Development of a comprehensive linac-based quality assurance program for a retrofitted micro-MLC SRS system

George H. Hancock
The University of Toledo
A Thesis

entitled


by

George H. Hancock

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Masters of Science in Biomedical Sciences Degree in Radiation Oncology Medical Physics

Dr. David Pearson, Committee Chair

Dr. E. Ishmael Parsai, Committee Member

Dr. Dianna Shvydka, Committee Member

Dr. Patricia R. Komuniecki, Dean
College of Graduate Studies

The University of Toledo
June 2013
In Stereotactic Radiosurgery, one of the most important factors that must be measured is the accuracy of the localization system, whether it be lasers or camera system; and the coincidence of the localized isocenter to the radiation isocenter. According to TG-142 the minimum deviation between the isocenter determined by the localization device and the radiation isocenter of the machine must be no more than 1 mm. In addition, the minimum deviation, also recommended by TG-142, between the radiation isocenter and the mechanical isocenter of the machine must be no more that 1 mm.

The purpose of this research was to develop a method that both of these parameters could be measured and add these tests to our patient specific QA, monthly QA, and annual QA procedures. A plastic phantom was constructed with holes drilled in each of the sides to meet at a common point in the middle of the phantom. This common intersection was then set as the isocenter for the treatment beams, and the coordinates of the point were sent to the camera system. Measurements were then taken with both the EPID and GafChromic film with the use of rigid tungsten rods in each hole to mark the position of the holes on the film and EPID. The films were then scanned and the field edges and isocenter positions were determined by taking the coordinates of a point that was halfway between the minimum and maximum
points in all cases.
Acknowledgments

I would like to thank all of the members of the Radiation Oncology staff at the University of Toledo for providing an excellent clinical and learning environment for me to acquire the skills that I have developed. I would, next, like to thank Dr. Feldmeier for his continued support of academic research, and his patience and encouragement as we learned the different aspects of a Radiation Oncology department. Next, I would like to thank Dr. Parsai for his dedication to the program and doing whatever was necessary for us to learn every possible aspect of the responsibilities of a medical physicist. I would also like to thank Dr. Pearson for his patience and dedication while working with me both as a clinical instructor and as my research advisor. I would like to thank Dr. Dennis, Dr. Schvydka, and Nick Speerling for their assistance with both research and clinical questions.

Finally, I would like to thank my parents for their continued support through my pursuit of a Masters degree in Medical Physics. Without their financial support and encouragement this journey to obtain a Masters degree would have been much more difficult. I would, lastly, like to thank my entire family for their patience and encouragement as I reached the completion of my degree and the beginning of my career as a Medical Physicist.
Contents

Abstract iii
Acknowledgments v
Contents vi
List of Tables viii
List of Figures ix
List of Abbreviations xi

1 Introduction 1
   1.1 Stereotactic Radiosurgery . . . . . . . . . . . . . . . . . . . . . . . . . 2

2 Literature Survey 6

3 Methods and Materials 11
   3.1 Electronic Portal Imaging Devices . . . . . . . . . . . . . . . . . . . . . . 11
   3.2 Gafchromic RTQA Film . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 12
   3.3 Isocenter Phantoms . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 13
       3.3.1 Mechanical and Radiation Isocenter Phantom . . . . . . . . . . . . . . 13
       3.3.2 Radiation and Localized Isocenter Phantom . . . . . . . . . . . . . . 14
   3.4 Isocenter Tests . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 15
       3.4.1 Attachment of Micro-MLC Gantry Attachment . . . . . . . . . . . . . . 15
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4.2 Mechanical and Radiation Isocenter Coincidence Test</td>
<td>16</td>
</tr>
<tr>
<td>3.5 Camera System Test</td>
<td>17</td>
</tr>
<tr>
<td>3.5.1 Initial Camera System Localization Test</td>
<td>18</td>
</tr>
<tr>
<td>3.5.2 DynaTrac Camera System Calibration</td>
<td>19</td>
</tr>
<tr>
<td>3.5.3 Post DynaTrac Camera Calibration</td>
<td>20</td>
</tr>
<tr>
<td>3.6 Backup Jaw Settings Test</td>
<td>21</td>
</tr>
<tr>
<td>3.6.1 GafChromic Film</td>
<td>22</td>
</tr>
<tr>
<td>3.7 Analysis of Film using RIT and OriginPro7</td>
<td>25</td>
</tr>
<tr>
<td>3.7.1 RIT Dose Calibration</td>
<td>25</td>
</tr>
<tr>
<td>3.7.2 Analysis of GafChromic and EPID films</td>
<td>27</td>
</tr>
<tr>
<td>4 Results</td>
<td>31</td>
</tr>
<tr>
<td>4.1 Initial Verification of Isocenter Position</td>
<td>31</td>
</tr>
<tr>
<td>4.2 DynaTrac Localization Test</td>
<td>33</td>
</tr>
<tr>
<td>4.2.1 Initial Isocenter Localization Test</td>
<td>33</td>
</tr>
<tr>
<td>4.2.2 Post-Camera Calibration Localization Test</td>
<td>34</td>
</tr>
<tr>
<td>4.3 Backup Jaw Settings Test</td>
<td>35</td>
</tr>
<tr>
<td>5 Conclusions</td>
<td>37</td>
</tr>
<tr>
<td>References</td>
<td>39</td>
</tr>
<tr>
<td>A Example of isocenter position calculation.</td>
<td>41</td>
</tr>
<tr>
<td>B Daily/Patient Specific Isocenter QA Instructions</td>
<td>42</td>
</tr>
<tr>
<td>C Monthly Isocenter QA Instructions</td>
<td>45</td>
</tr>
<tr>
<td>D Annual Isocenter QA Instructions</td>
<td>47</td>
</tr>
<tr>
<td>E DynaTrac Camera System Calibration</td>
<td>48</td>
</tr>
</tbody>
</table>
List of Tables

1.1 RTOG 90-05 Dose Escalation Trial Recommendations [1] ........................................ 4

2.1 Tests suggested by TG-142 for Stereotactic Procedures ........................................ 8

3.1 Doses calculated by Pinnacle for each point. ............................................................. 26

4.1 Initial Results of film scans to verify isocenter position ........................................... 32
4.2 Initial Results of film scans to determine the isocenter position with Dyana-Trac .......................................................... 33
4.3 Results of film scans to determine the isocenter position with DyanaTrac after the camera system was re-calibrated ......................................................... 34
4.4 Results of film scans to determine the field size and out-of-field dose ..................... 35
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>CT localizer frame for Stereotactic Radiosurgery by Elekta</td>
<td>2</td>
</tr>
<tr>
<td>1-2</td>
<td>Micro-MLC gantry attachment by Elekta</td>
<td>4</td>
</tr>
<tr>
<td>3-1</td>
<td>Depiction of the different layers of GafChromic RTQA film</td>
<td>12</td>
</tr>
<tr>
<td>3-2</td>
<td>Lateral and Oblique views of the constructed film holder</td>
<td>13</td>
</tr>
<tr>
<td>3-3</td>
<td>Superior-Inferior measured profile plot with EPID at a Gantry angle of 0°.</td>
<td>17</td>
</tr>
<tr>
<td>3-4</td>
<td>Left-Right measured profile plot with EPID at a Gantry angle of 180°.</td>
<td>19</td>
</tr>
<tr>
<td>3-5</td>
<td>Inferior-Superior measured profile plot with film at a Gantry angle of 270°.</td>
<td>21</td>
</tr>
<tr>
<td>3-6</td>
<td>Profile plot in the X direction to check for out-of-field dose due to improper back-up jaw settings.</td>
<td>23</td>
</tr>
<tr>
<td>3-7</td>
<td>Profile plot in the X direction for a 3x3 field to check for out-of-field dose due to improper back-up jaw settings.</td>
<td>24</td>
</tr>
<tr>
<td>3-8</td>
<td>Profile plot in the X direction for a 5x5 field to check for out-of-field dose due to improper back-up jaw settings.</td>
<td>24</td>
</tr>
<tr>
<td>3-9</td>
<td>Film shot at 0° gantry angle scanned in transmission mode.</td>
<td>27</td>
</tr>
<tr>
<td>3-10</td>
<td>Positions of the cross profile and depth profile lines in RIT.</td>
<td>28</td>
</tr>
<tr>
<td>3-11</td>
<td>Sample film image plotted in the inferior-superior direction with points I and S labeled to mark the position of the field edges and points ( I_i ) and ( S_i ) labeled to mark the positions of the edges of the tungsten marker in the middle of the field.</td>
<td>30</td>
</tr>
</tbody>
</table>
A-1 Example of the spreadsheet created to calculate the point at which the isocenter is located and the location of each field edge . . . . . . . . . . . 41
List of Abbreviations

