into the Beam Data workspace in Eclipse. The beam model at UVH was configured using the TrueBeam Representative Beam Data (TBRBD). Table 3 lists the required scans needed to configure the open field.

Table 3 - SCANS REQUIRED TO CONFIGURE AN OPEN BEAM (ADAPTED FROM ALGORITHM REFERENCE GUIDE[27])

Measured Parameter	Scan Axis Depth [cm]	Field Size [cm^2]
Depth Dose Curves	Central Axis	FS < 10x10, 10x10
		10x10
		Intermediate Field Sizes.
		Largest Field Size
Profiles	dmax, 5, 10, 20, & 30 cm	FS < 10x10
		10x10
		Intermediate Field Sizes
		Largest Field Size
Diagonal Profile	dmax, 5, 10, 20, 30 cm	Largest Field Size
Output Factor	5 cm depth ≤ 15 MV	See Table 4.
	10 cm depth for > 15 MV	

The list of field sizes for the output factors is listed in

Table **4**.

Table 4 - OUTPUT FACTORS REQUIRED TO COMMISSION ACUROS (ADAPTED FROM ALGORITHM REFERENCE GUIDE[27])

Field Size [cm/cm]	3	5	7	10	15	20	30	40
3	3x3	3x5	3x7	3x10	3x15	3x20	3x30	3x40
5	5x3	5x5	5x7	5x10	5x15	5x20	5x30	5x40
7	7x3	7x5	7x7	7x10	7x15	7x20	7x30	7x40
10	10x3	10x5	10x7	10x10	10x15	10x20	10x30	10x40
15	15x3	15x5	15x7	15x10	15x15	15x20	15x30	15x40
20	20x3	20x5	20x7	20x10	20x15	20x20	20x30	20x40
30	30x3	30x5	30x7	30x10	30x15	30x20	30x30	30x40
40	40x3	40x5	40x7	40x10	40x15	40x20	40x30	40x40

The beam data listed in Table 3 and

TABLE **4** is compared to the TBRBD via gamma analysis. Once the data is in good agreement, the

TBRBD is imported into the treatment planning system and used to configure the photon beam

source model.

Beam modifying information is also inputted into the TPS which includes but is not

limited to the jaw transmission factor, the dosimetric leaf gap, & the MLC transmission factor.

 Once all this data has been imported, the beam model is further configured by optimizing the

parameters, listed in Table 5, to match the TPS's calculated distribution with the measured

distribution.

Table 5 - MACHINE PARAMETERS TO BE OPTIMIZED

Machine Parameters
Photon Energy Spectrum
Mean Radial Energy
Location off virtual second source, X & Y collimator jaws, and MLC
Relative intensity of the virtual second source, energy and size of the second source
Material of flattening filter

This step is performed by using an objective function consisting of a total gamma error metric and a penalty term. Similarly, to the comparison of the TBRBD to the measured data, this gamma error metric will compare calculated data points to measured data points by considering dose differences and distances to agreement. The penalty term is added into account for noise, increasing mean energy, an increasing intensity profile, and unphysical second source parameters.

Lastly, the Acuros parameters set in calculating a dose distribution are displayed in Figure 11.

Calculation resolution in cm	0.25
Calculation resolution in cm for SRS and HyperArc™	0.125
Field normalization type	100% to isocenter
Dose reporting mode	Dose to medium
Heterogeneity correction	ON
Plan dose calculation	OFF
Use GPU	Yes
Automatic high-density material	Bone
Maximum automatic high-density volume in cm³	0.5

Figure 11 - ACUROS XB CALCULATION SETTINGS

A calculation resolution of 0.125 cm is selected to provide a better representation of the dose differential across the medium, especially at inhomogeneous interfaces. Lastly, to ensure an expedient calculation time, GPU acceleration is turned on.

VisionRT

SRS treatments deliver a limited number of fractions (e.g. 1-5 fractions) to their target with tight margins to the CTV (0-2 mm) with a high dose of radiation. A potential miss of the target(s) can lead to damaging nearby healthy tissue with the risk of irreversible effects to the patient. Additional challenges arise when the targets are adjacent to a critical structure such as the brainstem, which is commonly seen when treating the trigeminal nerve. These risks are further exacerbated when treating patient with a frameless mask where there is the possibility of movement from the patient during treatment delivery.

One method to minimize such risks is to incorporate the use of surface tracking. Utah Valley Hospital uses surface guided technology (VisionRT) for all SRS cases. The Vision RT system consists of a three-camera pod system that uses stereoscopic video images and a speckle pattern projected onto the patient's surface to continuously capture and reconstruct maps of the patient's surface.[28] Additionally, this technology compliments the Encompass mask system as the mask has an opening around the eyes to allow for surface monitoring of the patient. The system's software then makes a comparison of the reference image to the current patient's setup and the discrepancies between the two are reported out as translational and rotational shifts. Therapists use this information to accurately shift the couch and the patient into the correct treatment position and to monitor for any sub-millimeter movements that may occur during the radiation delivery.

To ensure that the camera pods have not shifted relative to each other, daily QA is performed before any patient treatment.[11] Additionally, monthly QA for the VisionRT system is performed to calibrate the camera pods to the treatment room isocenter. The second part of

the monthly QA is to calibrate the cameras' ability to track surfaces above isocenter. This calibration procedure should be performed in approximately the same lighting as when patients are treated to avoid erroneous feedback from the system. Lastly, periodically and following any Vision RT camera system upgrade, a MV isocenter calibration is performed. Performing the recommended QA tests of the VisionRT system ensures the system is able to accurately predict the shifts needed to correctly setup the patient and serves as an independent check tool for the therapists.

Per TG-147's recommendation,[28] the effects of thermal drift on the VisionRT system was characterized. When the cameras are actively monitoring the location of a static object, the VisionRT system will display a spatial drift in its readout of the object's location. This phenomenon was confirmed by setting up a Styrofoam mannequin head on the treatment couch, capturing the current position of the head with the cameras, and monitoring its location over time. The results for VisionRT's translational thermal drift are displayed in Figure 12.
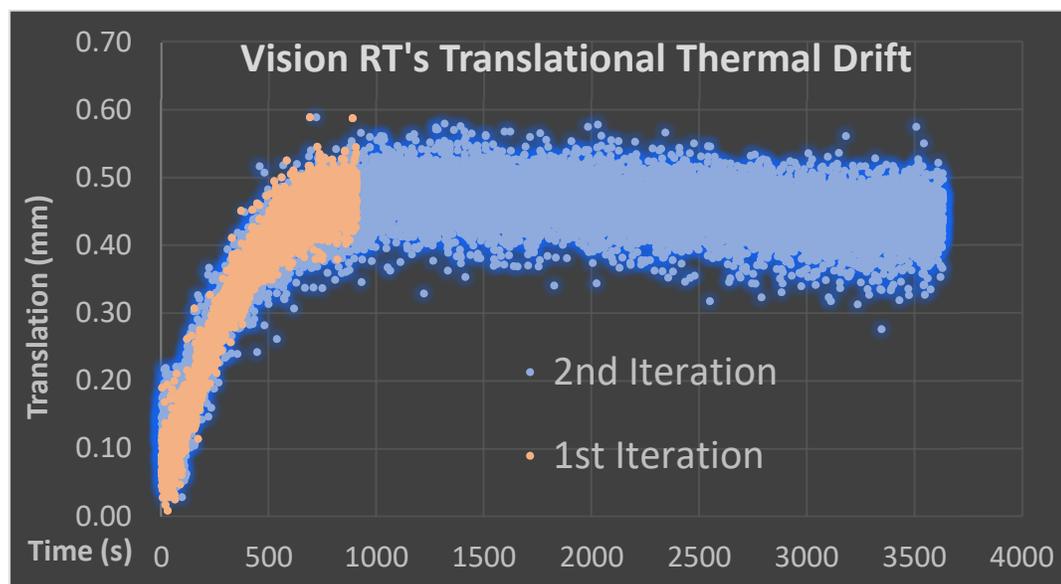
Figure 12 - CHARACTERIZING VISIONRT'S THERMAL DRIFT

The results suggest that in ~10 minutes the thermal drift of the VisionRT system approaches an asymptote. This test was performed twice. In the original setup, tape was used to hold the mannequin head in place. Since the translational shifts are being read out in millimeters, there was concern that over time the tension from the tape may diminish which might cause the mannequin head to slightly shift. Therefore, this test was repeated but without the tape; however, the 2nd iteration shows similar results to the first test.

Machine Specific Quality Assurance

Since SRS delivers radiation treatments with a narrow margin of 1 mm (margin may slightly vary depending upon institution) in 1-5 fractions and with a high dose; it is imperative to characterize and to limit the uncertainties of each step and to compare with the standards recommended by a professional organization. Therefore, recommendations from the Medical Physics Practice Guideline (MPPG) 9.a. document endorsed by the American Association of Physicists in Medicine[29] (AAPM) is commonly referenced to ensure a safe and well-understood treatment delivery process. Recommendations from the AAPM regarding C-arm LINAC QA tests are displayed in Figure 13 which includes the test and its associated tolerance.[30]

TABLE 1 Minimum SRS-SBRT relevant equipment QA and tolerances for C-arm linac systems.

Frequency	Test	Tolerance
Daily	Laser localization — only if using SRS techniques relying on lasers for target localization (e.g., frame-based SRS without X-ray IGRT)	1 mm
	Collimator size indicator for clinically relevant aperture	2 mm total
	Radiation isocentricity test (limited gantry and couch positions) — maximum deviation in center of target object relative to each projection's beam central axis	1.0 mm SRS, 1.5 mm SBRT
	IGRT positioning/repositioning	1 mm SRS, 2 mm SBRT
	Imaging subsystem interlocks	Functional
	Stereotactic interlocks — cone size, backup jaws	Functional
	Accelerator output constancy	±3%
Monthly	Radiation isocentricity test — covering complete range of gantry, couch, collimator positions used clinically — *maximum deviation in center of target object relative to each projection's beam central axis* *Note: If both MLC and fixed conical collimators are used, both must be evaluated at least monthly*	1.0 mm SRS, 1.5 mm SBRT
	Treatment couch position indicators: relative over the maximum clinical range	1 mm/0.5°
	Output constancy at relevant dose rates	2%
Annually	SRS arc rotation mode (if used clinically)	1 MU, 1°
	MU linearity (≥5 MU to highest MU used clinically)	±2%
	Accelerator output	±1.5%
	Coincidence of radiation and mechanical isocenter	±1.0 mm maximum 3-D displacement from center of target object
	Verification of small-field beam data — relative output factors for cones and/or MLC	±2% from baseline for >1.0 cm apertures, ±5% from baseline for ≤1.0 cm apertures
	E2E localization assessment "hidden target test" using SRS frame and/or IGRT system	1.0 mm
	E2E dosimetric evaluation using SRS frame and/or IGRT system	±5% measured vs. calculated

Tolerances are absolute accuracy, not variation from baseline, unless otherwise stated.

Figure 13 - MEDICAL PHYSICS PRACTICE GUIDELINE 9.A. FOR SRS-SBRT[30]

Validation of the Beam Model

Per MPPG 9.A, an end-to-end test was performed to assess the SRS clinical workflow, to evaluate the processes performed at each step and to evaluate the overall treatment accuracy. Additionally, this test was completed to serve as an independent audit on the current UVH SRS program. A head phantom embedded with TLDs, film, and fiducials was ordered from the Imaging and Radiation Oncology Core (IROC) group.[31] After receiving the phantom, a Qfix mask was created for the phantom with the aid of the therapists. Next the phantom was scanned on the Phillips Big Bore CT using the SRS scan protocol. The scan protocol settings are listed in Table 6.

Table 6 - CT SCAN PROTOCOLS FOR SRS H&N PHANTOM

CT Parameters	Value
Thickness [mm]	0.8
kV	120
mAs/Slice	1305
# of Images	368

After importing the CT images into the contouring workspace, the following high-resolution structures were added: Lt and Rt Eye, Lt and Rt TLD powder, a spherical PTV contour (~Diameter of 1.9 cm), an external body contour (encompassing the phantom head and Encompass system), and the Encompass support structures. Additionally, the search body tool was used at a range of -600 HU to generate a surface structure to be used by the VisionRT system. A dosimetrist was tasked with creating a plan to deliver 25 Gy to the target with a maximum dose of 30 Gy. The plan was calculated using the AAA algorithm (Acuros was not

commissioned at the time) with a resolution of 0.1 cm and heterogeneity corrections turned on.

Per our defined pretreatment QA process, the plan was delivered and recorded on the EPID. In Portal Dosimetry, a gamma analysis was performed for each subarc with a dose difference and distance-to-agreement criteria of 1% and 1 mm, respectively. All comparisons had a gamma passing rate greater than 96%.

Next, a point dose measurement was taken with the blue cube phantom. All measurements were within 5% with one measurement coming in just under 5%. The results for each measured arc are included in Figure 14.

Blue Cube + A26 Dose Verification

Date	9/20/2019					Copy plans to this CT dataset		
Patient	zzz SRS, Hamlet					Patient: zzz Stereotactic phantom		
Tx Plan Name	SRS 25Gy					Patient ID: sp11/04/2016		
QA Plan Name	PhanV_SRS25Gy					CT: A26 -H-(Axial Res)-(Slice Thickness)		
Electrometer	CapinTec Model 192							
Electrometer settings	Exp: Med, Charge: 300V					***ADD 10x10 100MU calibration field to verification plan		
Reference Dose Measurement (TrueBeam)						on A26 scan	in H2O phan	Diff
6 FFF, 100MU, 10x10, D5, 95SSD	1.78	1.78		mR	6 FFF, D5, 10x10 TMR	0.904	0.911	0.007
Field Measurements								
	1	2	3	4	Total			
Energy	6 FFF	6 FFF	6 FFF	6 FFF				
Gantry	181-179	310-210	130-30	30-130				
MU	4182.1	1309.4	1340.7	1465.0	8297.2			
Plan Dose (cGy)	1758.1	404.5	412.2	432.9	3007.7			
Reading (mR)	35.03	8.06	8.14	8.93				
Measured Dose (cGy)	1779.1	409.3	413.4	453.5	3055.3			
+/- 3%	1.2%	1.2%	0.3%	4.8%	1.6%			

Figure 14 - BLUE CUBE +A26 DOSE VERIFICATION

The disagreement in the 4th arc may be attributed to the active volume of the chamber measuring in a semi-steep dose gradient region which results in volume averaging or can be the result of the couch walkout being greatest at perpendicular angles to 0 degrees. Overall, the cumulative results are in excellent agreement.

