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Bladder and Rectal Dosimetric Doses Upon Magnetic Resonance Imaging Integrated Into Tandem and Ovoid Brachytherapy Treatment Planning.

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August 2, 2021

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Graduate Medical Dosimetry Program

Abstract

Introduction

Brachytherapy is a common treatment for women that have cervical cancer. Patients can experience many side effects when receiving intracavitary treatment. Using more advanced imaging techniques such as MRI in the treatment planning process may be able to help reduce some of these side effects to the organs at risk and give patients an overall better quality of life during treatment and after treatment is complete. This study was performed to see if MRI has an impact in reducing these side effects to women undergoing these treatments.

Methods

This study is a retrospective chart review of 20 patients with Stage III cervical cancer. These patients were previously treated with Tandem and Ovoid brachytherapy and planned off CT or CT and MRI images at a hospital located in the Southeast. The subjects were selected at random, using the simple random method, mainly focusing on stage of cancer, number of treatments, how the treatments were planned and ensuring the bladder and rectal contours were averaging the same size. Each of the 20 patients were diagnosed with Stage III cervical cancer, completed five fractions of brachytherapy delivered with an ^{192}Ir source and a single tandem and two symmetric ovoid applicators to a prescribed dose of 30Gy, 6Gy per fraction.

Results

The results displayed that the overall dose to the bladder and rectum were lower with patients that were planned using MRI and CT imaging compared to patients just planned off CT imaging. Bladder and Rectum volume plays a large role when comparing dose to patients and how they were planned.

Conclusion

This study suggests looking at Bladder and Rectum on the Dose Volume Histogram using $D_{0.1cc}$, D_{1cc} and D_{2cc}. Once MRI planning was integrated into brachytherapy for cervical cancer patients using Tandem and Ovoids, the clinic did see an overall decrease in bladder and rectal doses compared to patients planned with only CT scans.

Introduction

Cervical Cancer is the uncontrolled growth of abnormal cells in the lining of the cervix. Cervical cancer is still one of the most common causes of death for women and is the fourth common gynecological cancer[1]. If Cervical cancer is detected early, it is often curable. Cervical cancer is treated in different ways depending on how advanced the cancer is at the time of diagnosis. Cervical cancer is typically treated using a multimodality approach including treatment options of surgery, external radiation therapy and/or internal radiation therapy, and chemotherapy. The most common modality for treatment is a combination of internal and external radiotherapy which typically last around 5 to 8 weeks along with chemotherapy[5]. Treating cervical cancer can be challenging using radiation therapy. This is mainly due to the location of the tumor and how it is positioned in-between many critical organs that are radiosensitive. This is the reason why cervical cancer is treated using external beam radiation therapy along with brachytherapy. High dose radiation therapy cannot be administered solely by external beam due to not being able to spare dose to the critical organs. Internal radiation therapy also known as brachytherapy typically consists of five treatments, delivering 6Gy per fraction for a total of 30Gy. Studies have shown by incorporating brachytherapy into the treatment plan for patients with cervical cancer have shown reduced local recurrence while also improving the overall survival rate compared to external beam radiation therapy alone[2].

The cervix is part of the female reproductive system and is located in the lower portion of the uterus, that connects to the vagina[1]. "Most cervical cancers (80 to 90 percent) are squamous cell cancers. Adenocarcinoma is the second most common type of cervical cancer, that account for the remaining 10 to 20 percent"[3]. The cervix is surrounded by critical organs including the vagina, bladder, rectum. These organs can be affected by the cancer and the treatment of the cancer. Side effects from radiation therapy can include vaginal stenosis, vaginal dryness, rectal bleeding and urinary issues[4]. To try and reduce these side effects, a different approach to planning brachytherapy has been implemented. For planning purposes, an MRI (magnetic resonance imaging) is now being used along with computed tomography (CT) to help better visualize the patient's anatomy. Since MRIs can distinguish between the different components of the body and can provide a much better soft tissue contrast than a CT, they are useful in treatment planning for being able to visualize the tumor and surrounding organs.