SRS ....................... Stereotactic Radiosurgery
UTMC ..................... University of Toledo Medical Center
TG ......................... Task Group
Epid ........................ Electronic Portal Imaging Device
SSD ........................ Source-Skin Distance
MU ............................ Monitor Unit
TIFF ........................ Tagged Image File Format
ASCII ...................... American Standard Code for Information Interchange
QUANTEC .................... the Qualitative Analysis of Normal Tissue Effects in the Clinic
AAPM ...................... American Association of Physicists in Medicine
CBCT ...................... Cone-beam computed tomography
DPI .......................... Dots per Inch
TPS ........................... Treatment Planning System
Chapter 1

Introduction

Patients who are diagnosed with intra-cranial lesions, whether benign or malignant, are presented with either surgery or radiation therapy as viable treatment options. The treatment option depends on the size, grade, and location of the tumor. For those patients whose tumors are located in close proximity to critical structures, a specific modality of radiation therapy can be used called stereotactic radiosurgery (SRS). An important distinction needs to be made between SRS and standard fractionated radiation therapy. The distinction is that with SRS the objective is to cause cell death to all of the cells within the opening of the aperture, either cones or micro-MLCs, in either a single or small number of fractions; whereas with standard radiation therapy, due to the much lower doses delivered per fraction, some cell death is caused while normal tissue cells are also given the ability to regrow in between fractions. Cell death in both of these cases is caused by the high energy radiation interacting with, most likely, the water molecules within the area being irradiated to produce free radicals. These free radicals are highly reactive and interact with DNA molecules within the target causing either single or double strand breaks leading to cell death.
1.1 Stereotactic Radiosurgery

Stereotactic Radiosurgery (SRS) is defined as a single fraction or a few fractions of radiation therapy treatment that consist of delivering a high total dose of a highly collimated beam of radiation to a very small target or targets with very high precision [1]. The term stereotactic originates from the fact that a three-dimensional system is used to localize the target within the patient’s anatomy. The method of stereotactic radiosurgery arose from the use of stereotaxis in neurosurgery in the 1940’s by Spiegel and Wycis [2].

In 1951 Lars Leksell, a Swedish physician, and Borje Larsson, a physicist, pioneered the use of stereotaxis in radiosurgery through the use of proton beams from a cyclotron using the localization apparatus that Leksell developed in 1949, which is very similar to the ones that are still used today. A modern localization device can be seen in figure 1-1 below; this is the current localization device used in our clinic. It wasn’t until 1967 that the first photon treatment device, the Gamma Knife

![Figure 1-1: CT localizer frame for Stereotactic Radiosurgery by Elekta](image)

(Elekta Stockholm, Sweden), was invented for SRS. This device is still in existence today. The Gamma Knife consists of typically 201 small sized sources of Co-60 each containing about 30 Curies of activity spaced in a circular pattern within a highly
shielded apparatus that allows for specified sources to be exposed at different times, based on the plan and location of the tumor.

It wasn’t until the late 1970’s and early ’80s that the adaptation of a standard linear accelerator started to arise by the use of two main retrofitted devices. The two primary devices used to perform SRS on a standard linear accelerator by producing a highly collimated photon beam are conical collimators, referred to as cones, and a micro-MLC attachment, which consists of a number of narrow tungsten leaves about a quarter the width of the primary MLCs used for a standard radiation therapy procedure. The cones can come in a variety of sizes ranging from 4 to 50 mm in diameter. These cones are mounted onto a metallic plate which can be bolted on the head of the gantry just below the mylar sheath. The micro-MLC system also attaches to the gantry in a similar fashion as the cones. However, the micro-MLC system consists of 24 leaf pairs with each leaf having a width of 2.905 mm and a flat edge, as is the case of the 3DLine (Elekta, Stockholm Sweden) gantry attachment at the University of Toledo Medical Center (UTMC) (Toledo, Ohio), versus the rounded standard linac leaves. Each of the 48 leaves are able to move individually and conform to the target as the gantry rotates around the patient. Figure 1-2 below is the 3DLine gantry attachment used in our clinic and for this research.

Some of the more common classifications of the types of tumors treated with SRS include primary and secondary malignant brain tumors, vascular disorders, skull-based tumors, and functional brain disorders. Patients with primary or secondary malignant brain tumors are typically treated with a dose between 15 and 24 Gy based on the size of the tumor. Table 1.1 below outlines the recommended prescription doses based on the tumor size. Patients with vascular disorders are typically treated with an average dose of 19.8 Gy. The prescribed dose can go as high as 27 Gy and as low as 13.3 Gy; this dose is dependent on the toxicity to the normal surrounding tissue and critical structures [1]. Both skull-based tumors and functional brain disorders are typically
Table 1.1: RTOG 90-05 Dose Escalation Trial Recommendations [1]

<table>
<thead>
<tr>
<th>Tumor Size</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤2 cm</td>
<td>24 Gy</td>
</tr>
<tr>
<td>&gt;2-3 cm</td>
<td>18 Gy</td>
</tr>
<tr>
<td>≥3-4 cm</td>
<td>15 Gy</td>
</tr>
</tbody>
</table>

treated with a dose between 12 and 14.5 Gy, once again determined by the toxicity to the normal surrounding tissue and critical structures. QUANTEC (the Qualitative Analysis of Normal Tissue Effects in the Clinic) lists several recommendations for dose limit to critical structures when dealing with SRS. For example, less than 5-10 percent of the brain may not receive more that 12 Gy, the brain stem may not receive more than 12.5 Gy, and the maximum dose within the optic nerve/optic chiasm structures may not be any more than 12 Gy [3]. Based on these recommended dose constraints, that many clinics follow, and the typical doses delivered in an SRS treatment, it is quite apparent how important the proper localization of the target and isocenter accuracy is in an SRS treatment.

A recent white paper was published in 2011 in the Practical Radiation Oncology Journal concerning the safety and quality assurance associated with SRS. Such events
as those in Florida; Toulouse, France; Springfield, Missouri; and Evanston, Illinois were what triggered the publication of the paper by Solberg et. al. [4] The causes of the events mentioned above were improper backup jaw setting and output factor measurement. With quality assurance being the main responsibility of the medical physicist, much weight lies on the shoulders of the physicist in these circumstances. In light of this recent publication, the QA procedures for our SRS modality were assessed and modified to cover the concerns raised in this white paper, and to be in accordance with the most current American Association of Physicists in Medicine (AAPM) Task Group’s recommendations summarized in the report produced by Task Group 142: Quality Assurance of Medical Accelerators in 2009. [5] This report includes the recommendations suggested by Task Group 42’s report on Stereotactic Radiosurgery, specifically, published in 1995.
Chapter 2

Literature Survey

The significantly greater dose per fraction, small target volume, and proximity to normal structures are the three main principles that can cause a single treatment of stereotactic radiosurgery to become life threatening if a comprehensive quality assurance procedure is not formed or followed properly. It was based upon these principles that report number 54 of AAPM TG-42 was written. In 1995 report number 54 was written to provide recommendations for a clinic’s implementation of stereotactic radiosurgery. For example, the report suggests that routine QA will take approximately 0.5 days per month and an SRS case could take between 8 to 12 hours from the time it take to design the mask (for a frameless-based SRS procedure) or the attachment of the head frame to the patient (for a frame-based SRS procedure) to the time the treatment is completed. [6] The portion of this report that covers the quality assurance of stereotactic radiosurgery systems discusses the issues and recommended tolerances for individual clinics to base their QA procedures off of. Some issues that are discussed are the different sources of error that need to be taken into account when measuring the isocenter position; such as the width of the laser (1 mm) where lasers are used for localization, the tolerance set on the camera system (for clinics that use the camera system as their main method of localization), and the 1 mm slice thickness of the CT scan. TG-42 recommends that a set of orthogonal films
should be taken and compared to the digitally reconstructed radiographs from the treatment planning system to verify that the patient is in the correct position, the shift differences must be less than 1 mm for the procedure to continue.