38

After the physics team reviewed the plan, it was determined to be acceptable for treatment delivery. The phantom was setup in the Encompass system by the therapists with the guidance of VisionRT. Also, the attachable ears were placed on the outside of the mask as it's used by IROC as an imaging background measurement. After the VisionRT values were within tolerance, a CBCT scan was taken to correct any residual setup errors. After comparing the CBCT scan to the planning CT and shifting the phantom, the ears were removed, and the plan was delivered to the phantom. Next, an output measurement of the TrueBeam was required from IROC where the TLD was irradiated. This involved setting up a TLD block on a plastic platform with a set SSD of 100 cm and a field size of 10x10 cm^2.

Following irradiation, the phantom was sent back to IROC along with isodose distributions in the coronal and sagittal planes through the center, screenshots showing the TLD contour, the DICOM information (CT, RD, RP, and RS files), and trajectory log files. The gamma analysis results for the film were deemed acceptable. A 5% dose difference and 3 mm distance to agreement were set as the tolerance values. The coronal and sagittal planes had a gamma index of 98% and 97%, respectively. Additionally, the TLD results were deemed acceptable as the average ratio of the measured recorded dose of the TLD as compared to UVH's TPS recorded value was 1.01. The full report can be found in Appendix B.

Winston Lutz Test

Another QA performed, which is also recommended in the MPPG 9.a, is the Winston Lutz test.[32] This test allows for the verification of the congruency between the radiation and mechanical isocenters. The linear accelerator has three mechanical axis of rotation that includes the gantry, collimator, and couch. All three of these mechanical axes intersect at a point known as

isocenter. A small spherical radiopaque ball mounted onto a thin rod is attached to the

treatment couch with various dials to adjust the position of the ball in the x, y, and z planes. The

ball is approximately aligned to isocenter using the intersection of the lasers and evaluating the

projection of the ball's shadow relative to the light field cross hairs. Figure 15 displays the initial

setup of the ball.

Figure 15 - INITIAL WINSTON LUTZ ROD SETUP

Once the ball is visually aligned, MV images using the EPID panel are taken at gantry angles of 0

and 90 degrees. These images are used to further refine the placement of the ball to isocenter.

This test was originally designed to test the coincidence of the radiation and the mechanical

isocenter. However, with the incorporation of the imaging component, one can analyze the

imaging and treatment coordinate coincidence and test the position and repositioning of the

couch, based on the suggested shifts from the imaging system. Once the ball is aligned to

www.manaraa.com

isocenter, a MV image is acquired for various combinations of the gantry, couch, and collimator angles. These images are saved in a DICOM format and they are imported into a software program, such as PIPSPRO, for analysis. An example of the analysis is displayed in Figure 16 where the ball's position relative to the field size is characterized.
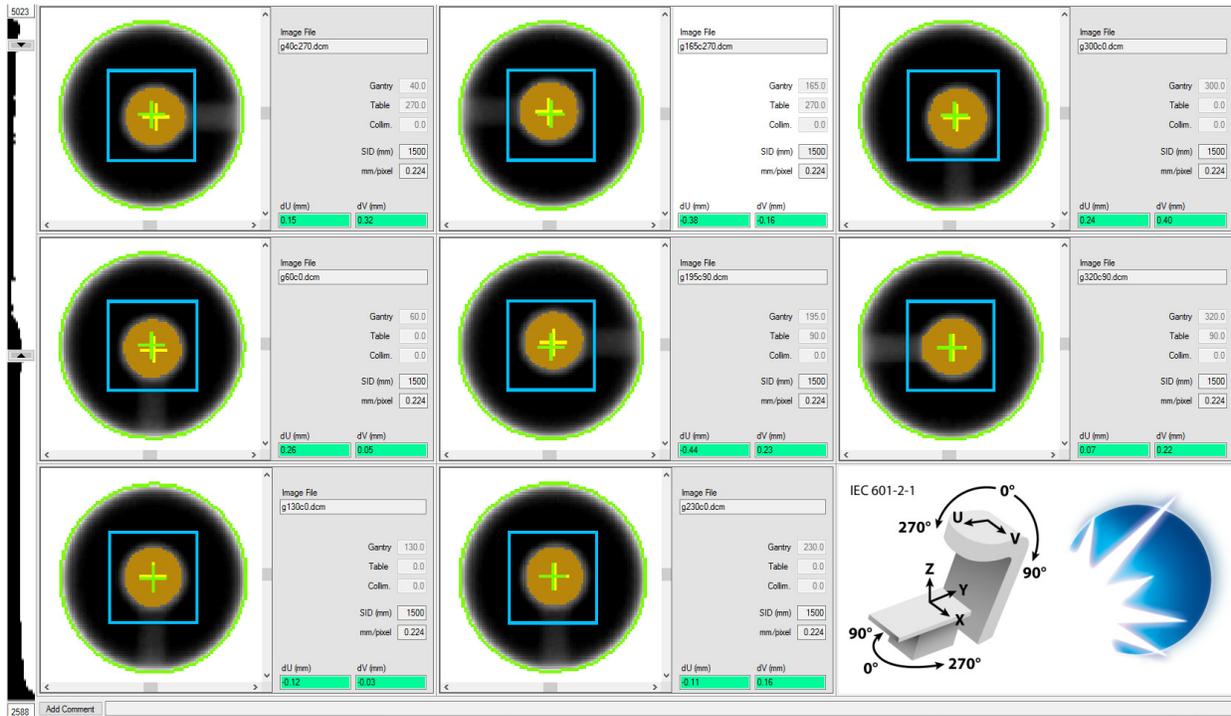

Figure 16 - WINSTON LUTZ ANALYSIS

Performing this test satisfies many of the recommended QA tests outlined in TG 142[33] and MPPG 9a.[30] These image pairs are taken using either a cone or with the MLCs. In all SRS cases, a cone could be used to perform the Winston Lutz test and only for MLC cases the MLCs may be used.

Monthly Output

The constancy of the output for relevant dose rates of the accelerator for all photon and electron energies is verified. To measure the output of the 6 MV FFF beam (the energy commonly used in SRS cases), the gantry, collimator, and couch are set to 0 degrees. A 5 cm thick solid water phantom followed by a 2 cm thick solid water phantom with a hole drilled for an ion chamber is placed on the treatment couch. The 2 cm block contains inscribed black lines with an area of 10x10 cm^2. The blocks are centered using the light field and the inscribed black lines with a set SSD of 100 cm. A thermometer is placed into that cavity to measure the temperature while a barometer is used to record the pressure. These two values are used to correct the ion chamber readings by accounting for the change in the mass of air present in the chamber. Next the thermometer is taken out of the cavity and a PR-06G farmer chamber is placed in its stead, and the chamber is connected to an electrometer with a voltage of 300 V. Once the block is setup, an additional 2 cm block is placed on top of the current setup, putting the chamber at a depth of 3 cm with a SSD of 98 cm. The SSD is set back to 100 cm by adjusting the vertical height of the couch. An example of this setup is displayed in Figure 17.

Figure 17 - MONTHLY WATER PHANTOM OUTPUT SETUP

Once the setup is complete, 100 MU at a dose rate of 1400 MU/min is delivered to the

ion chamber for a field size 10x10 cm^2 with a gantry angle of 0°. A 2nd reading is always taken

for the first measured energy (6 MV) to verify constancy of the chamber. Finally, an energy

measurement is taken by placing 25 brass plates on the central axis and an additional reading is

recorded. Figure 18 displays the readings taken through the 2019 year for output and energy

verification.

| DATE	6FFF d=3.0cm		25 Brass	Output	Energy	Check
1/29/19	71.8	71.7	41.5	0.6%	0.1%	RH
2/22/19	71.3	71.2	41.2	0.5%	0.0%	RH
3/22/19	71.6		41.4	1.0%	0.0%	RH
4/17/19	72.1		41.7	0.9%	0.1%	RH
5/24/19	70.7		40.9	-0.3%	0.1%	RH
6/27/19	71.2		41.2	0.3%	0.1%	RH
7/9/19	71.3		41.3	-0.1%	0.2%	RH
8/29/19	71.3		41.3	0.6%	0.2%	RH
9/23/19	70.9		41.0	-0.5%	0.0%	RH
10/20/19	71.1		41.2	-0.2%	0.3%	RH
11/18/19	71.0		41.0	0.3%	-0.1%	RH
12/22/19	71.5		41.3	0.4%	-0.1%	RH
				-	-	-
				-	-	-
				-	-	-
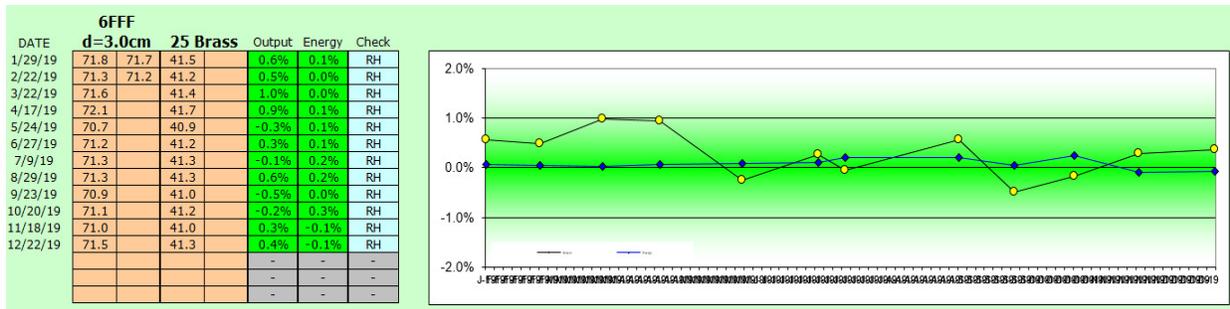
Figure 18 - MONTHLY OUTPUT CHECK ON THE 6X FFF BEAM

The results from Figure 18 showcase the all monthly output measurements were within 1% from baseline. Per MPPG 9.a. recommendation, the monthly output constancy is to be within 2%.

Electronic Portal Imaging Detector QA

At the time of writing this document, there is not a formal document from the AAPM addressing Electronic Portal Imaging Dosimetry (EPID) based QA. Therefore, UVH's EPID QA process is presented here to illustrate steps taken by the Radiation Oncology department to ensure proper operation of the EPID. The EPID QA tests are presented in Table 7.

Table 7 - MONTHLY EPID QA

EPID QA Checks
Graticule Accuracy for Jaws & MLC
X-ray vs. Light for Jaws & MLC
Image Quality
Dosimetric Constancy
Integrated Image Alignment Accuracy
Picket Fence Test
Tongue & Groove Leakage

44

First a test is performed to evaluate the physical and digital graticule accuracy. The physical graticule is slid into the treatment head slot and an image is recorded on the panel. In offline review, the center from the physical graticule is compared to the digital graticule by determining the x and y discrepancies between the two. Next an x-ray vs. light field comparison is made by measuring the distances acquired at the time of image acquisition and the recorded image is then measured. The contrast resolution is assessed with the Las Vegas phantom by evaluating the number of distinguishable holes of different depth and diameter. A dosimetric calibration check is performed by delivering 100 MU to the panel and going into the PD workspace and analyzing the max CU recorded at the central axis and comparing this value to baseline. An image alignment accuracy is checked by using the PD software to match the expected dose distribution with the measured dose distribution. These values are tracked to serve as a constancy check of panel positioning vs. the treatment beam. A MLC performance test is conducted through the picket fence pattern where the MLCs move in unison to programmed positions with a small amount of MU delivered at each dwell position. This test is designed to identify any possible MLC positional or speed errors. Finally, a tongue and grove leakage constancy check is performed by measuring the highest recorded dose in units of CU measured with the MLCs in a closed position.

Mechanical QA

Mechanical quality assurance tests are performed on a monthly basis to ensure continuity in the accurate radiation delivery of the LINAC. The monthly mechanical checks are listed in Table 8.

Table 8 - MONTHLY MECHANICAL QA

Mechanical Checks:
Gantry/Collimator Angle Indicators
Collimator Walkout
Graticule vs. Crosshair
Mechanical Pointer & ODI Agreement
X, Y Jaws Close Symmetrically Around Crosshair
Field Size Check (Symmetrical & Asymmetrical)

A digital leveler is placed onto the treatment head with the gantry at 270 degrees. The collimator is rotated until the leveler reads out the angle of interest. The collimator readout from the LINAC is then recorded. Figure 19 displays an example of the collimator angles tested with the corresponding measurement.

Collimator Check (Gantry=270°)
Level on inside track of shadow tray

Level	Readout
0°	359.9
90°	90.2
315°	314.9

Figure 19 - COLLIMATOR ANGLE INDICATOR

Next, the gantry angle indicator is verified with the leveler by rotating the gantry to various angles of interest using the leveler and reading out the gantry angle. The recorded results are presented in Figure 20.

Gantry Check (Collimator=0°)

Level	Readout
135°	134.8
90°	89.9
0°	359.8
225°	225.1
180°	180.2

Figure 20 - GANTRY ANGLE INDICATOR

Next, a 1 mm spaced grid paper is set on the treatment couch at 100 cm SSD. An intersection of the vertical and horizontal grid lines is aligned to the central axis light field cross hair. The gantry is returned to 0° and the collimator is rotated from 90° to 270° to discern any noticeable crosshair and light field walkout. Next, the collimator is closed along the crosshair to identify if there are any asymmetries. Figure 21 presents those recorded values.

Collimator "Walk" (180° Rotation): **90°-->270°**

Crosshairs: <0.5	mm	
Light Field: <0.5	mm	
X Jaws close Symmetrically around crosshair:		yes
Y Jaws close Symmetrically around crosshair:		yes

Figure 21 - COLLIMATOR WALKOUT AND SYMMETRY OF JAWS

Next a comparison is made between the optical distance indicator as compared to the mechanical front pointer. Both measurements should read out a distance of 100 cm. The physical graticule is then slid onto the treatment head and its alignment is checked against the

light field graticule. Finally, the independent jaw readouts are compared by the light field projection onto the graph paper. This is done for all 4 jaws (X1, X2, Y1, & Y2) for various positions and again grouping the y and x jaws. Figure 22 and Figure 23 represent the jaw position measurements for the symmetry and asymmetry, respectively.

Field Size Check (Gantry=0° Collimator=0°)

Nominal	Light Field	
	Upper (Y)	Lower (X)
3	3.0	3.0
10	10.0	10.0
20	20.0	20.0
40	40.0	40.0

Figure 22 - JAW POSITION INDICATORS (SYMMETRIC)

Independent Jaw Readouts

Nominal	Light Y1	Light Y2	Light X1	Light X2
-10.0	-10	-9.9	-	-
-2.0	-2.0	-2.0	-2.0	-1.9
0.0	0.0	0.0	0.0	0.0
4.0	4.0	4.0	4.0	4.0
10.0	10.0	10.0	10.0	10.0
20.0	19.9	20.0	20.0	20.0

Figure 23 - JAW POSITION INDICATORS (ASYMMETRIC)

Computed Tomography Quality Assurance

Acquiring a CT scan allows for contouring and treatment planning. It is desirable to obtain an accurate dataset that best represents the patient's anatomy with accurate image quality. Therefore, every month, the CatPhan 604 is scanned and a series of tests, as seen in Table 9, are performed to evaluate CT images.

Table 9 - MONTHLY CT QA

Monthly CT Simulator QA: Image Quality
Image Noise & Uniformity
HU Constancy
Low Contrast, High Resolution
In Plane Spatial Accuracy
Longitudinal Spatial Accuracy

The CT dataset that is evaluated every month is the *SRS HEAD* scan protocol which consists of 0.8 mm slices. Image noise and uniformity (from Table 9) is assessed by measuring the mean HU and standard deviation at the center of the phantom and then the HU at the following locations: 12, 3, 6, and 9'O clock. A region of interest of 1 cm by 1 cm is used when measuring the HU. This process is represented by Figure 24. The HU of each position is expected to be around 0 with an expected standard deviation of 20.
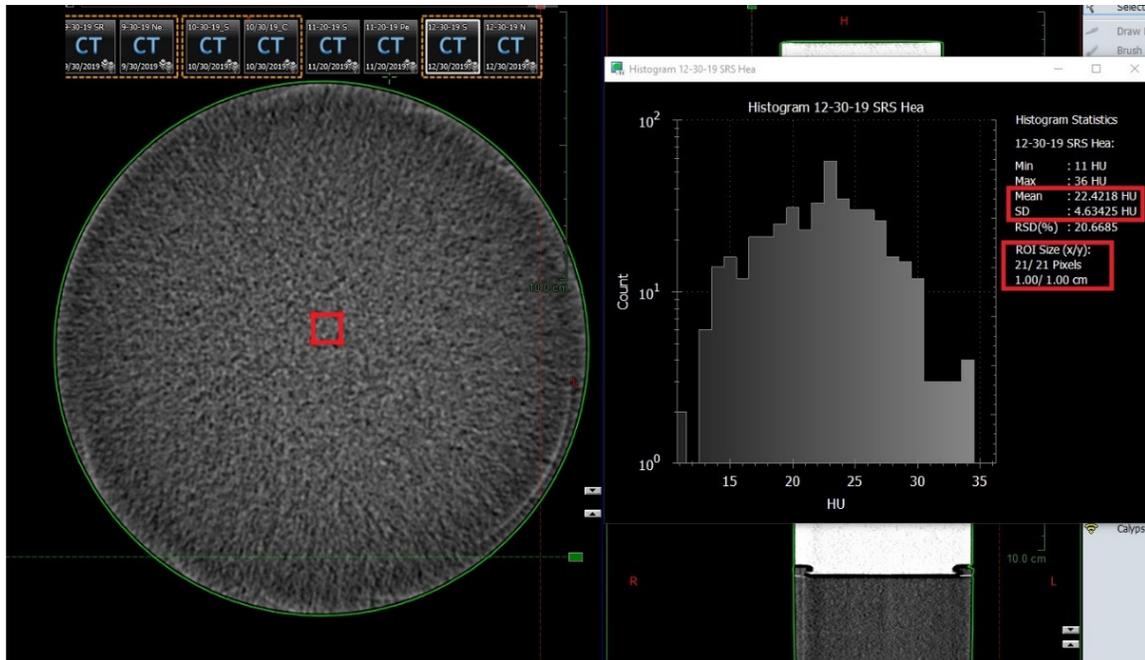
Figure 24 - IMAGE NOISE & UNIFORMITY

Next a HU constancy check is performed by evaluating the various plugs. This is

performed for the following materials: air, Teflon, Delrin, bone 20%, bone 50%, acrylic,

polystyrene, LDPE, and PMP. Figure 25 displays the plugs present in the phantom.
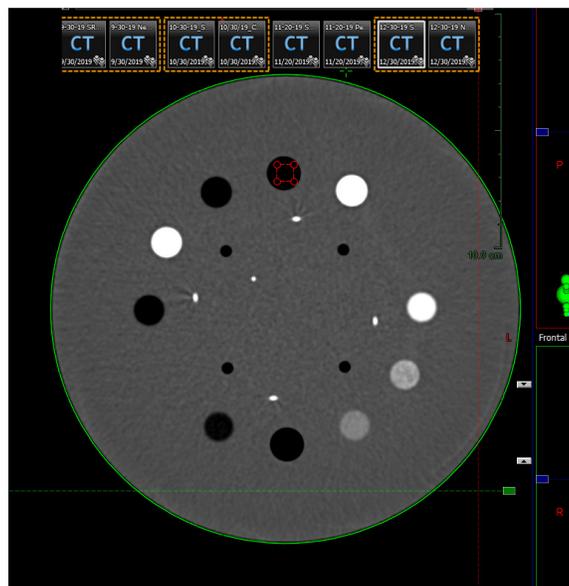
Figure 25 - HU CONSTANCY CHECK

50

Image quality is evaluated by assessing the high and low-resolution contrast. Figure 26 represents low contrast test where the number of visible circles is counted and compared to a baseline.
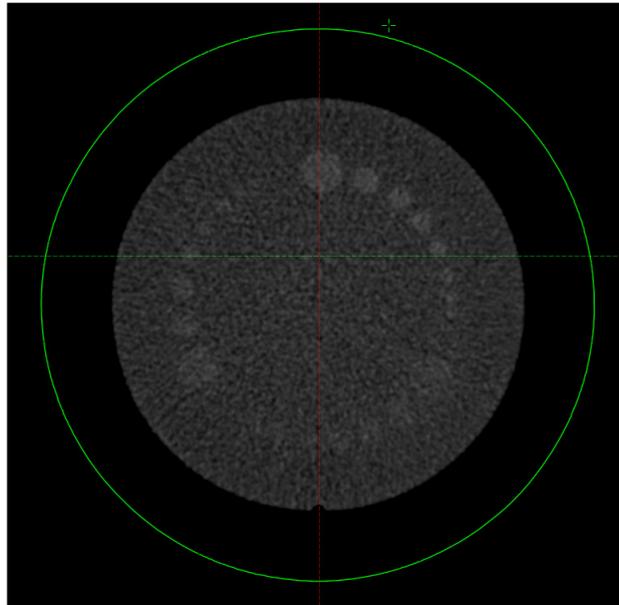

Figure 26 - OUTER LOW CONTRAST

Figure 27 represents the high contrast test where the number of distinguishable line pairs is counted and compared against baseline.
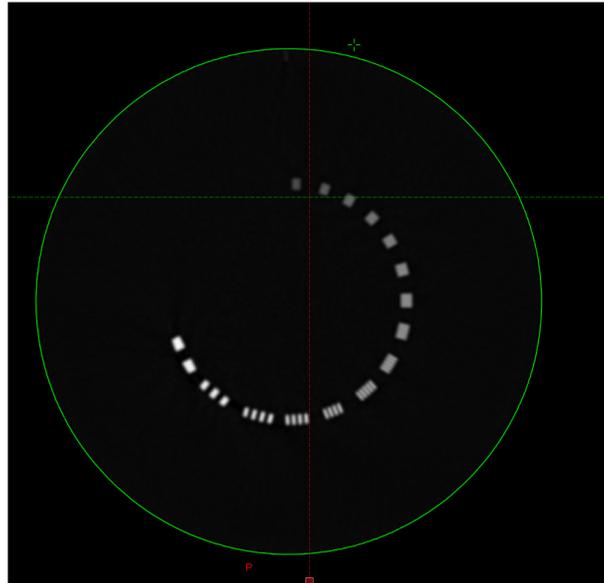
Figure 27 - LINE PAIR RESOLUTION

Finally, the constancy of the in-plane and the longitudinal spatial accuracy is evaluated measuring known distances between objects in the phantom. For example, measuring the distance between the two upper holes that gives a distance of 5 cm and measuring the diagonal distance between two of the holes yields a distance of 7.07 cm. The in-plane and longitudinal measurements are displayed in Figure 28 and Figure 29, respectively.

www.manaraa.com
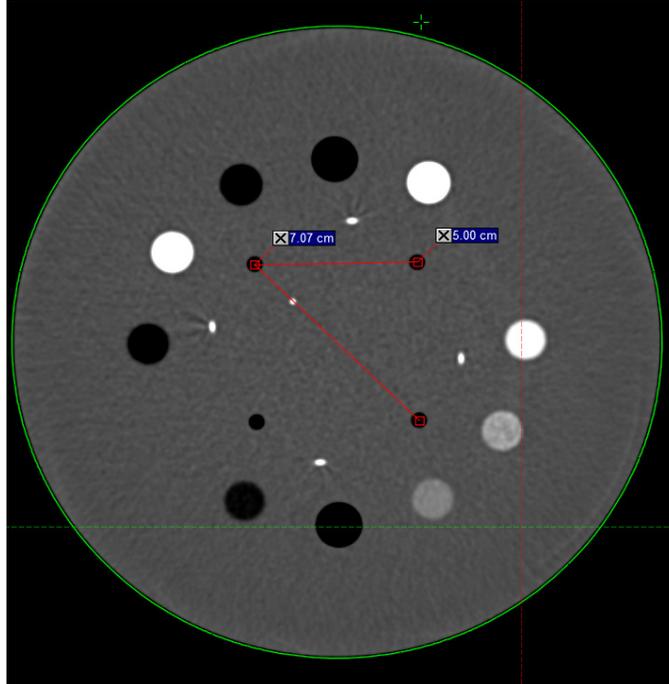
Figure 28 - IN PLANE SPATIAL CONSTANCY
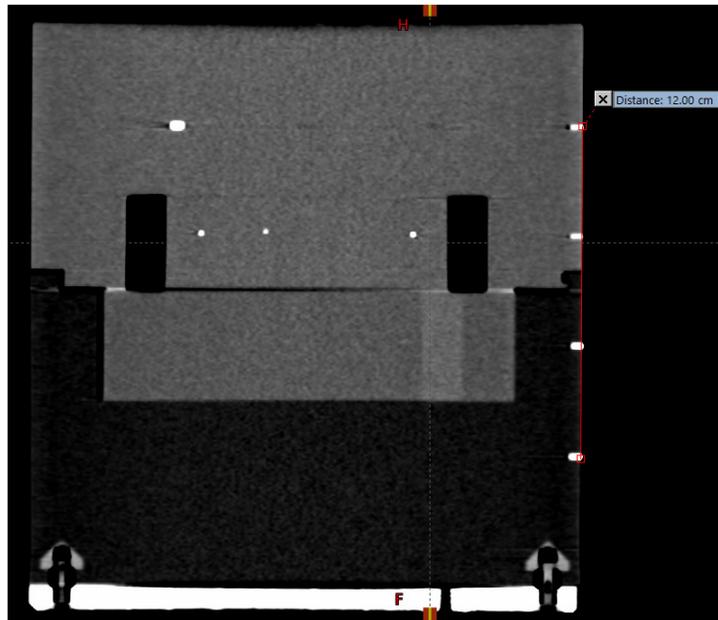
Figure 29 - LONGITUDINAL SPATIAL CONSTANCY

53

Machine Performance Check

Every morning when the therapists perform the daily QA to verify items such as the output, the positioning and repositioning of the couch based on imaging, and other tests, they also run the machine performance check (MPC).[34] MPC is a software package supplied by Varian that performs geometry and beam checks for the LINAC and that data is displayed as a trend chart. A complete list of the checks as performed by MPC are listed in Table 10.