Another test that is recommended in TG-42 is a test to verify the laser and radiation isocenter coincidence. A test was investigated using a pointer mounted to the couch top with a metallic BB on the tip. The BB was then aligned to the intersection of the lasers and a set of films were taken with the EPID of a linear accelerator. Measurements were then obtained from the EPID image to verify the center of the ball was within 1 mm of the field center at different gantry angles. This test verified both the isocenter of the machine and the accuracy of the localization system, the lasers.

It is also important to note that in addition to TG-42 covering the recommendations for patient specific and routine QA, it is also the main reference for recommendations having to do with obtaining commissioning data such as output factors, and in-plane and cross-plane profiles. SRS is one of the few topics that TG-106, a report on accelerator beam data commissioning equipment and procedures, only briefly touches upon and then refers the reader to TG-42 for a more detailed set of recommendations. The main point presented in both of these reports is the need to use an ion chamber with a very small detector volume for obtaining beam measurements due to the potential loss of lateral electronic equilibrium caused by the very small field sizes measured with a standard ion chamber.

The AAPM TG-142, a group formed to update the QA tests and tolerances for medical accelerators recommended by TG-40, added the tolerances recommended by TG-42 for isocenter verification and localization to the list of tests they recommend be performed for medical linear accelerator QA on a daily, monthly, and annual basis. Table 2.1 highlights the tests specific to SRS according to TG-142 to be performed daily, monthly and annually, respectively, for linear accelerators that perform SRS
Table 2.1: Tests suggested by TG-142 for Stereotactic Procedures

<table>
<thead>
<tr>
<th>Test</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Localization</td>
<td>1mm</td>
</tr>
<tr>
<td>Distance Indicator</td>
<td>2mm</td>
</tr>
<tr>
<td>Collimator Size Indicator</td>
<td>1mm</td>
</tr>
<tr>
<td>Stereotactic Interlocks</td>
<td>Functional</td>
</tr>
</tbody>
</table>

**Monthly QA Tests**

<table>
<thead>
<tr>
<th>Test</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Dose Rate Output Constancy</td>
<td>2% at SRS dose rate, MU</td>
</tr>
<tr>
<td>Treatment Couch Position Indicators</td>
<td>1mm/0.5°</td>
</tr>
<tr>
<td>Localizing Lasers</td>
<td>&lt;1mm</td>
</tr>
</tbody>
</table>

**Annual QA Tests**

<table>
<thead>
<tr>
<th>Test</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRS arc rotation mode (range 0.5-10 MU/deg)</td>
<td>MU set vs. delivered: 1 MU or 2%</td>
</tr>
<tr>
<td>X-ray MU linearity (output constancy)</td>
<td>Gantry arc set vs. delivered 1° or 2%</td>
</tr>
<tr>
<td>Coincidence of Radiation and Mechanical Isocenter</td>
<td>5% (2-4 MU) 2% 5 MU</td>
</tr>
<tr>
<td>Stereotactic accessories, lockouts, etc.</td>
<td>1mm from baseline</td>
</tr>
<tr>
<td></td>
<td>Functional</td>
</tr>
</tbody>
</table>

The AAPM Task Group 179’s main focus was to develop a report that covers the quality assurance necessary for image-guided radiation therapy utilizing CT-based technologies. [7] Since current recommendations state that both SBRT and SRS treatments should use some sort of imaging technique to verify that the intended target is being treated, this report describes a method by which the isocenter of the imaging technique used to verify patient positioning in SBRT cases (typical CBCT) is calibrated to coincide with the radiation isocenter of the treatment beam. The test described in this report begins with several portal images being acquired at each cardinal angle, with a ball bearing positioned at the radiation isocenter. To ensure the proper positioning of the jaws, the collimator is rotated by 180° for each portal image. A CBCT of the field containing the ball bearing is then obtained. The distances between the pixel position of the EPID image and the CBCT images are
then figured and the difference between the two isocenters is plotted and this plot is called a flexmap. The flexmap shows how far off the CBCT isocenter is from the radiation isocenter. The whole point of this test is to expect flexing and potential misalignment to occur and be able to correct for it.

A recent white paper in the Journal of Practical Radiation Oncology on the quality and safety considerations in stereotactic radiosurgery and stereotactic body radiation therapy really emphasizes the need for a robust quality assurance procedure. Solberg et. al. cites the clinical effectiveness of SBRT in the treatment of inoperable early-stage lung cancer as “the 3-year primary tumor control rate of 98% is roughly twice what would be expected from conventional RT given over a 6- to 7-week period.” [4] This is due to the fact that a much higher dose is delivered to a target increasing the cell-killing effect on the targeted area while reducing the toxicity to normal tissue. This is precisely the reason why a robust and comprehensive quality assurance procedure is necessary. One of the crucial errors in recent years mentioned were 77 patients in Florida being affected by a calibration error on a radiosurgery linac. Another event affected 145 patients in Toulouse, France and 152 patients in Missouri caused by errors in output factor measurements. In addition, seven centers in Europe and the United States were affected by an error in the cranial localization accessory. Finally, improper back-up jaw settings affecting a patient in France and 3 patients in Illinois, one of which led to the patient being in a vegetated state. The recommendations from this paper are for increased awareness to the importance of a robust QA process and the potential effects that it can have if one is not developed, improvement in training for personnel involved with SRS and SBRT procedures to the point where training is added into both the residency training of a radiation oncologist and the educational work a medical physicist completes. The continual evolution of current QA procedures is also critical due to the advancement of technology in the field.

One of the most critical issues in SRS treatments has to do with the position
of the isocenter—all the coincidence of the radiation and mechanical isocenter and
the accurate localization of the radiation isocenter using either lasers or a camera
system. In 2011, Rowshanfarzad et. al. performed a study measuring the radiation
isocenter and mechanical isocenter deviation on 5 Varian linear accelerators (Varian
Medical Systems, Palo Alto, CA). This study was carried out using a 30 mm circular
collimator attached to the gantry and cine-EPID images were obtained of a 5 mm
diameter tungsten ball embedded in a polymethyl methacrylate holder positioned at
the nominal linac isocenter using the room lasers. A MATLAB code (MathWorks,
Natick, MA) was developed to obtain the positions of the 50% isodose lines of the field
edges and the “shadow” created by the tungsten ball. The code then determined the
offset of the radiation isocenter, determined by the point halfway between the field
edges, and the nominal isocenter indicated by the point halfway between the 50%
isodose line of the shadow, for each EPID image. The code then produced an output
sheet with a graph of the deviations with respect to gantry angle and highlighted the
portions that failed the test. A deliberate shift was then applied to the phantom and
the procedure was rerun to ensure that the code could detect the shift, which it did.
This method was reported to have an accuracy of 0.03 ± 0.02 mm, a reproducibility
of 0.86 micrometers and a repeatability of 3 micrometers [8] indicating that this is
a robust code and can be used to determine the coincidence of the radiation and
nominal isocenter to within the 1 mm tolerance recommended by TG-142.
Chapter 3