Table 10 - MACHINE SPECIFICATIONS

Geometry Checks	Beam Checks
Treatment Isocenter Size & Location	Beam Output Constancy
Coincidence Between Treatment Isocenter & MV & kV Imaging Isocenters	Beam Profile Constancy
Collimator Rotation Offset	Beam Center Shift
Gantry Positioning Accuracy	
Couch Position Accuracy for 6 DOF	
MLC Leaf Position for Inner Leaves	

This tool does not replace any of the existing QA performed by the department but is an extension of the QA program. Instead, it is complimentary to the current QA program as it provides an immense amount of high precision data on many critical sub-systems of the LINAC, serves as an independent check from the current QA program, and adds confidence to the LINAC performance. An example of the graphical user interface alongside the data displayed is shown in Figure 30.

www.manaraa.com
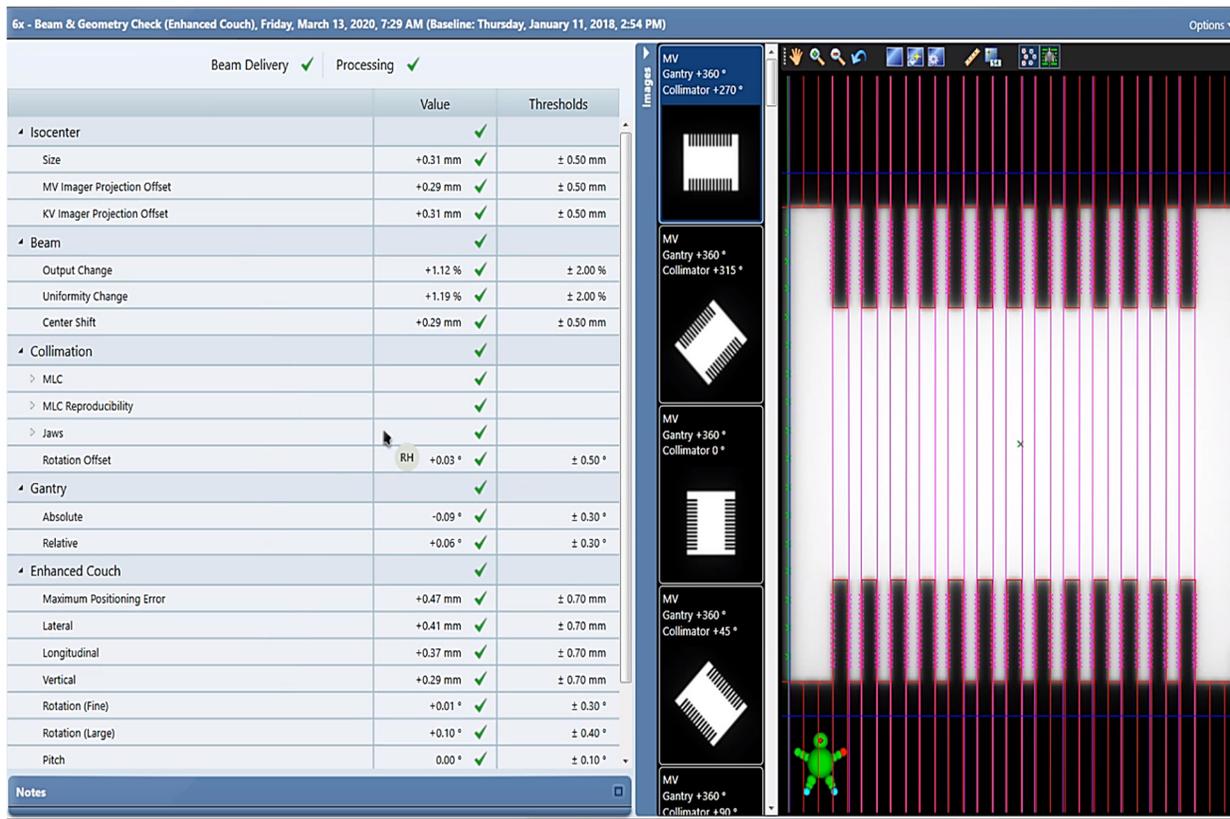
Figure 30 - MACHINE PERFORMANCE CHECK DATA

To give an example of MPC's utility, there was a slight but noticeable trend in the output increasing over time. The physicist performed an absolute calibration (TG51[35]) to bring the beam's output back down. However, before doing so, having the beam output measurement from MPC allowed the physicist to compare that value to the daily and monthly output measurements. It was found that the output measurement for all 3 measurements were in close agreement. Having this additional information from MPC is not critical, but it serves as an additional layer of quality assurance checks.

ACR MR Image Analysis Instructions

The American College of Radiology (ACR) MRI phantom was scanned to evaluate the image quality.[36] The image quality parameters analyzed are listed in Table 11. These tests were

55

selected and performed per the guidance of the ACR guidance document that assists facilities in

performing quality control and system performance testing.

Table 11 - ARC MR INSTRUMENT PARAMETERS

ACR MR Instrument Parameters
Geometry Accuracy
High-Contrast Spatial Resolution
Slice Thickness Accuracy
Slice Position Accuracy
Image Intensity Uniformity
Percent-Signal Ghosting
Low-Contrast Object Detectability

For SRS cases, having high spatial resolution devoid of geometric distortions is

imperative especially due to the tight treatment margins. To evaluate distortions the geometric

accuracy is tested which involves measuring lengths on the images and comparing these values

to the known lengths of the phantom. Following the instructions of the ACR guidance

document,[36] the window level (WL) was adjusted to better visualize the phantom. Then

measurements of the phantom in the in-plane and sagittal plane were measured to be ~190

mm and 148 mm, respectively. Figure 31 & Figure 32 display the length measurements.
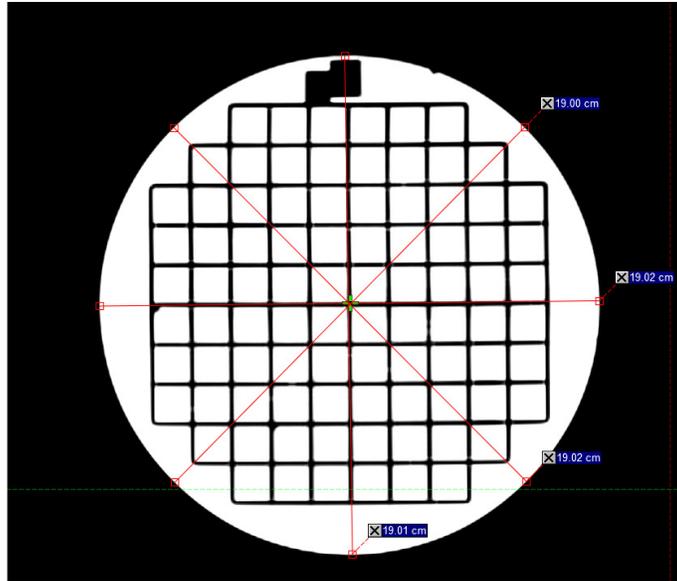
Figure 31 - INPLANE GEOMETRIC ACCURACY
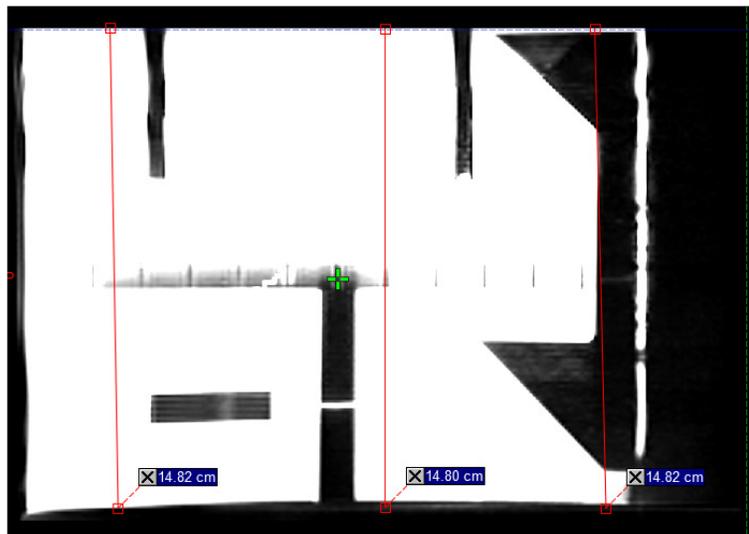
Figure 32 - SAGITTAL END TO END LENGTH MEASUREMENT

The expected values of the inside diameter of the phantom and the end-to-end length of the phantom was 190 mm and 148 mm, respectively. The measured values are well within the action criteria as they are within 2 mm. The high-contrast spatial resolution test is performed when the scanner's contrast-to-noise is high where the ability of the scanner is tested to

resolve small objects. In the ACR phantom there are 3 pairs of matrices that are squarish in shape. Each row and column are evaluated by determining if one hole is distinguishable from one another. Figure 33 represents the matrix of objects used for the high-contrast spatial resolution test. This process is repeated for the remaining two arrays where all holes in relation to the adjacent hole is evaluated on whether it is distinguishable from another. A 1 mm resolution is required which can be satisfied if some of the holes for the vertical and horizontal direction can be resolved in the middle array.
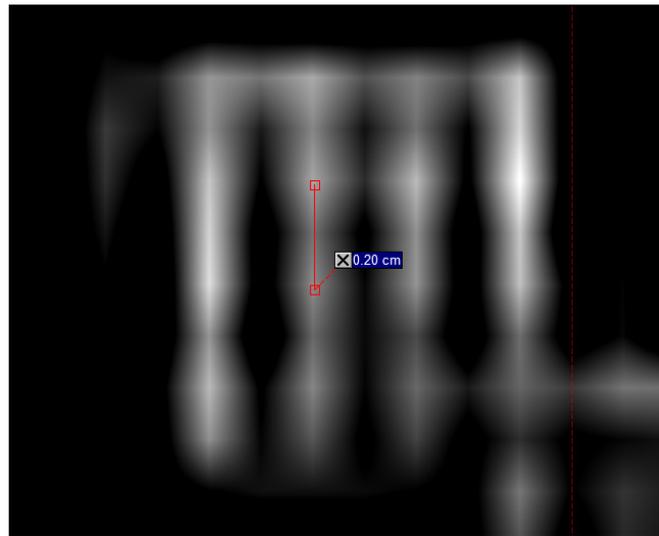

Figure 33 - HIGH CONTRAST SPATIAL RESOLUTION

The slice position accuracy test assesses if the slices are at specific locations. This test analyzes the length differences between two bars (right and left). If the two bars differ by a length greater than 5mm, there may be a few different scenarios causing this test to fail. For example, a failure of this test may be due to the table positioning system. An example of the two bars is displayed in Figure 34.

www.manaraa.com
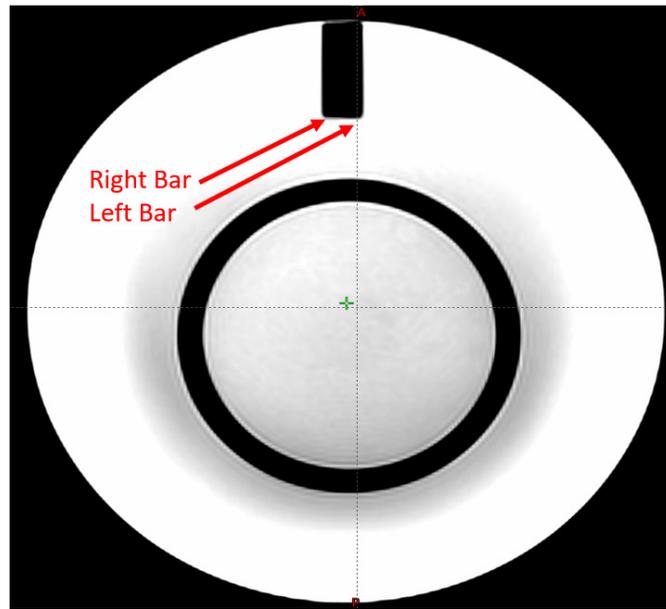
Figure 34 - SLICE POSITION ACCURACY TEST

To test for slice thickness accuracy the length of two signal ramps in the phantom are

evaluated. The window level is adjusted to visualize ramps as seen in Figure 35.
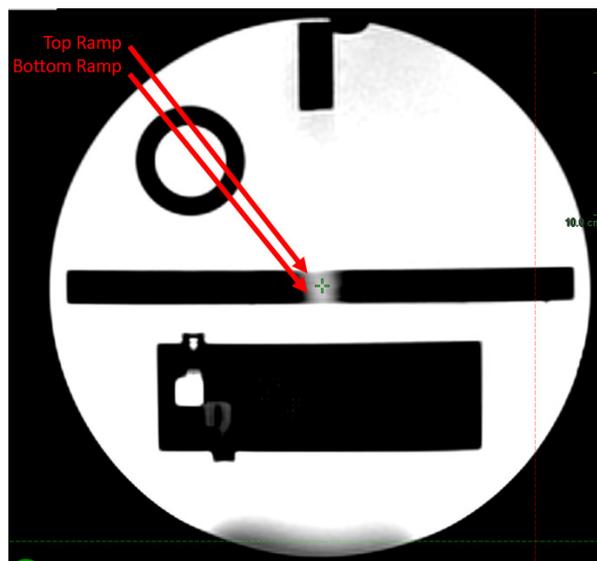

Figure 35 - SLICE THICKNESS ACCURACY (SIGNAL RAMPS)

Then, the mean ramp signal (HU) is measured and then the window level is lowered by half of the signal measured. Then, the length of the two ramps is measured and recorded. These two values are then used to calculate the slice thickness using Equation 5.