Methods and Materials

3.1 Electronic Portal Imaging Devices

Most commercial Electronic Portal Imaging Devices (EPIDS) consist of a dual detector set-up. The initial detector that the incoming X-rays interact with is scintillating phosphor which converts the incoming X-rays into optical photons to be detected by the secondary detector. This detector material consists of a series of amorphous silicon photodiodes. When the optical photon, produced by the interaction of the X-ray with the initial scintillating phosphor detector, is registered in the semiconductor layer of the photodiode, it leads to the creation of electron-hole pairs in the semiconductor. This semiconductor layer is pixilated with each pixel configured as a thin film transistor. When the transistors are properly biased, the charges generated by the production of the electron-hole pairs in the semiconductors can then be registered as an electrical current coming from each pixel of the semiconductor layer. It is this signal that is transformed into an image by the image acquisition software of the particular EPID that the user sees.
3.2 Gafchromic RTQA Film

Gafchromic RTQA QA+ film (Ashland Inc. Covington, Kentucky) was the primary material used for data collection along with the periodic use of the EPID of an Elekta Precise SL25 linear accelerator (Elekta, Stockholm Sweden) and MapCHECK2 (Sun Nuclear Melbourne, Florida). This Gafchromic film is a product of Advanced Materials, a business unit of ISP (International Specialty Products), recently obtained by Ashland Inc.. The film consists of five layers as depicted in figure 3-1. The active layer consists of a chemical that forms an image as the result of a polymerization process. When the energy from the high energy particles, in this case photons, interact with the receptive part of the photomonomer molecule, a chemical change is initiated and can be seen in the change in the yellow-dyed polyester surface [9].

Figure 3-1: Depiction of the different layers of GafChromic RTQA film
3.3 Isocenter Phantoms

3.3.1 Mechanical and Radiation Isocenter Phantom

The first phantom made was one that would be able to mark the mechanical isocenter of the machine on a piece of film to be analyzed and compared to the radiation isocenter. This phantom consisted of two 7.7 by 7.1 cm$^2$ pieces of 2 mm thick plexiglass. The top piece of plexiglass was designed so that it could be removed from the rest of the phantom with the use of two small doweling pegs. This top piece of plexiglass consisted of a 1 cm long by 1 mm in diameter tungsten rod to mark the position of the mechanical isocenter in the radiation field on film. The based piece of plexiglass was fixed 2.2 cm from the base of the two side panels. This plexiglass slab was supported by two 0.5 by 0.5 cm$^2$ pieces of dowel rods running the length of the supporting side panels. These panels were made of the same thickness of plexiglass used for the rest of the phantom, but had a height of 5.3 cm and a length of 7.6 cm. Finally to increase the structural integrity of the film holder, two 1.1 by 1.1 cm$^2$ dowel rods of length 7.7 cm were glued from one side panel to the other at the base of the phantom. Figure 3-2 below shows two views of the constructed film holder.

![Figure 3-2: Lateral and Oblique views of the constructed film holder.](image)

Several preliminary tests were performed to ensure that this holder would produce
the desired data. First, it had to be verified that the pieces of plexiglass that the film would be sandwiched between would be perfectly perpendicular to the face of the beam to obtain flat portions of the profile curve where the dose to the film was at its maximum. It also had to be verified that the tungsten marker would indeed create a mark distinguishable enough to see it on the film and analyze it. This was done by using a short piece of the tungsten rod and extending through a thin slab of bolus material with gafchromic film sandwiched underneath it, and then delivering a variety of MUs to figure how many MUs were needed to get a good profile plot. Another feature that was discovered during this test was that while the lack of a backscattering medium would require more monitor units, a sharper beam penumbra was noticed.

3.3.2 Radiation and Localized Isocenter Phantom

The second phantom constructed was to test the coincidence of the radiation isocenter to the isocenter of the machine localized with the camera system. The phantom for this test was formed using Castin’ Craft (Environmental Technology Incorporated, Fields Landing, CA) polyester casting resign that was poured and molded into a rough square and then machined down into a 7.5 x 7.5 x 6.5 cm$^3$ phantom. Next, 0.5 mm diameter holes were drilled into the center of the phantom from each side to meet at a common point in the phantom which would be aligned to the mechanical isocenter of the linear accelerator. It was important that the points on the side of the phantom accurately represented the common point in the center because the holes would be later used to mark the film. Finally, the phantom was glued securely onto a thin sheet of plexiglass. This piece of plexiglass had holes drilled in two corners that could be fixed into matching holes in the SRS head-holder in only one possible configuration using plastic pegs. A piece of 0.5 mm diameter tungsten rod was cut to fit into each of the holes securely while still being able to be removed when
necessary and not altering the set-up of the phantom on the treatment couch. It was important to ensure that the holes were drilled carefully to accurately represent the position of the point at the intersection of all of the holes in the center on the outside of each side of the phantom. While the test using this phantom were performed, it was verified that the intersection of the x and y axes and the room lasers coincided with each of the holes on the outside of the phantom once it was positioned using the camera system. This quick verification demonstrated that the tungsten rod placed in each hole would indeed mark the isocenter of the machine.

3.4 Isocenter Tests

The primary purpose of this research was to develop a method to quantitatively determine the mechanical and radiation isocenter coincidence that could be added to the annual, monthly and patient-specific quality assurance procedures for linear accelerators retrofitted with an SRS gantry mount to deliver SRS treatments. The mechanical isocenter is defined as the point around which the gantry rotates. In contrast, the radiation isocenter is the central point around which the radiation beam rotates; which, for an open field, should be the same point. Thus, a test was first developed to verify the coincidence of the mechanical and radiation isocenter and then a test was designed to quantify the accuracy of the camera localization system in placing a predetermined point at the radiation isocenter.

3.4.1 Attachment of Micro-MLC Gantry Attachment

Prior to performing any tests with the 3DLine gantry mount, it first needed to be attached and calibrated as follows. The gantry was set to 180° and the collimator was set to 0°. The 3DLine Stereotactic gantry attachment was mounted to the gantry with 4 bolts in each of the four corners of the gantry attachment. The communication
cable was then connected to the stereotactic gantry attachment and then to the head of the gantry. The 3DLine controller was then turned on and an MLC calibration was performed to ensure the controller was communicating correctly with the micro-MLCs. A standard gantry calibration was performed by rotating the gantry in a counterclockwise direction to \(-179.9^\circ\) and then back to past \(0^\circ\) until the controller system displayed that the gantry calibration was complete. The controller system is now ready to be used for a stereotactic procedure.

3.4.2 Mechanical and Radiation Isocenter Coincidence Test

Before analyzing the radiation and mechanical isocenter of the linear accelerator with the 3DLine gantry attachment, a quick test was performed to verify that the gantry attachment was centered on the gantry with respect to the graticule. The test showed that the mechanical isocenter of the machine with the 3DLine attachment could be verified using the graticule. This verification test was performed by placing a large piece of graph paper at 100 SSD, and with a 4x4 cm\(^2\) field set using the micro-MLCs, measuring from the center of the graticule (determined by the intersection of the x and y-axis cross-hairs) out to each field edge; verifying that the distances are the same. This procedure was performed with the gantry at both \(0^\circ\) and \(90^\circ\). Results from this test warranted small adjustments to center the gantry attachment in the light and radiation field, indicating that such a test is necessary. Now that the mechanical isocenter with respect to the 3DLine gantry attachment has been verified, the coincidence between the mechanical and radiation isocenter can be measured.

The home-made film holder described in section 3.3.1 was used for this test. The film was placed at 100 SSD and the tungsten marker of the film holder was centered in the field using the graticule. A 3x3 cm\(^2\) field was then irradiated at a collimator angle of \(0^\circ\) and then a collimator angle of \(90^\circ\) to verify the positioning of the radiation isocenter versus collimator angle. This test was then repeated at a gantry angle of \(90^\circ\).
with the film holder tilted on its side so that the plane of the film was perpendicular to the beam. At the conclusion of this test with the film, the test was then repeated using the EPID as a second means of verification. However, since it wasn’t possible to place the EPID in the film holder, the fields were just irradiated with the EPID extended to capture the entire field. The EPID images were then exported, along with their log files, from the EPID computer to a network drive that could be accessed from other computers in the department. An example of a profile plot that was obtained from the EPID using the above method is represented in figure 3-3 below. A description of the method used to analyze the film is discussed in section 3.7.2.