$$Slice\ Thickness = 0.2\ \frac{Top*Bottom}{Top+Bottom} \qquad [5]$$

A large volume of water is analyzed in the phantom for uniformity of image intensity. This is performed by lowering the window level until the phantom displays the color white. Next, the lower level is raised until dark pixels develop, which displays the area of the lowest signal. This is represented by Figure 36.
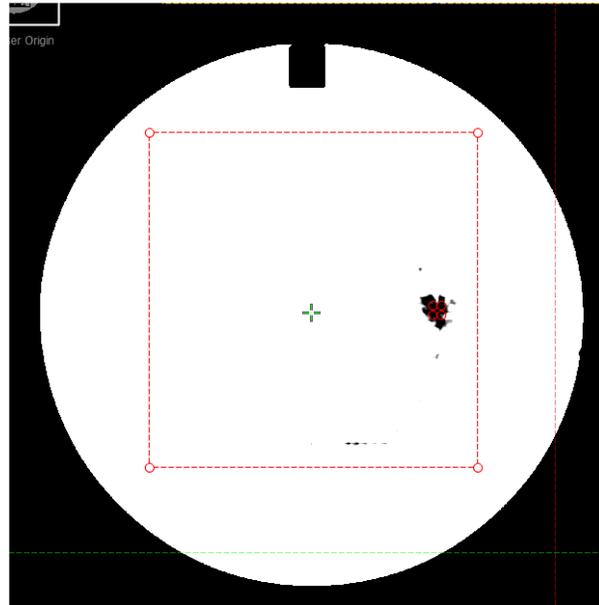

Figure 36 - IMAGE INTENSITY UNIFORMITY

www.manaraa.com

Then the level is raised further until a small section of white pixels remain, which signifies the area with the highest signal. These two values are recorded and plugged into Equation 6 to calculate the percent integral uniformity (PIU).

$$PIU = 100\left(1 - \frac{high-low}{high+low}\right) \qquad [6]$$

To measure the quantity of ghosting artifact in the phantom, the percent signal ghosting test is used. 5 average signal measurements are taken. The first measurement is the HU measured across the phantom, and the other 4 are measured in the right, left, top, and bottom directions just outside of the phantom as seen in Figure 37.
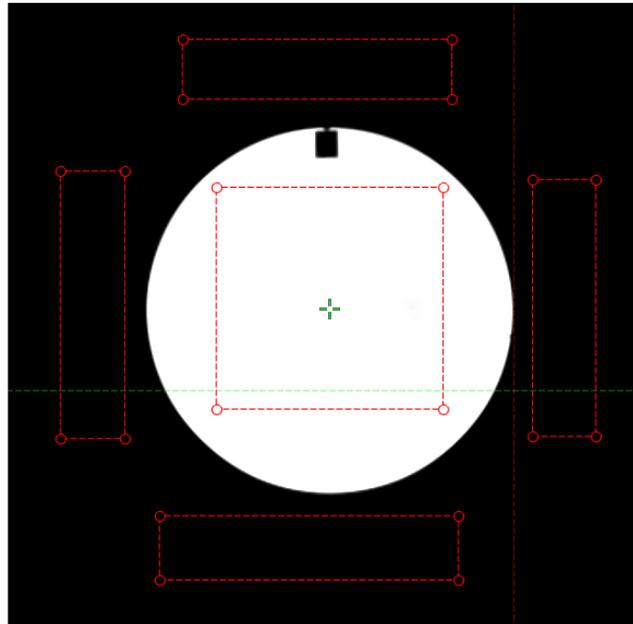

Figure 37 - PERCENT SIGNAL GHOSTING

These recorded measurements are used to calculate the ghosting ratio using Equation 7.

$$Ghosting\ Ratio = \left|\frac{Top+Btm-Left-Right}{2*Phantom\ ROI}\right| \qquad [7]$$

61

The last test performed is the low-contrast object detectability test. The purpose of this test is to discern objects of low contrast from other pixels. This test is performed by adjusting the WL until the low contrast circles are visible (See Figure 38).
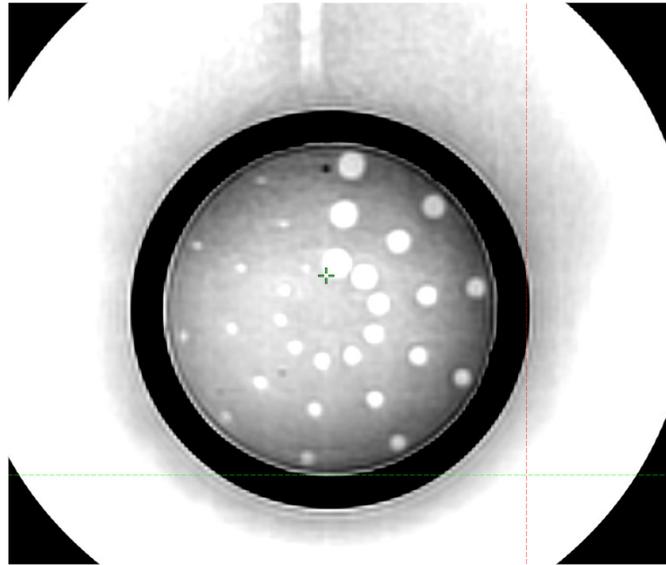

Figure 38 - LOW-CONTRAST OBJECT DETECTABILITY

Then, starting with the largest diameter circle, the number of circles visible in that spoke are counted. A spoke is considered to be visible if all three are counted. Then, the next circles with a slightly smaller diameter are counted. This process is repeated once all visible spokes are counted.

Future Equipment and Technology

HyperArc

HyperArc[37] is an additional software package offered through Varian that streamlines clinical workflow for SRS cases. This software simplifies the treatment planning and treatment delivery process and provides additional tools to assess the quality of a treatment plan. As advertised on Varian's website, the dosimetrist has access to tools that optimize the dose and the treatment delivery while receiving feedback on the plan quality. Additionally, the software will provide suggestions on imaging way points, it provides a tool to visualize the treatment delivery sequence, and it requires less therapist user input during treatment delivery. Acquisition of this product will reduce the investment of resources (e.g. dosimetrist planning time, beam delivery time, etc.), which in turn will allow resources to be redirected to other areas. This scenario is particularly favorable when UVH is experiencing high patient volumes.

Independent MU verification algorithm

The 3-Source algorithm in IMSure algorithm provides a 2nd independent check on the dose and MUs that were to be delivered to the patient. This algorithm was sufficient when providing these checks for standard 3DCRT plans, IMRT plans, and for VMAT plans. However, with the advent of small fields in SRS and SBRT and treating in heterogeneities, there have been considerable discrepancies between the IMSure algorithm and the primary dose calculation algorithm, Acuros. Therefore, the Radiation Oncology department is currently exploring modern 3D algorithms that can better account for heterogeneities and small fields. Varian Mobius 3D, Sun Nuclear DoseCheck and IBA SciMoCa are all being actively compared to serve this purpose.[38–40]

63

SRS MapCheck

Using film to verify dose planes for SRS plans is resource intensive which requires a physicist to prepare the phantom with film, to find time available to use the treatment machine, and post processing before a comparison can be made. This process is especially demanding in times when there is a high workload of patients being treated during the day which will limit the physicists' opportunity to use the machine during normal working hours and when their time is devoted to other tasks in the department. A tool that is capable of measuring SRS dose planes and providing near instantaneous feedback would eliminate many of the challenges as described above. One tool being capable of offering this kind of utility is the SRS Mapcheck.[41] This device is composed of 1,013 diode detectors in an active area of 7.7 cm to 7.7 cm. This device is capable of measuring multiple planes of dose and it is able to take the 3D dose DICOM file from the treatment plan that is exported from the Eclipse TPS and import into the SRS Mapcheck software. From there, it is able to make gamma analysis comparisons of the dose being delivered to the dose calculated by the TPS. The UVH Radiation Oncology department is expecting to purchase this equipment in 2020. It is expected that this equipment will replace the film QA process and utilize less resources from the department.

Conclusion

Utah Valley Hospital was charged with implementing a SRS program as an additional line of service. The deliverable was a timely, validated SRS program. This required a significant undertaking from the physics team, but also the dosimetrists, therapists, physicians, and management. The process first began with each physicist brainstorming various items that would need to be completed before implementing the program and conversing with various staff members to receive their input. For example, one notable conversation was whether to commission the cones in the department. Once the physics team had created a list of all the items needed for the SRS program, it was set into motion. One of those items was the evaluation of the patient specific QA to ensure that those tests were adequate. For example, one item of concern was using the IC point dose measurement to compare the measurement to the TPS value. Since SRS uses small fields it was a concern that the differences between the two values may be considerable as the field sizes became smaller. Then there were efforts into validating the beam delivery process and incorporating a patient specific QA process that was representative of an E2E test. This invoked the use of the gafchromic film in previous stereotactic body radiation therapy treatments to test the workflow of this QA process and the feasibility of it. Next an independent E2E validation test was performed with the SRS head phantom (HAMLET) that was provided by IROC. While these projects were being conducted on the beam delivery, there were also efforts put forth in researching various metrics to include when evaluating a SRS plan. Finally, there were meetings between various individuals to set up processes related to the program. For example, a physicist met with MR staff members to discuss which scan protocols would provide the most valuable MR images and receiving scans

of the ARC MRI phantom to evaluate the image quality. An additional example is the radiation oncologists and physicists meeting with the neurosurgeons to involve their clinical expertise with these SRS cases. After validating the SRS program and treating the first couple of cases, additional efforts were made to improve upon the clinical workflow and processes. For example, it is expected that the size of Provo, Utah, where UVH is located, will continue to grow in population and thus the workload for department staff will increase. To account for the growing population, additional purchases have been made on technologic upgrades. For example, acquisition of HyperArc and SRS Mapcheck is expected to decrease the time required to plan, QA the plan, and to treat the patient. Lastly, while this document displays the significance of various steps, it is important to recognize that implementing a SRS program should be viewed as a dynamic process. The radiation therapy field is constantly changing, and new technology is becoming available which simplifies many of the mundane and/or undesirable tasks. For example, only recently has frameless SRS treatments performed on LINACs become easily achieved on a general use LINAC. A large part of this change was due to the introduction of surface tracking that replaced the need for frame-based SRS programs. Also, within the UVH Radiation Oncology department, attempts have been made that hold true to this dynamic philosophy. For example, one of the physicists proposed adding a Styrofoam mannequin face mounted on a slab as an add on to the stereotactic dose verification phantom. The idea was to integrate the VisionRT tracking system into the IC measurement QA to measure the absolute dose of a point while characterizing the VisionRT shift readouts throughout the QA process. Although this idea was tabled, it is true to the virtue of recognizing the fluidity of an ever-changing field.

Appendix A: Film QA
Film fragment calibration technique:

Gafchromic RTQA2 Film & Espon 10000XL Flat Bed Scanner are used

1. A sheet of Gafchromic RTQA2 film is taken and cut up into 12 squares each measuring 6.35 cm by 6.35 cm

2. Set a 5 cm water equivalent block on the treatment couch and set the SSD readout on the block to 100 cm

3. Create a 10x10 cm^2 field, center the water block to the light field cross hair, and place the film square on the water block and center it to the light field cross hair

4. Place a 5 cm water equivalent block on top of the film and water block. Each film piece is irradiated to a different dose to reconstruct the sensiometric curve. See Table 12 for a representative list of dose values

Table 12 - SENSIOMETRIC CURVE DATA FOR 10 FFF

10FFF	D5TMR	0.952
Film at 100SAD/Isocenter		
Dose (cGy)	MU	
0	0	
25	26	
50	53	
75	79	
100	105	
150	158	
200	210	
300	315	
400	420	
500	525	
600	630	
700	735	

5. Irradiate the film square using the appropriate MU to the specified dose (as seen in Table 12)

6. Once irradiated, place a sticky note onto the back of each film piece with the known MU and dose to distinguish it from the other irradiated film pieces

7. Repeat the steps above to irradiate additional pieces of film to a different dose

8. Scan each film piece following the writeup titled, "Film Scanning"

9. Open ImageJ and drag one of the film scans into the software

10. Select "Image", "Color", "Split Channels" and close all windows except the red channel

11. Left click on the image and drag a region of interest box over the area to be measured

12. Press "Control m" to record the measured optical density

13. Record this value as it relates the OD to dose. Repeat steps 11-12 for all film fragments

Gafchromic RTQA2 film irradiation for patient specific plans

1. Create verification plan using Pt. ID sp11/04/2016. Image set: Film-V-512-0.8
    a. This is the blue phantom in film configuration, vertical orientation, 512 axial matrix, 0.8mm slices

2. Verify the dose distributions of interest fall intersect the position of the film on the CT. If the dose distributions are not intersecting the film, the isocenter may need to be shifted.

3. Approve the plan (planning approved) and schedule it for delivery on the TrueBeam

4. While wearing gloves, cut out a 6.35 cm by 6.35 cm film square and place it in onto the film slab from the blue cube phantom (2 corners of the film may be clipped to ensure a good fit)

5. Place the film slab with the other film slabs onto the two anchors embedded in the bottom component of the blue cube. Lastly place the remaining blue cube component and tighten with provided screws

6. Align the blue cube phantom to the lasers in the treatment vault and use the light field crosshair to make any final adjustments

7. Pull up the patient specific film QA plan and acquire a cone beam CT to further align the phantom and irradiate the phantom with the embedded film

8. Irradiate the phantom with the embedded film using all arcs

Film Scanning

1. All films scanned should be placed near the center of the scanner to avoid lateral scan effects and should be straightened out (void of rotations). The ROI tool can assist in identifying significant rotations.