![Superior-Inferior Field Symmetry Profile Plot](image)

Figure 3-3: Superior-Inferior measured profile plot with EPID at a Gantry angle of 0°.

### 3.5 Camera System Test

The phantom described in section 3.3.2 was used for this test. Once the phantom was constructed and mounted onto a plexiglass plate to be used to securely mount the phantom to the SRS head holder, it was then CT scanned with a CT compatible localization frame using 1 millimeter slice thicknesses. The localization frame would
provide a 3D coordinate system by which the isocenter would be localized in the treatment room using the camera system. The CT scan was then exported to the ERGO++ SRS treatment planning system. From here, a body contour was created to encompass the entire phantom; and a target contour was drawn to represent the target (the point at which all of the holes intersected). In addition, each of the fiducial markers of the CT localization frame were marked using the localize module in the treatment planning system. ERGO++ uses the 3D coordinates of these fiducials to come up with the coordinates of the isocenter which is automatically placed in the center of the target. The final preparatory step was then to export the plan to the DynaTrac camera localization system in the treatment room.

3.5.1 Initial Camera System Localization Test

With the coordinates of the beam isocenter (defined by the intersection of the holes in the phantom) exported to the DynaTrac camera system, the process of localizing the defined point using the camera system, irradiating Gafchromic film and acquiring EPID images to determine the position of the point within the radiation field was ready to be performed. The predefined point located within the phantom was localized to match up with the mechanical isocenter of the machine by using a frame that consisted of 5 radio-opaque markers. These radio-opaque markers are detected by the three DynaTrac cameras in the treatment room and are used to determine the position of the defined point in the phantom and provide shifts to position it with the mechanical isocenter of the machine.

Once the phantom was adequately localized, a tungsten rod was placed in the right side of the phantom, and film was taped onto the same side of the phantom. The gantry was then rotated to 270° and a beam with a 3x3 cm² field was irradiated to mark the rod’s position on the film. The film was then removed from the side of the phantom and an image was acquired with the EPID. This procedure using both
film and the EPID was repeated for a gantry angle of 180° and a tungsten rod was placed in the top drilled hole of the phantom. An example of an analyzed EPID image obtained from this test can be see below in figure 3-4. And the full results from this test are presented in section 4.2.1.

Figure 3-4: Left-Right measured profile plot with EPID at a Gantry angle of 180°.

Due to the fact that four out of the eight measurements taken didn’t pass the 1 mm isocenter alignment criteria recommended by TG-142, the next step was to perform a camera calibration on the DynaTrac camera system. This procedure is discussed in the following section.

3.5.2 DynaTrac Camera System Calibration

Due to the fact that the results from the Initial isocenter test did not meet the tolerances suggested by TG-142 and that it was verified previously that the mechanical and radiation isocenter are within 1 mm of each other, the DynaTrac Camera
system was recalibrated following the steps outlined in the User Manual found in appendix E. Below is a brief summary of the calibration process. It is not unusual for the camera system to need recalibration because, just as with most electronic equipment, their sensitivity can change causing the camera system’s accuracy to be compromised. The calibration of the camera system consists of two phases, the first is the actual calibration of the camera system, and the second is the setting up of a reference system (i.e.: the coordination of the camera system to the linac isocenter by using the lasers). The calibration procedure used a template with 13 reflector spheres and ensured that all of the 13 spheres could be seen by all 3 cameras used for localization. The setting of the reference system procedure was performed using another phantom provided for the Dynatrac camera system and cross referencing the laser position on the phantom with the cameras recognition of the 5 reflecting spheres on the phantom.

3.5.3 Post DynaTrac Camera Calibration

The procedure from the Initial Camera System Localization Test was then repeated after the calibration of the camera system to verify that the calibration of the camera system corrected the positioning inaccuracies seen in the initial camera system test. Results from this test can be seen in section 4.2.2 in the Results portion of this paper. Figure 3-5 below is an example of a profile that was obtained from this test.
3.6 Backup Jaw Settings Test

Another issue that was reported in the recent white paper concerning safety and quality considerations for Stereotactic Radiosurgery was the proper position setting of the back-up jaws for stereotactic gantry attachments [4]. Therefore a test was designed using both GafChromic film and the MapCHECK 2 diode array to insure that the jaws of the linear accelerator were properly positioned as to not allow for dose outside the maximum field size of the gantry attachment to be delivered. The importance of this test relates to the extremely large dose that is delivered in a single SRS fraction. If even a smaller portion of this dose reaches the patient outside of the intended treatment target, critical structures could be irradiated beyond their radiation tolerance and the patients health could be compromised. The jaw setting for the linear accelerator with the 3DLine gantry attachment used in this test was 8
cm by 8 cm. This jaw setting is slightly larger than the maximum 7 cm by 6.972 cm field size of the 3DLine head to allow for a sharper penumbra to be created with the micro-MLCs. This test was performed with GafChromic film for one field size and then an additional field size was added to the test when run with the MapCHECK 2.

### 3.6.1 GafChromic Film

Measurements were first taken with GafChromic RTQA+ film, from the same batch of film that was used for the mechanical and radiation isocenter tests. A 3x3cm² field was loaded with the micro-MLCs and a long strip of film was placed in the left and right direction, centered in the middle of the field, at 100 SSD on top of a thick water-equivalent plastic slab, and then another thinner water-equivalent slab was added on top of the film. These two slabs were used to provide radiation backscatter and build-up, respectively. The backscatter slab accomplished this by providing an additional thickness of medium beyond the film in which the high-energy photons from the linear accelerator could interact with and the resulting backscattered electrons would add dose to the film. The build-up slab accomplished this in a much simpler manner. Photons with an energy of 6 megavolts are known to have a depth at which they deposit their maximum dose (d_{max}) at approximately 1.5 cm in water, so placing the film underneath a piece of water-equivalent plastic of thickness 1.5 will allow for the incident photons to deliver the maximum amount of their dose to the film. After the field had been irradiated, the film was then replaced by another long thin strip of film positioned in the superior and inferior direction centered in the middle of the field. An example of a profile plot that was obtained from this test can be seen in figure 3-6 below. These plots serve both as a means of confirming that the location of the backup jaws is correct so as not to allow for a significant increase in dose outside of the desired field size. In addition to this, the test can be used to compare the expected field size to the measured field size by using the 50% isodose
Figure 3-6: Profile plot in the X direction to check for out-of-field dose due to improper back-up jaw settings.

If film is not available, this jaw settings test can be performed with a diode detector array, such as MapCHECK2. Two quick test were performed using the MapCHECK2 to verify the feasibility and a sample of the results obtained can be seen in figures 3-7 and 3-8 below. For both the film and MapCHECK2 measurements the Y-axis profiles showed the same result- no undue out of field dose delivered. This demonstrates that the correct settings were be used and loaded producing no regions outside the intended field receiving dose.
Figure 3-7: Profile plot in the X direction for a 3x3 field to check for out-of-field dose due to improper back-up jaw settings.

Figure 3-8: Profile plot in the X direction for a 5x5 field to check for out-of-field dose due to improper back-up jaw settings.
3.7 Analysis of Film using RIT and OriginPro7

Now that all of the measurements have been taken, the task of scanning, obtaining dose values, and analyzing the film began. This involved a number of steps which will be summarized in the following sections. The first step involved was obtaining a dose calibration that the RIT113 IMRT QA Software (Radiological Imaging Technology Colorado Springs, CO) would use to correspond the digital values obtained from the film depending on the amount of light that could be transmitted through the film into an actual dose value. The next step was to obtain the appropriate profiles to export and use in OriginPro. Finally, the actual analysis of the film could be performed.

3.7.1 RIT Dose Calibration

The scanner measures the amount of either transmitted or reflected light, depending on the type of scan that was performed, through the film and then converts the analog value that it measures into digital values that range from 0 to 65,535 A/D units where 0 reflects no light being transmitted (most dense) and 65,535 represents all the light being transmitted, similar to that in air (least dense) [10]. Therefore, an absolute dose calibration file is necessary to be performed in order to convert the digital signal between 0 and 65,535 into an actual applicable dose value.