2. Once the film is placed onto the scanner, the following scan parameters listed below are used (See Figure 39)
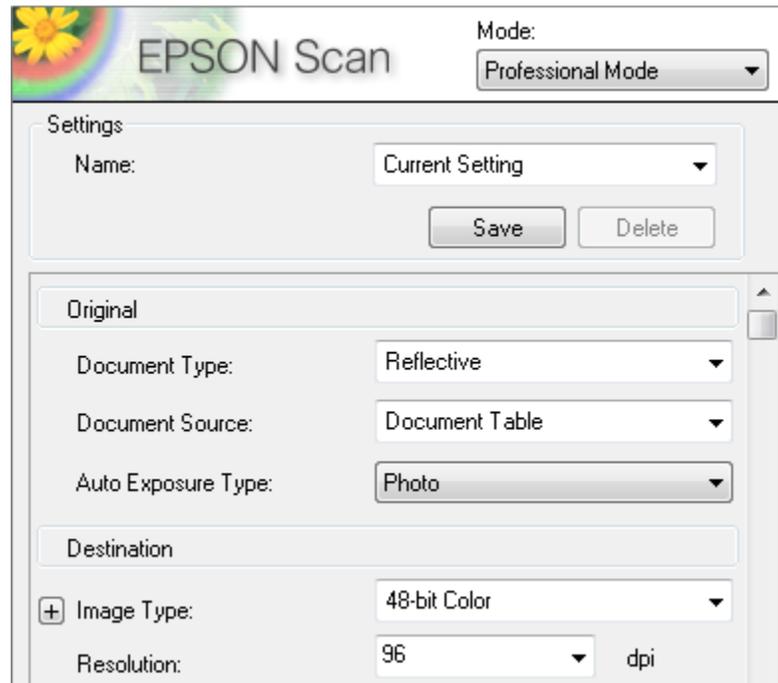

Figure 39 - FILM SCAN PARAMETERS

3. Once all image correction options are turned off, the film can be scanned

4. All scanned films are saved in the TIFF file format

Comparison of an axial TPS dose plane compared to an axial dose on film

1. Open the ImageJ software

2. Drag in the scanned patient specific QA film image

3. Select "Image", "Color", "Split Channels". Close green and blue channel windows, leaving only the red channel

4. Select "Image" and "Crop" to only include the region of interest on the film. Ensure the film dimensions are equal (e.g. 512 x 512). Record the pixel size and length in inches for the rows and columns (This information is used later). Calculate the resolution by multiplying the length [inches] by 25.4 and divide by the pixels (e.g. 2.5 inch * 25.4 mm/inch / 512 = 0.124 mm/pixel)

5. Pull up the sensiometric curve values (dose and OD) generated from the "Film fragment calibration technique" In Image J, select "Analyze" then "Calibrate". Function: 3rd Degree Polynomial, Unit: cGy, type in dose values for each film on Right side. Select "Yes" Global Calibration. Save, OK

6. Select "process" then "filters" and "median" and type in the value of 3 to filter out irregularities in the film

7. Using the following header (Figure 40) below, paste to matrix of dose values just under the [Data] row.

```
                        [General]
FileFormat=Generic Dosimetry Exchange Format
Version=1.0
Creator=Review
CreatorVersion=7.1.35
[Geometry]
Dimensions=2
Axis1=X
Size1=[*NEED TO ENTER FIRST PIXEL SIZE* e.g. 512]
Res1= [*NEED TO ENTER RESOLUTION IN MM* e.g. 0.124]
Offset1=0
Unit1=mm
Separator1=\t
Axis2=Y
Size2= [*NEED TO ENTER SECOND PIXEL SIZE* e.g. 512]
Res2= [*NEED TO ENTER RESOLUTION IN MM* e.g. 0.124]
Offset2=0
Unit2=mm
Separator2=\n
[Interpretation]
Type=Acquired Portal
DataType=%f
Unit=CU
Location=Imager
Medium=Ion Chamber
[Patient]
PatientId1= 1000000
PatientId2=
LastName= John
FirstName= Doe
[Field]
PlanId= 1111111111
FieldId= 2
ExternalBeamId=Toestel 5
BeamType=Photon
Energy=6
SAD=100
Scale=IEC1217
GantryAngle=0
CollRtn=0
CollX1=-2
CollX2=2
CollY1=-2
CollY2=2
[PortalDose]
SID=100
Date=01/20/2020, 13:25:33
[Data]
[*ENTER ALL DATA VALUES BELOW*]
```

Figure 40 - PORTAL DOSIMETRY TEXT DATA FILE

71

8. In (Figure 40) update the size and resolution rows using the values calculated and recorded from step 7

9. More information can be updated for accuracy, but it's not required to successfully import into the Portal Dosimetry workspace

10. Save the text file in the .dxf format with the following name "Film QA Data"

11. Next the TPS axial plane of dose must be exported and formatted for Portal Dosimetry import. Open the patient film QA plan created in the "Gafchromic RTQA2 film irradiation for patient specific plans" writeup

12. Right click the dose and export the dose plane corresponding to the center of the film. Make sure the axial plane window is selected.

13. The following is selected when exporting the axial dose plane to a local folder:
   Absolute dose; Planar plan dose; Size-6.35 cm, Pixels-512

14. Import the file created in step (13) (Disregard message saying image is incompatible with calibration)

15. Select "Image" and "Show info" (See Below)

```
3004,0002 ---: GY
3004,0004 ---: PHYSICAL
3004,0006 ---: SBRT TSpine2
3004,000A ---: PLAN
3004,000E ---: 1.947799e-6
```

16. Record the last line This last line is the conversion of image values to Gy. To convert to cGy multiply by 100.

17. Select "Process" then "Math" then "Multiply" and enter value from above to convert to cGy.

18. Select "File" then "Save As" and "Text Image"

19. Repeat steps 7-9 above for this file

20. Save the text file in the .dxf format with the following name "TPS Data"

21. Import both .dxf files ("TPS DATA" and "Film QA Data") into Portal Dosimetry to perform a Gamma Analysis comparison.

THE UNIVERSITY OF TEXAS

MD Anderson
~~Cancer~~ Center

Making Cancer History®

MD Anderson Dosimetry Lab
1515 Holcombe Blvd., Unit #607
Houston, Texas 77030
(713) 792-3233

REPORT OF STEREOTACTIC RADIOSURGERY
HEAD PHANTOM IRRADIATION

Date of Report:	October 24, 2019
Institution:	Utah Valley Hospital
Physicist:	Ryan Hecox
Radiation Machine:	Varian, TrueBeam (H193182) – 6 MV FFF
Treatment Planning System:	Varian Eclipse (Algorithm AAA)
Date of Irradiation:	September 24, 2019

Description of procedure:

An anthropomorphic head phantom containing a 1.9 cm diameter spherical target was imaged and irradiated. Two TLD capsules provided dose information near the center of the target. Two orthogonal sheets of GAFChromic Dosimetry Media provided dose profiles and an evaluation of the delivered dose distribution. The results are presented in summary below and the detailed report is attached.

The dosimetric precision of the TLD is ±3%, and the spatial precision of the film and densitometer system is ±1 mm.

Summary of TLD and film results:

	Ratio	Criteria	Acceptable
Dose to the center of the target (IROC-H/Institution)	1.01	0.95 – 1.05	Yes

Film Plane	Gamma Index*	Criteria	Acceptable
Coronal	98%	≥85%	Yes
Sagittal	97%	≥85%	Yes

*Percentage of points meeting gamma-index criteria 5% and 3 mm

The phantom irradiation results listed in the table above **do** meet the criteria established by IROC Houston.

TLD and Film Analysis by: Stephen Kry, Ph.D. and Trang Nguyen

Report Checked by:

David S. Followill, Ph.D.
Chief, Section of Outreach Physics

CARING   INTEGRITY   DISCOVERY

Comprehensive Cancer Center Designated by the National Cancer Institute

The information provided to you in this report should be considered as a quality assurance peer review and should only be used as a supplement to your institution's own commissioning and quality assurance measurements. Changes should be made by your institution only after you have determined that changes are warranted. Changes should not be made on the basis of this report alone. Such changes, if necessary, should be deliberate, and with the full knowledge of all individuals concerned.

If these results are publically presented, MD Anderson Phantom Laboratory should be acknowledged.

TLD Results:

Dose to TLD Capsules (cGy)		Institution Dose (cGy)		Average Ratio Measured/Institution
Upper	Lower	Upper	Lower	
2879	2947	2864	2884	1.01

Measured profiles along principal axes through the isocenter:

Profile 1:

Profile 2:

Anterior Posterior Profile

Posterior — Anterior

Dose (Gy) vs Distance (cm)

Legend: Film · Institution Values

Profile 3:

Superior Inferior Profile

Inferior — Superior

Greatest DTA ~2.4mm - RH

Dixie had similar size and direction shift also only on the S/I plane...

Dose (Gy) vs Distance (cm)

Legend: Film · Institution Values

Utah Valley Hospital

76
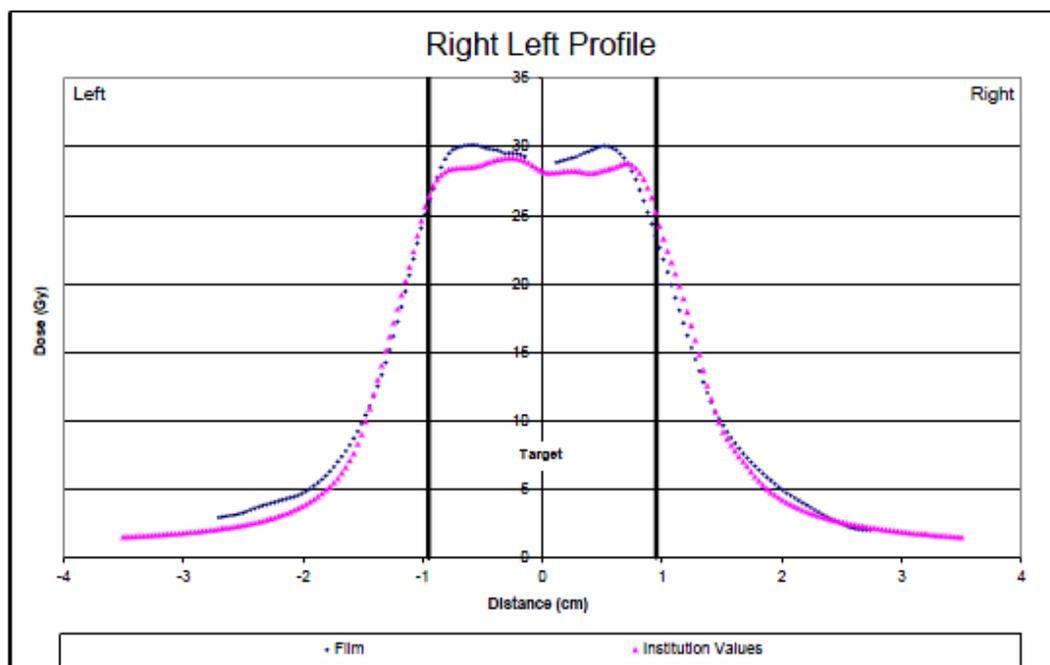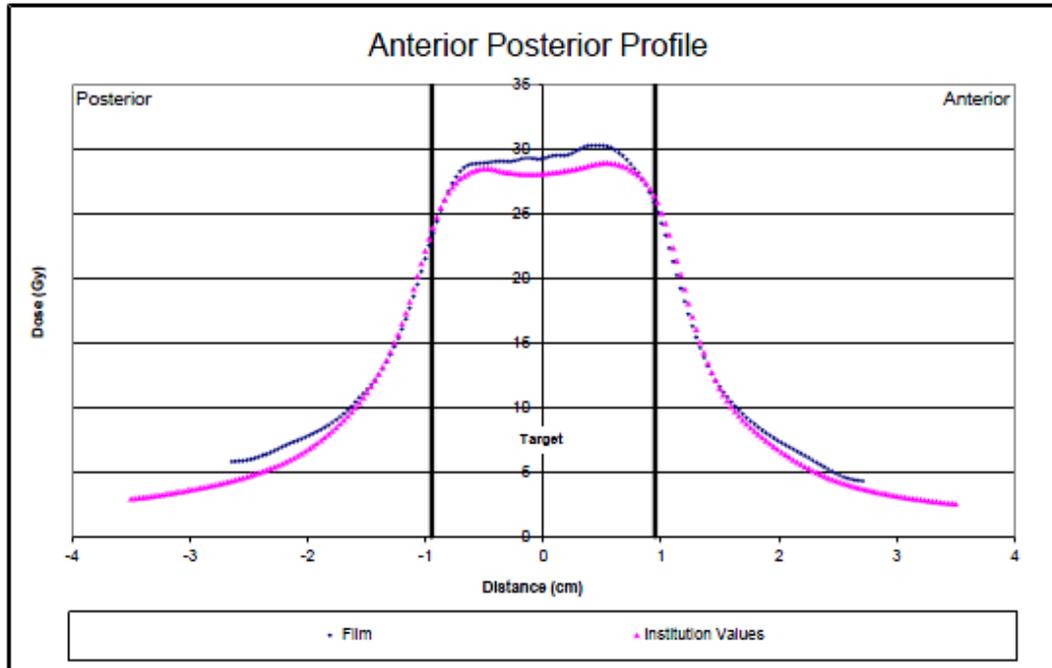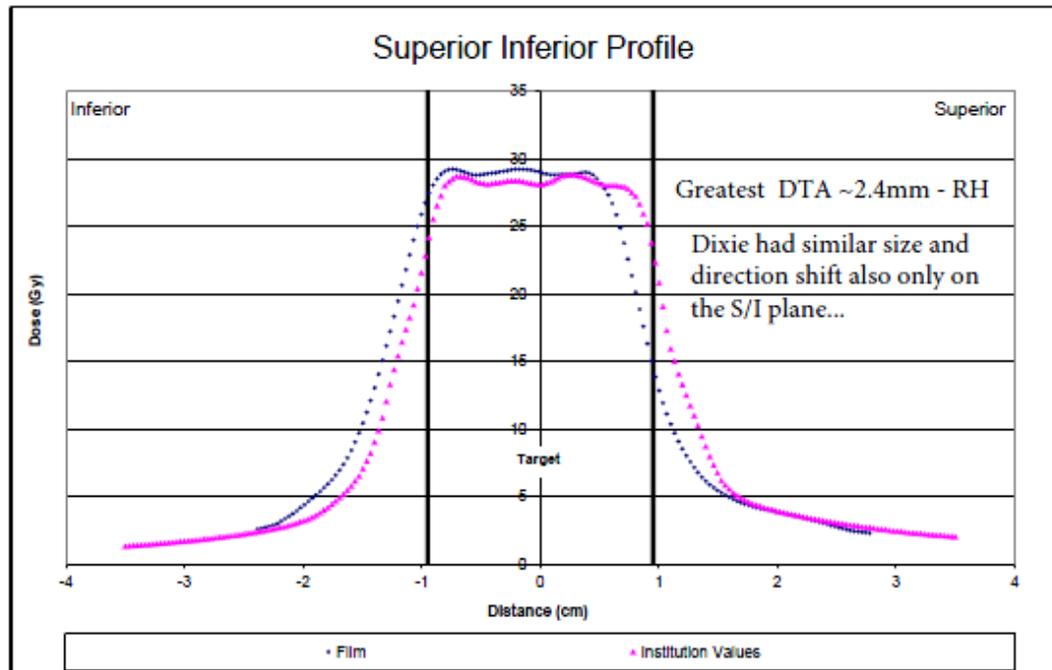
Figure 4a: The area on the coronal film that was used for gamma analysis. Artifacts have been masked and are not included in the gamma analysis.
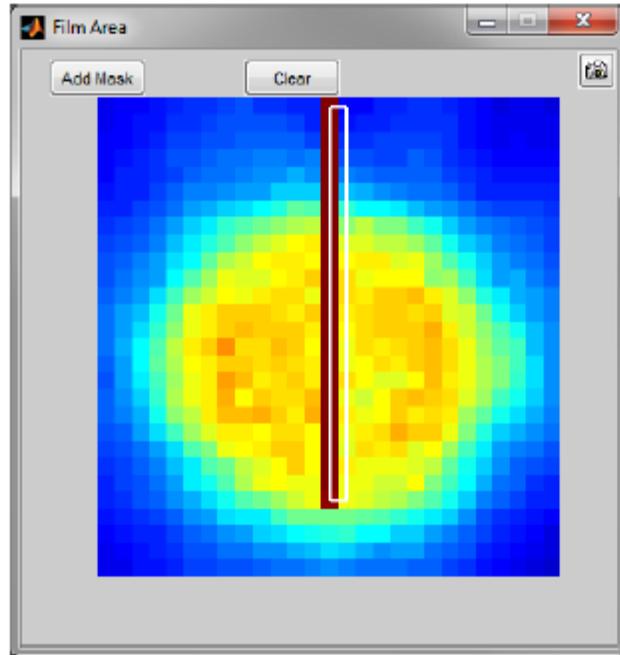