In our Medical Physics department a step-wedge dose calibration was performed. A treatment plan was generated with a beam on an infinitely large water phantom with the gantry set at 0° and an overall initial field size of 30 cm by 10 cm. This beam consists of individual fields that deliver 25 MUs each totaling 375 MUs. To determine the dose delivered to each field the beam was set at 100 SSD and 15 points were created to calculate the dose delivered to the center of each individual field. An ion chamber reading was taken at several of the points to verify that the expected values from Pinnacle and what was actually being delivered was accurate. Table 3.1 shows
the doses calculated by Pinnacle to each of the 15 points. A long strip of film was then placed on top of a thick water equivalent slab to provide radiation backscatter and 1.5 cm thick slab was placed on top of the film to provide radiation build-up. The plan was then delivered using an Elekta linear accelerator.

The irradiated film was then scanned with a flatbed scanner with the irradiated side facing down in transmission mode. Also, a small unirradiated piece of GafChromic film was scanned in transmission mode to be used as a zero-dose reference point. The film was opened in RIT V5.2 as a reference image and an ROI was selected to encompass as much as possible of the image excluding the penumbra. A piecewise polynomial dose calibration curve was then created using the MLC Dose Calibration tool and entering in 13 of the 15 dose values for the corresponding fields that RIT recognized, in addition to the zero dose scan. This calibration curve was then saved to be applied to the GafChromic film scans. It is important to note that a calibration curve was not created for the EPID images because a relative

<table>
<thead>
<tr>
<th>Point</th>
<th>Calculated Pinnacle Dose (cGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34.6</td>
</tr>
<tr>
<td>2</td>
<td>59.3</td>
</tr>
<tr>
<td>3</td>
<td>86.5</td>
</tr>
<tr>
<td>4</td>
<td>111.1</td>
</tr>
<tr>
<td>5</td>
<td>137.2</td>
</tr>
<tr>
<td>6</td>
<td>161</td>
</tr>
<tr>
<td>7</td>
<td>185.3</td>
</tr>
<tr>
<td>8</td>
<td>207.6</td>
</tr>
<tr>
<td>9</td>
<td>233.8</td>
</tr>
<tr>
<td>10</td>
<td>261.2</td>
</tr>
<tr>
<td>11</td>
<td>289.8</td>
</tr>
<tr>
<td>12</td>
<td>317</td>
</tr>
<tr>
<td>13</td>
<td>345.2</td>
</tr>
<tr>
<td>14</td>
<td>370.8</td>
</tr>
<tr>
<td>15</td>
<td>393</td>
</tr>
</tbody>
</table>

Table 3.1: Doses calculated by Pinnacle for each point.
dose calibration curve is included in the text files that were exported over with their corresponding EPID images.

### 3.7.2 Analysis of GafChromic and EPID films

The two GafChromic films that were irradiated as described in section 3.4.2 were then scanned using the same method used for the calibration curve and were saved as lossless .tif images to preserve actual image dimensions. A film scanned in transmission mode can be seen in figure 3-9.

![Figure 3-9: Film shot at 0° gantry angle scanned in transmission mode.](image)

For each GafChromic film scan, the following procedure was performed to determine the location of the field’s isocenter. The scanned TIFF images were imported into RIT V5.2 as the reference image, and an ROI was applied to each of the images that encompassed as much of the film as possible. Next, the dose calibration curve was applied to the reference image as a means of accurately converting the digital signal from the scanner to the actual delivered dose data, similar to that measured by an ion chamber. Refer to section 3.7.1 for the creation of the dose calibration curve.

With each film scan imported into RIT and the appropriate dose calibration curve applied, both in-plane and cross-plane profile plots at the marked isocenter were obtained from RIT to be further analyzed with OriginPro. Figure 3-10 below demon-
strates the positions chosen for the cross and depth profile lines. The data from these

profile plots were then exported as ASCII data and imported into OriginPro7 to be
analyzed. A very similar method was followed for the EPID images. However, a dose
calibration curve was not needed to be applied from a dose calibration file, because
the log file contains the equation for the relative EPID dose calibration curve, and
RIT can apply that calibration curve.

OriginPro7 was then used to analyze the profile plots exported from RIT to de-
terminate the position of the radiation isocenter versus the mechanical isocenter for the
test described in section 3.4.2; and the actual radiation isocenter versus the intended
radiation isocenter localized using the camera system as described in section 3.5.1.
The following set of steps were followed to obtain each isocenter’s position. First,
in order to obtain a smoother profile plot, the 20 point smoothing function was ap-
plicated. Next, each profile was inspected to determine the values of the isodose points
that would reflect the position on the profile plot halfway between the maximum and

Figure 3-10: Positions of the cross profile and depth profile lines in RIT.
minimum points on either side represented by points I and S in figure 3-11 below. Next, to determine the actual x-coordinate of points I and S, an equation of the line connecting five points above the y values of points I and S and five points below the y values of points I and S was obtained using the tools in OriginPro. The determined y values of points I and S were entered into their respective linear equations to calculate their corresponding x-coordinates. This can be seen in figure A-1 in section A of the appendix. The average of the two x-coordinates of points I and S gives the position of the center of the radiation field. Now, the “valleys” in the middle of the profile plot were used to figure out the position of the center of the marker in the middle of the field. A similar method was used to find the center of the marker; however instead of using the 50% of entire field edge, just the 50% of the “valleys” were used. The points I_i and S_i in figure 3-11 represent these two points. The x-coordinates of points I_i and S_i were determined by finding the equation of a line that best connects the four points above and four points below points I_i and S_i respective y values. The average of their x-coordinates provide the location of the marker. The difference between the location of the marker and the center of the field determines the agreement between the position of the radiation isocenter versus the mechanical isocenter for the test described in section 3.4.2; and the actual radiation isocenter versus the intended radiation isocenter localized using the camera system as described in section 3.5.1. To determine the measured field size in the method described above, the positions of the field edges were used and then the absolute value of the x-coordinates were simply added.
Figure 3-11: Sample film image plotted in the inferior-superior direction with points I and S labeled to mark the position of the field edges and points $I_i$ and $S_i$ labeled to mark the positions of the edges of the tungsten marker in the middle of the field.

A very similar method of determining the isocenter of the field was presented in work by Rowshanford et al. [8], in which a MATLAB code was designed to compute the 50% of the peaks, in order to determine the field edges, and 50% of the valleys in the center of the field, to determine the isocenter position. Instead of a square field shaped by micro-MLC leaves, a 30 mm diameter cone was used and a 5 mm tungsten ball was used to mark the position of the isocenter on the film. The EPID of a Varian Trilogy linear accelerator was the instrument that was used. This analysis was done for both the in-plane and cross-plane profiles, and was proven to be a sufficient way to determine the isocenter location in the field.
Chapter 4

Results

4.1 Initial Verification of Isocenter Position

As can be seen in Table 4.1, when the field was shot with the gantry at 0°, the field size from the film measurement was 2.9 cm compared to the expected field size of 2.9 cm in the inferior and superior direction; and in the left and right direction 2.9 cm versus the expected 2.9 cm. The field sizes measured with the EPID for the same gantry orientation are 2.9 cm in the superior-inferior direction and 3.0 cm in the left and right direction versus the expected 2.9 cm and 2.9 cm dimensions respectively. The isocenter location from the film shot at a gantry angle of 0° was 0.1 cm in the inferior direction and 0.1 cm in the right direction; the expected isocenter location was 0 cm in the superior direction and 0 cm in the left direction. The isocenter location determined from the EPID was 0 cm in the superior direction and 0.1 cm in the right direction, versus the expected position of the isocenter at 0 cm in the superior direction and 0 cm in the left to right direction. Thus, for the AP fields shot, the isocenter meets the constraint of 1 mm set forth by TG-142 for all of the measurements except for the superior-inferior isocenter position on the film; however, the isocenter measurements from the EPID passed in that direction. The inaccuracy of the superior-inferior isocenter position is due to the varying response in the film.
Table 4.1: Initial Results of film scans to verify isocenter position

<table>
<thead>
<tr>
<th>Orientation and Scan Type</th>
<th>Isocenter (cm)</th>
<th>Field Size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured</td>
<td>Actual</td>
</tr>
<tr>
<td>0° Transmission (Inf.-Sup.)</td>
<td>-0.1</td>
<td>0</td>
</tr>
<tr>
<td>0° Transmission (Rt.-Lt.)</td>
<td>-0.1</td>
<td>0</td>
</tr>
<tr>
<td>0° EPID (Sup.-Inf.)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0° EPID (Lt.-Rt.)</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>90° Transmission (Inf.-Sup.)</td>
<td>-0.1</td>
<td>0</td>
</tr>
<tr>
<td>90° Transmission (Post.-Ant.)</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>90° EPID (Sup.-Inf.)</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>90° EPID (Ant.-Post.)</td>
<td>-0.1</td>
<td>0</td>
</tr>
</tbody>
</table>

when scanned. All of the field size measurements pass the 1 mm criteria set by TG-142 also.

With the fields shot at 90°, the film measured a 2.9 by 2.9 cm² field size versus a 2.9 by 2.9 cm² field size in the superior-inferior and anterior-posterior directions, respectively. The measurements from the EPID image were 2.9 by 2.9 cm² field size versus the expected 2.9 by 2.9 cm² field size. These measurements from both the film and EPID pass the 1 mm criteria of TG-142. The isocenter measurements using film with the gantry at 90° were 0.1 cm in the inferior direction and 0.1 in the anterior direction versus the expected values of 0 cm in the superior direction and 0 cm posterior. For the EPID, the measured isocenter was located at 0.3 cm inferiorly and 0.1 cm in the anterior direction. The expected isocenter position was 0 cm in the inferior direction and 0 cm in the anterior direction. The measured isocenter position is within TG-142’s tolerance for both the film and EPID images in both the anterior-posterior and superior-inferior directions with the exception of the EPID superior-inferior measurements.
4.2 DynaTrac Localization Test

4.2.1 Initial Isocenter Localization Test

Table 4.2: Initial Results of film scans to determine the isocenter position with DyanaTrac

<table>
<thead>
<tr>
<th>Orientation and Scan Type</th>
<th>Isocenter (cm)</th>
<th>Field Size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured</td>
<td>Actual</td>
</tr>
<tr>
<td>180° Transmission (Inf.-Sup.)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>180° Transmission (Rt.-Lt.)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>180° EPID (Sup.-Inf.)</td>
<td>-0.1</td>
<td>0</td>
</tr>
<tr>
<td>180° EPID (Lt.-Rt.)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>270° Transmission (Inf.-Sup.)</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>270° Transmission (Ant.-Post.)</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>270° EPID (Sup.-Inf.)</td>
<td>-0.1</td>
<td>0</td>
</tr>
<tr>
<td>270° EPID (Post.-Ant.)</td>
<td>0.3</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4.2 summarizes the results from the initial camera system test using the DynaTrac camera system to localize the radiation isocenter with the intersection of the drilled holes in the phantom. Starting with the gantry at 180°, all of the isocenter positions pass the criteria of the actual isocenter being less than 1 mm different than the expected isocenter set forth by TG-142. The largest deviation seen with the EPID images was in the superior-inferior direction in which the difference is 1 mm; and for the film, in the left-right direction in which the measured isocenter differed from the expected isocenter position by 0 mm. Both the field sizes for the film and EPID pass the TG-142 criteria of being within 1 mm of the indicated field size, which is noted as collimator size in TG-142. For the fields shot at a gantry angle of 270°, three out of the four isocenter measurements were outside of the TG-142 1 mm tolerance. Once again, both the field sizes for the EPID measurements and the film measurement were within the TG-142 tolerance.
4.2.2 Post-Camera Calibration Localization Test

Table 4.3: Results of film scans to determine the isocenter position with DyanaTrac after the camera system was re-calibrated

<table>
<thead>
<tr>
<th>Orientation and Scan Type</th>
<th>Isocenter (cm)</th>
<th>Camera Calibration Improvement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured</td>
<td>Actual</td>
</tr>
<tr>
<td>180° Transmission (Sup.-Inf.)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>180° Transmission (Rt.-Lt.)</td>
<td>0.02</td>
<td>0</td>
</tr>
<tr>
<td>180° EPID (Sup.-Inf.)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>180° EPID (Lt.-Rt.)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>270° Transmission (Inf.-Sup.)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>270° Transmission (Post.-Ant.)</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>270° EPID (Sup.-Inf.)</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>270° EPID (Post.-Ant.)</td>
<td>-0.1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4.3 above summarizes the measurements that were taken after the camera system was recalibrated to improve the localization accuracy of the drilled holes in the phantom to the isocenter of the machine. For both the EPID and film images shot at a gantry angle of 180°, the deviations between the measured isocenter position and the expected isocenter position were all well within 1 mm with a maximum deviation of 0.40 mm from the film measurement in the superior-inferior direction. For the fields irradiated with the gantry at 270°, all of the isocenter measurements were within the 1 mm tolerance specified in TG-142 with a maximum deviation seen in the film image for a measurement in the posterior-anterior direction and with the EPID image for the measurement taken in the superior-inferior direction. These deviations are 0.9 mm and 0.9 mm respectively. The final column in table 4.3 demonstrates the improve in millimeters from the isocenter positions prior to the camera calibration and afterwards. The measurements in parenthesis are those values that had a greater deviation from the isocenter after the camera calibration versus prior to the camera calibration.
To summarize the effects the camera calibration had on the deviations from the measured isocenter position to the expected isocenter position, the camera calibration either reduced or made no real difference to the deviations all of the image measurements. The films that were adversely affected by the camera calibration were the PA film measuring the inferior-superior direction and the right lateral film measuring the anterior-posterior direction. One important point to note is that the measurements with the alternate corresponding images were significantly decreased so the poor deviations could be due to a poor quality image scan due to other artifact on the film.

4.3 Backup Jaw Settings Test

Table 4.4: Results of film scans to determine the field size and out-of-field dose

<table>
<thead>
<tr>
<th>Direction</th>
<th>Field Size (cm)</th>
<th>Transmission 2%</th>
<th>Transmission 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured</td>
<td>Actual</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>2.9</td>
<td>2.9</td>
<td>-2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>Y</td>
<td>2.9</td>
<td>3</td>
<td>-2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
</tr>
</tbody>
</table>

Table ?? above first, is able to provide another means of calculation the field size and helping confirm that the field size is within 1 mm of the expected field size. Also, more importantly this table shows that the maximum distance from the center of the field in which a dose that is at least 2% of the delivered dose is -2.0 cm and 2.0 cm in the X direction and -2.0 cm and 2.0 cm in the Y direction. Finally, points that have greater than 5% transmission are between -1.9 cm and 1.8 cm in the X direction and -1.9 cm and 1.8 cm in the Y direction. These transmission measurements are important because it demonstrates that no extreme out-of-field dose is being delivers and thus
the back-up jaws are set to the correct setting for SRS. Although MapCHECK 2 was used to determine if there was any out-of-field dose, due to the large distance between each diode, it could not be used to accurately determine where exactly the points of 2% and 5% of the maximum doses was; however it would be a good tool, and less time consuming, to quickly determine if any significant out-of-field dose was present.
Chapter 5

Conclusions

For the most part, the method of obtaining the beam profiles with the Gafchromic film and Elekta EPID was very successful. In a few cases there was some trouble obtaining a uniform profile throughout the range of points that should have measured the maximum dose. Despite these minor issues, a sufficient method was developed to determine the field size and isocenter location by using the 50% isodose lines as the field edges and the x-coordinates of the points at which the dose halfway between the minimum dose at the isocenter and the maximum doses on either side of the isocenter.