Figure 4b: The corresponding area in the coronal plane from the treatment planning system.
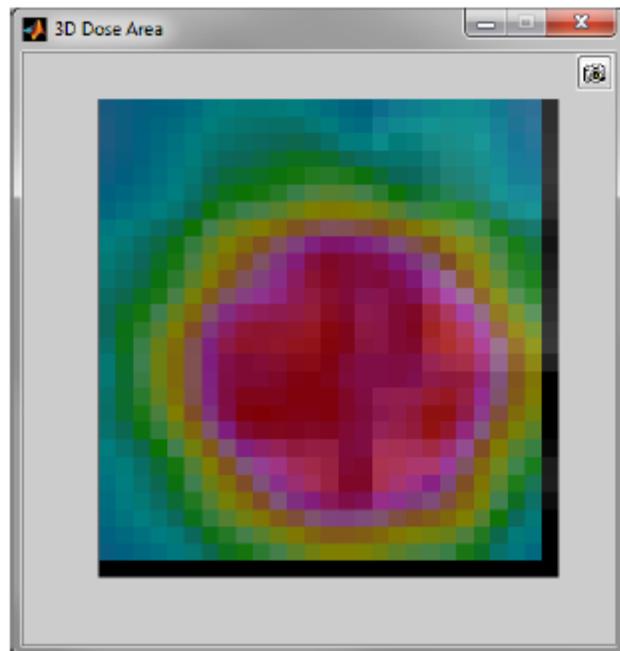
Utah Valley Hospital

Pie charts indicate percentages of pixels passing and failing the specified criteria.

Figure 4c: The result of the coronal gamma analysis (color scale).
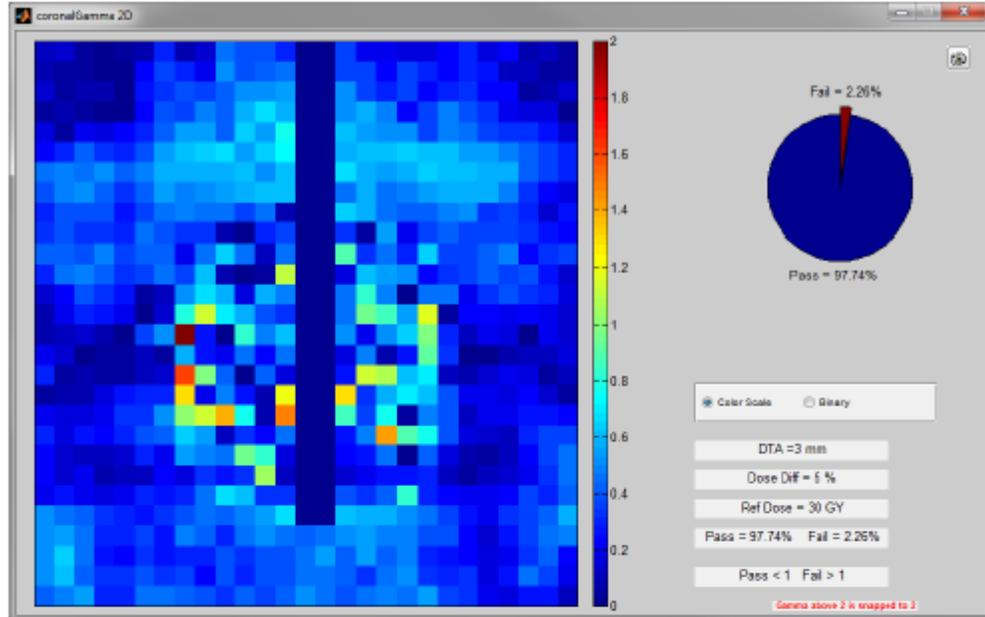
Figure 4d: The result of the coronal gamma analysis (binary). The red areas are locations that fail the criteria.
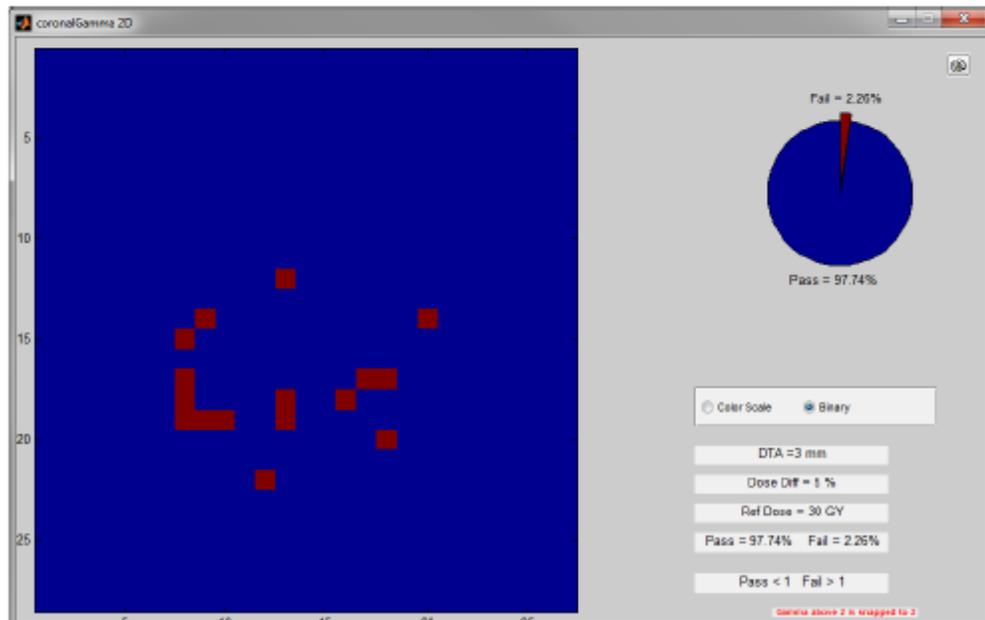
Utah Valley Hospital

Figure 5a: The area on the sagittal film that was used for gamma analysis. Artifacts have been masked and are not included in the gamma analysis.
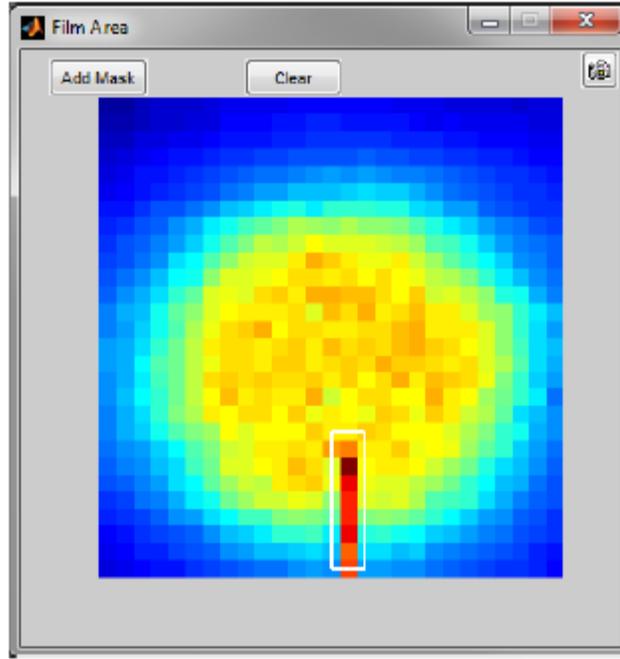

Figure 5b: The corresponding area in the sagittal plane from the treatment planning system.
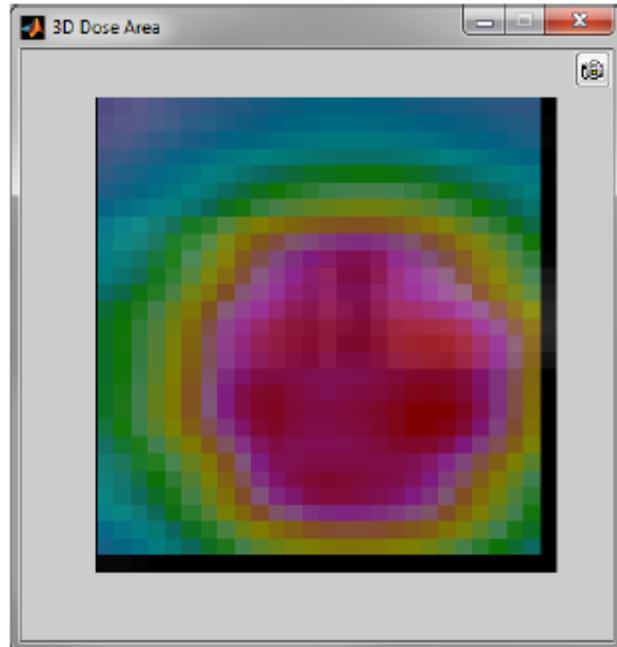
Utah Valley Hospital

Pie charts indicate percentages of pixels passing and failing the specified criteria.

Figure 5c: The result of the sagittal gamma analysis (color scale).
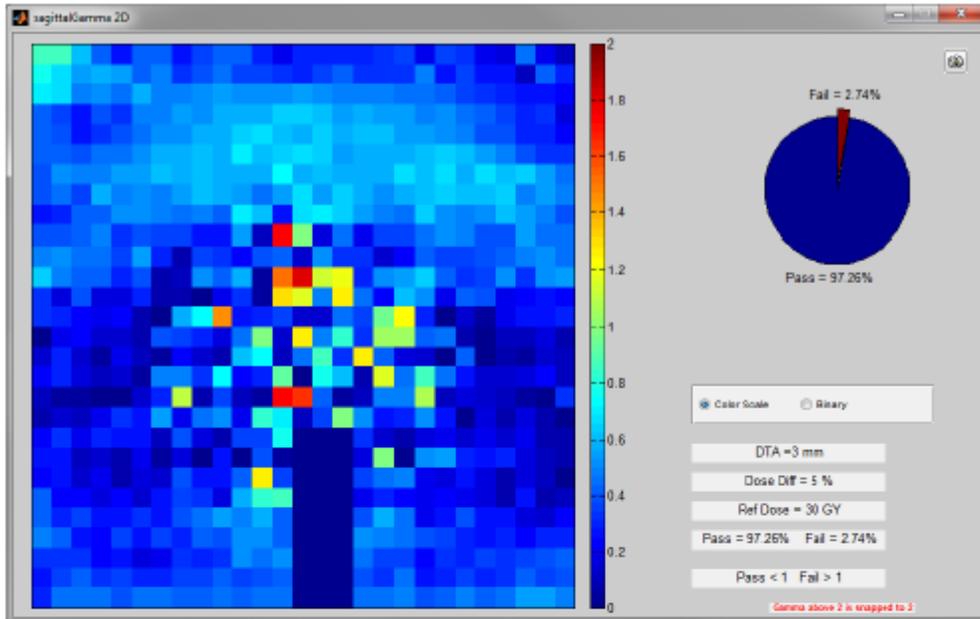
Figure 5d: The result of the sagittal gamma analysis (binary). The red areas are locations that fail the criteria.
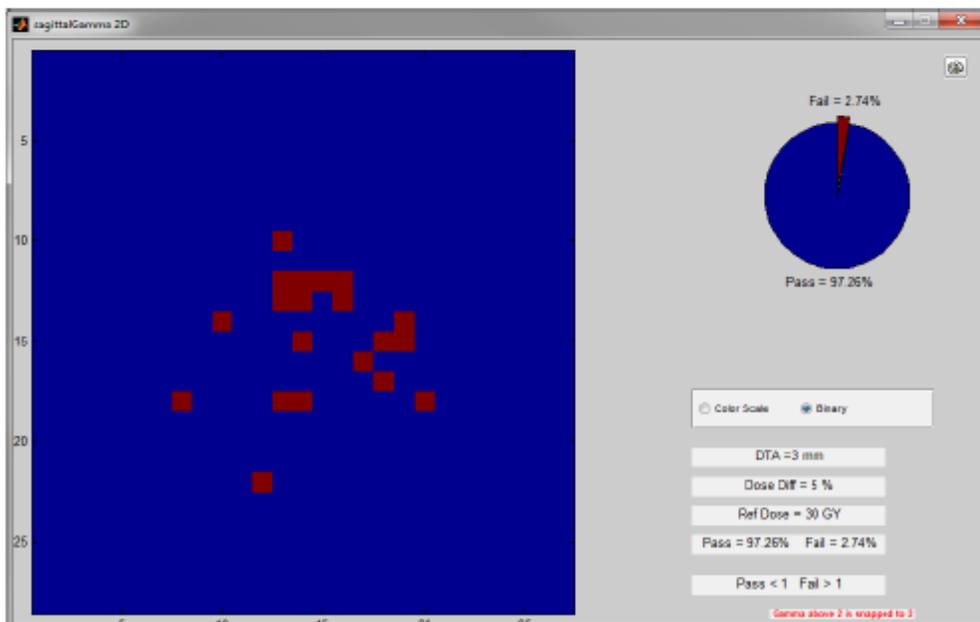

Utah Valley Hospital

References

1.   The American College of Radiology. *ACR Practice Parameter For The Performance Of Brain Stereotactic Radiosurgery*.; 2016.