Although film offers a better spatial resolution than the EPID, in terms of ease of use, we have shown that the EPID could be used to determine the isocenter position and field sizes accurately. With the use of the EPID, one does not need to worry about the inhomogeneities that could be seen with film scans due to artifacts on the film and scanner. The EPID has high enough resolution to account for areas of high dose gradient at the field edges and isocenter.

With the addition of this robust isocenter test to the tests already performed for each SRS patient, monthly and annually, the requirements set forth by TG-142 are fulfilled. The tests performed and outlined in this paper cover the Laser Localization and Collimator Size Indicator tests as suggested by TG-142 for daily QA tests necessary for SRS machines; and the other two tests suggested, Distance Indicator and
Stereotactic Interlocks, are already performed on a daily basis. It is recommended that the Laser Localization and Collimator Size Indicator test outlined in this paper for SRS only need to be done on the day of an SRS treatment rather than every day because our machine is not a dedicated SRS linear accelerator. It would also be recommended that for the daily laser localization test, the EPID could be used instead of film in the interest of time and ease.

In terms of the monthly QA tests, adding the Laser Localization test outlined in this paper to the current monthly tests performed would meet the requirements of TG-142. It would be proposed that this test be done with film due to the fact that it does indeed have a higher spatial resolution than the EPID. Also, since time isn’t an issue in performing monthly QA, the necessary care can be taken in the set-up, measurement and analysis of this test. For the annual QA tests, the addition of the outlined isocenter test in this paper, would satisfy the requirements of TG-142. We currently perform all of the other annual tests on a monthly or annual basis.
References


Appendix A

Example of isocenter position calculation.

Figure A-1: Example of the spreadsheet created to calculate the point at which the isocenter is located and the location of each field edge.
Appendix B

Daily/Patient Specific Isocenter QA Instructions

1) Select Patient: Isocenter QA from the patient list on the DynaTrac camera system computer in the treatment room.

2) Attach the isocenter cube to the SRS headholder by aligning the holes in the plexiglass base with the holes in the headholder and secure with the provided black pegs.

3) Attach the SRS headholder securely to the end of the treatment couch using the provided accessories.

4) Place the DynaTrac localization frame onto the headholder and secure it using the clips in each side of the frame, including the clips on the inferior side of the frame.

5) Align the couch so that all of the boxes in the DynaTrac software turn from red to green, including pitch, yaw, and roll. As a second check verify the numbers that the lasers line up to on the side of the fram to the coordinates given by ERGO++ for the isocenter coordinate.

6) Remove the localization frame from the headholder and insert a tungsten rod into the top of the isocenter cube.

7) Rotate the gantry to 180 degrees and attach the 3DLine head to the gantry head using the 4 provide screws and connect the data connection cable to the 3DLine head.
and the gantry.

8) Extend the EPID imager out so that a field can be captured.

9) Outside of the treatment room, turn on the power strip by the DynaTrac computers.

10) Perform a gantry calibration by clicking the “Gantry Calibration” button on the 3DLine computer and rotate the gantry in a full 360° and back until the 3DLine computer states that the gantry has been calibrated.

11) Perform a leaf calibration by clicking on the “leaf calibration” button on the 3DLine computer.

12) On the 3DLine computer select “Fixed Beam” and load a 3x3cm² square field with the micro-MLCs.

13) Select the PA field from the iView computer and click single exposure, with the gantry at 180° deliver 4 MU.

14) Repeat the above step with the tungsten rod in the left side of the cube, the gantry rotated to 270°, and the Rt Lat field selected on the iView computer.

15) Now that both images have been obtained, a quick analysis of the isocenter position can be performed in the iView computer system by drawing two diagonal lines connecting the corresponding corners of the field.

16) With the measuring tool measure from the center of the mark from the tungsten rod to the intersection of the two diagonal lines, and verify the distances are no more than 1 mm.

The above procedure concludes the isocenter test on a daily/patient specific basis. It is also still recommended that point dose measurements are also still taken for each arc using an A16 ion chamber and the cylindrical phantom. In addition, verify the localization of the isocenter for the patient to be treated by placing the DyanTrac localization frame on the table in the appropriate orientation and with the patient loaded in the DyanTrac software, position the headframe so that all of the fields turn
green and cross check the coordinates that the lasers indicate with the coordinates from ERGO++. 
Appendix C

Monthly Isocenter QA Instructions

1) Repeat the procedure in Appendix B for obtaining the EPID images to be analyzed.

2) Export both the EPID image and its corresponding log file from the iview computer to a network folder to be analyzed with RIT. The EPID image should be exported as a lossless jpeg image to preserve the image dimensions and resolution. It is important that the name of the EPID image and its corresponding log file have exactly the same name.

3) On the RIT computer import the EPID image by selecting ELEKTA EPID image from the list of image options under the import menu. In doing so, be sure to accept the relative dose calibration curve when RIT asks if you would like to do so.

4) With the EPID image loaded select a region of interest (ROI) that encompasses the entirety of the field and try as best as possible to the center the ROI to the field or else the coordinates for the isocenter location will require shifting.

5) Once the ROI has been selected, obtain both a cross-plane and depth profile to see where the isocenter marker showed up within the field. Make note of these positions for each EPID image and ensure they are within the 1 mm tolerance recommendation from TG-142.

With the addition of this test to the current tests for Monthly QA, the recom-
mendations from TG-142 are satisfied.
Appendix D

Annual Isocenter QA Instructions

1) Repeat the procedure in Appendix B; however, instead of using the EPID, GafChromic film will be used to acquire the isocenter position in the irradiated field.
2) For the PA field, place the tungsten marker in the top of the cube and place a 5x5cm² piece of GafChromic film on the top of the cube centered as best as possible with respect to the tungsten marker.
3) Irradiate the film using 400 MU and repeat the steps for the Rt Lat field with the tungsten marker in the left side of the cube and the GafChromic film placed on the left side of the cube.
4) Scan the films using the flatbed scanner in transmission mode and save as a lossless jpeg image.
5) Import the image into RIT and apply the dose calibration curve that was created for the film.
6) Select an ROI in the same manner as was done for the monthly test.
7) Obtain both a cross-plane and depth profile to see where the isocenter marker showed up within the field, and export the data from each profile as ASCII data to be further analyzed in OriginPro7 as described in section 3.7.2.
Appendix E

DynaTrac Camera System

Calibration

Phase 1:

1) Place the template, provided for DynaTrac, of 13 of the reflector spheres on the treatment couch in a manner such that all of the 13 spheres can be visualized by each of the 3 cameras.

2) In the DynaTrac Software on the computer in the treatment room, press the calibration button to enter the calibration module of the tracking software.

3) Select the name of the localizer, that was positioned on the treatment couch, from the list of Localizers in the right bar of the main window.

4) Confirm that each of the 13 spheres can be recognized by each of the 3 cameras and the “Calibrate” button in the right bar of the window is enabled, indicating that the calibration process could begin.

5) Click the “Calibrate” button and the calibration process will begin. After a few seconds, “SUCCESS” should appear in the Calibration Result Box indicating that the system has been calibrated and that no errors were found.

6) Select the option “Yes” when asked if “you would like to save the current calibration parameters."
7) After the new parameters are saved, the reference system needs to be calibrated, which is Phase 2, because the reference system is arbitrary and not initialized.

**Phase 2:**

1) Verify that the room lasers are indeed indicating accurately the isocenter of the machine using the daily laser QA device.

2) Position a cube provided for DynaTrac for this procedure so that the marking on the sides of the cube aligned to the room lasers used for patient set-up.

3) Choose this new cube from the localizer list view in the main calibration window.

4) The Calibrate Isocenter button is then activated indicating that the cube’s 5 spheres can all be detected by each camera.

5) Click the “Calibrate Isocenter” button and the calibration process is completed once a message box appeared indicating the completing of the process.

6) In order to save the calculated parameter, the “Set-up” context needs to be entered and the Save button clicked. This concludes the calibration of the DynaTrac Camera System.