2.   Khan F, Gibbons J. *The Physics of Radiation Therapy*. 5th ed. (Jonathan Pine, ed.). Philadelphia: Lippincott Williams & Wilkins; 2014.

3.   Shepard B. New radiation therapy shows promise for treating essential tremor. https://www.uab.edu/news/health/item/10548-new-radiation-therapy-shows-promise-for-treating-essential-tremor. Published 2019.

4.   Leksell L. The Stereotaxic Method and Radiosurgery of the Brain. *Acta Chir Scand*. 1951;102(4):316-319.

5.   Elekta. Gamma Knife Treatment Process. https://www.elekta.com/patients/gammaknife-treatment-process/.

6.   Babic S, Lee Y, Ruschin M, et al. To frame or not to frame? Cone-beam CT-based analysis of head immobilization devices specific to linac-based stereotactic radiosurgery and radiotherapy. *J Appl Clin Med Phys*. 2018;19(2):111-120. doi:10.1002/acm2.12251

7.   Accuray. Cyberknife. https://www.accuray.com/cyberknife/.

8.   Varian Medical Systems. TrueBeam. https://www.varian.com/oncology/products/treatment-delivery/truebeam-radiotherapy-system%0A.

9.   Qfix. https://qfix.com/.

10.   Intermountain. About Intermountain. https://intermountainhealthcare.org/about/who-we-are/mission-vision-values/.

11.   VisionRT. AlignRT. https://www.visionrt.com/product/alignrt/.

12.   Clark GM, Popple RA, Prendergast BM, et al. Plan quality and treatment planning technique for single isocenter cranial radiosurgery with volumetric modulated arc therapy. *Pract Radiat Oncol*. 2012;2(4):306-313. doi:10.1016/j.prro.2011.12.003

13.   Korytko T, Radivoyevitch T, Colussi V, et al. 12 Gy gamma knife radiosurgical volume is a predictor for radiation necrosis in non-AVM intracranial tumors. *Int J Radiat Oncol Biol Phys*. 2006;64(2):419-424. doi:10.1016/j.ijrobp.2005.07.980

14.   Minniti G, Clarke E, Lanzetta G, et al. Stereotactic radiosurgery for brain metastases: Analysis of outcome and risk of brain radionecrosis. *Radiat Oncol*. 2011;6(1):48. doi:10.1186/1748-717X-6-48

15.   Blonigen BJ, Steinmetz RD, Levin L, Lamba MA, Warnick RE, Breneman JC. Irradiated Volume as a Predictor of Brain Radionecrosis After Linear Accelerator Stereotactic Radiosurgery. *Int J Radiat Oncol Biol Phys*. 2010;77(4):996-1001. doi:10.1016/j.ijrobp.2009.06.006

16.   Standard Imaging. Stereotactic Dose Verification Phantom. https://www.standardimaging.com/solutions/stereotactic.

17.   Varian Medical Systems. *Portal Dosimetry*.; 2012. https://www.varian.com/.

18.   Varian Medical Systems. TrueBeam STx System Specifications. https://varian.force.com/servlet/servlet.FileDownload?retURL=%2Fapex%2FCpEventPresList%3Fid%3Da0OE000000pZaMdMAK&file=00PE000000VdZ5OMAV.

19.   Miften M, Olch A, Mihailidis D, et al. Tolerance limits and methodologies for IMRT measurement-based verification QA: Recommendations of AAPM Task Group No. 218.

Med Phys. 2018;45(4):e53-e83. doi:10.1002/mp.12810

20. Ashland. Gafchromic Film RTQA2. http://www.gafchromic.com/gafchromic-film/radiotherapy-films/RTQA2/index.asp.

21. National Institutes of Health, Laboratory for Optical and Computational. Image Processing and Analysis in Java. https://imagej.nih.gov/ij/docs/intro.html.

22. Micke A, Yu X. New Performance standard: Gafchromic film based dosimetry system.

23. Méndez I. Model selection for radiochromic film dosimetry. *Phys Med Biol*. 2015;60(10):4089-4104. doi:10.1088/0031-9155/60/10/4089

24. Méndez I, Peterlin P, Hudej R, Strojnik A, Casar B. On multichannel film dosimetry with channel-independent perturbations. *Med Phys*. 2014;41(1):1-11. doi:10.1118/1.4845095

25. Méndez I, Hartman V, Hudej R, Strojnik A, Casar B. Gafchromic EBT2 film dosimetry in reflection mode with a novel plan-based calibration method. *Med Phys*. 2013;40(1):1-9. doi:10.1118/1.4772075

26. Xia P, Chuang C, Colussi V, Lo Y-C. Task Group 315: Medical Physics Practice Guideline (MPPG) For Plan and Chart Review in 2 External Beam Radiotherapy and Brachytherapy.

27. Varian Medical Systems. Eclipse Photon and Electron Algorithms 15.1 Reference Guide. 2016.

28. Willoughby T, Lehmann J, Bencomo JA, et al. Quality assurance for nonradiographic radiotherapy localization and positioning systems: Report of Task Group 147. *Med Phys*. 2012;39(4):1728-1747. doi:10.1118/1.3681967

29. American Association of Physicists in Medicine. https://www.aapm.org/.

30. Halvorsen PH, Cirino E, Das IJ, et al. AAPM-RSS Medical Physics Practice Guideline 9.a. for SRS-SBRT. *J Appl Clin Med Phys*. 2017;18(5):10-21. doi:10.1002/acm2.12146

31. Imaging and Radiation Oncology Core. http://rpc.mdanderson.org/RPC/home.htm.

32. Lutz W, Winston KR, Maleki N. A system for stereotactic radiosurgery with a linear accelerator. *Int J Radiat Oncol Biol Phys*. 1988;14(2):373-381. doi:10.1016/0360-3016(88)90446-4

33. Klein EE, Hanley J, Bayouth J, et al. Task group 142 report: Quality assurance of medical acceleratorsa. *Med Phys*. 2009;36(9):4197-4212. doi:10.1118/1.3190392

34. Varian Medical Systems. Machine Performance Check. 2016.

35. Almond PR, Biggs PJ, Coursey BM, et al. AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams. *Med Phys*. 1999;26(9):1847-1870. doi:10.1118/1.598691

36. American College of Radiology. Phantom Test Guidance for Use of the Large MRI Phantom. *Am Coll Radiol*. 2017:1-28.

37. Varian Medical Systems. HyperArc. https://www.varian.com/products/radiosurgery/treatment-delivery/hyperarc.

38. Varian Medical Systems. Mobius3D. https://www.varian.com/products/software/quality-assurance/mobius3d.

39. Sun Nuclear Corporation. SunCHECK. https://www.sunnuclear.com/suncheck.

40. IBA. Monte Carlo Accuracy. https://www.iba-dosimetry.com/product/scimoca-monte-carlo-calculation/.

41. Sun Nuclear Corporation. SRS MapCheck. https://www.sunnuclear.com/products/srs-mapcheck.

Curriculum Vitae

Ryan Sharp

Therapeutic Medical Physicist
2 years of clinical experience
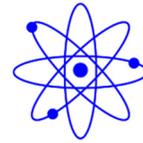
E-mail: rsharp156@gmail.com

2012 - Present Education:

2018- 2020 Doctor of Medical Physics (DMP)

University of Nevada, Las Vegas: CAMPEP Accredited Graduate Program
- Residency experience at: Intermountain Healthcare (Provo, Utah & American Fork, Utah)
  Northern Nevada Radiation Oncology (Reno, Nevada)

2016 - 2018 M.S. of Health Physics: Concentration in Medical Physics

University of Nevada, Las Vegas: CAMPEP Accredited Graduate Program
- Thesis performed under supervision of Benjamin Smith & Matthew Schmidt with Varian Medical Systems: "Electron Monte Carlo Dose Calculation Model Dependency on Optional Applicator Specific 1D Profiles"

2012 - 2016 B.S. of Nuclear Engineering & minor in Mathematics

University of New Mexico
- Senior Design Project: "Low Enriched High Flux Moly-99 Medical Isotope Production Reactor"

2018 – Present Clinical Experience:

Linac EBRT: Varian TrueBeam equipped with FF & FFF photons, electrons, integrated with a 6 DOF couch, kV/MV imaging, & VisionRT
Clinac iX equipped with FF photons, electrons, integrated with kV/MV imaging, & Calypso
- Performing daily, monthly, & annual QA (TG51, TG142, TG56, & TG40)
- Running pretreatment QA using a variety of QA tools (see attached equipment list)
- Characterizing VisonRT's thermal drift
- Performing monthly EPID & CT QA

Treatment Planning System: Eclipse
EBRT Planning:
- Practice plans: (20 cases planned)
  o 3DCRT, IMRT, VMAT & SBRT planning (breast, lung, prostate, & H&N)
  o SRS planning

RapidPlan Implementation:
- Built RapidPlan prostate model for clinical use
- Validated efficacy of model by comparing to clinical plans

Treatment Planning System QA:
- Following TG53 and MPPG 5.A recommendations, a series of tests plans were created & compared against measured scans & IMSure
- Test plans used as benchmarks following the Eclipse/Aria upgrade to version 15

Brachytherapy: HDR & LDR:
HDR: BrachyVision & GammaMedPlus iX
- Clinical Planning Experience: (50 cases planned)
    - Breast (SAVI, interstitial, & AccuBoost)
    - GYN (Cylinder, T&R, T&O, & interstitial)
    - Custom surface applicators
    - Prostate interstitial
- Responsible for HDR source exchange and daily QA
- Performed 2nd independent checks on HDR plans using RadCalc

LDR: IsoAid Stranded Pd-103 seeds:
- Volume study, ordering, receiving, shipping, and handling Pd-103 seeds
- Assist Physician with seed implant in OR

EyePlaque: IsoAid I-125 seeds:
- Observation of planning of plaque in BrachyVision and Plaque Simulator
- Assaying source strength & loading seeds into plaque
- Observing placement & removal of eye plaque

Xofigo Injections:
- Receiving, surveying, & handling radioactive material
- Assaying and preparing radionuclide(s) for patient injection

Film Dosimetry:
- Created excel spreadsheet for reference film calibration using Gafchromic film
- Generated a fragment calibration curve in ImageJ
- Performed a feasibility test of calibrating plan specific film and comparing it to an axial dose plane in Portal Dosimetry

2012 – 2018 Graduate & Undergraduate Experience:

2017 – 2018 Volunteer at Comprehensive Cancer Centers of Nevada:
- Performed TG51 under the direct supervision of an ABR certified physicist
- Assisted with monthly & annual TG142
- Observed HDR source exchange

2017 – 2018 Commissioning (Research based) at Varian Medical Systems:
- Acquired PDDs, profiles, and output factors required for commissioning electron Monte Carlo (eMC)
- Configured eMC algorithm and benchmarked against TrueBeam Representative Beam Data
- Configured two eMC algorithms (characterizing impact of including optional profiles in eMC)

2017 – 2018 Clinical Training Courses taken at Varian Medical Systems:
- EC101 Eclipse Basic Operations
- EC201 Eclipse Commissioning I: Administration and Algorithms
- EC204 Beam Data Scanning
- EC301 Eclipse Scripting API Basics
- ECB101 3D BrachyVision

2016 – 2018 Graduate Teaching Assistant for Radiation Biology at UNLV:
- Lecturing, preparing presentations, & grading coursework

2014 – 2016 Radiation Safety Assistant at UNM Health Sciences Center:
- Surveying of research laboratories
- Performed gamma spectroscopy on unlabeled legacy sources to identify and quantify unknown radioactive material
- Assist with preparation of radioactive waste for outgoing shipment
- Receiving, surveying, & delivering radioactive materials
- Surveying for possible radiation contamination in I131, Zevalin, Xofigo, and SirSphere cases
- Responsible for conducting daily checks on radiation detectors

Achievements and Memberships:
- **Passed ABR Part 1: General and Clinical sections**
- In accordance with 49 CRF 172.704, completed training for receiving and shipping radiopharmaceuticals
- Student member of the American Nuclear Society (ANS), American Association of Physicists in Medicine (AAPM), American Brachy Society (ABS), Radiosurgery Society (RSS), & Health Physics Society (HPS)
- Best in Presentation in Isotopes & Radiation ANS Student Conference 2016