External beam radiation therapy uses x-rays that are emitted from a linear accelerator that rotates around the patient to encompass the primary tumor, lymph nodes and to control microscopic disease. Internal radiation therapy is also known as brachytherapy. Brachytherapy is when a radiation source is placed internally near the tumor[4,5]. A common radioactive active source used for cervical brachytherapy is Iridium 192. There are two different types of brachytherapy, low dose rate brachytherapy (LDR) and high dose rate brachytherapy (HDR). When treating cervical cancer with brachytherapy the most common type is referred to as intracavitary brachytherapy. Intracavitary brachytherapy involves inserting a radioactive source using an applicator, through the vaginal cavity, and is able to treat the upper vagina, cervix, and uterus[5]. The applicator used is called tandem and ovoids (T&O). The tandem is an intrauterine tube, which is placed through the cervix to the level of the uterine fundus, and there are two ovoids that are then inserted on both sides of the cervix in the lateral fornices[5]. Brachytherapy is used to boost the tumor dose because it is able to give a high dose of radiation while being able to spare organs at risk compared to external beam radiation therapy. This study will use Brachytherapy plans using tandem and ovoids to show how radiation is delivered to the tumor while potentially sparing critical organs using different imaging techniques.

In the years past, only CT scans were used to plan T&O brachytherapy for cervical cancer, which has many limitations. A CT scan is a two-dimensional (2D) scan that uses x-rays to capture different slices of the internal body. Limitations to using just CT scans to plan, include not being able to fully see the actual tumor as well as the organs at risk. Another limitation caused by planning off just a CT scan is when placing these points, the radiation is prescribed to a fixed point. These points are not taking into consideration the anatomy of the patient, which can cause inadequate coverage to the tumor while increasing the dose to the organs at risk[7]. MRI imaging is 3-dimensional (3D) and uses a magnetic field and radio waves to produce images. MRI is able to capture more detailed slices of the internal anatomy specifically soft tissue and being able to identify the tumor and organs at risk. Studies have shown by using MRI imaging, the dose can be prescribed to a 3D tumor volume which allows adequate tumor coverage and reduces the amount of dose to the organs at risk[7]. When the ICRU points are placed using MRI image guided imaging they are more exact since there is better visualization of the patient's anatomy. Studies show that 3D MRI image-guided brachytherapy planning for cervical cancer using T&O is the favored image modality due to its exceptional soft tissue contrast[8].

Simulation and planning for T&O cervical brachytherapy can now include MRI and CT scans to accurately prescribe dose to the exact location. Once the applicator has been inserted into the patient an MRI and CT scan are performed to ensure the T&O are positioned in the correct place. These scans are imported into the treatment planning system and are registered together. Contours will be drawn on the organs at risk including the bladder and rectum and point doses placed to where the radiation is to be prescribed. Using the International Committee on Radiation Units and Measurements' Report 38 (ICRU38), point A will be the location where the radiation dose is prescribed. "Point A, is a point that is placed 2 cm superior to the cervical os, and 2 cm lateral, along the plane perpendicular to the intrauterine tandem"[5]. Based on ICRU38, bladder and rectal points are also placed in exact locations to see how much dose each organ is receiving per fraction. The bladder reference point is placed on the posterior surface of the Foley balloon and the rectal reference point is placed at the location 0.5 cm posterior to the posterior vaginal wall[6].

Literature Review

A prospective study was conducted to compare the tumor dose coverage and dose that was received by the OARs between 3D-MRI and 2D point-A based brachytherapy planning for patients with cervical cancer[7]. There was a total of 79 patients in this study that had received external beam radiation therapy and were going to receive HDR brachytherapy. The histology and stage were confirmed on each patient before entering the study. Twenty of the patients in the study had big tumors, while 59 had small tumors. Each patient was planned using the 2D and 3D technique, the treatment was carried out with the 2D fixed point-A treatment plan prescribing 24Gy in 4 fractions, and immediately followed by the 3D planning and compared. The results to this study showed 2D point A- based and 3D planning have very different effects depending on the size of the tumor. Using 3D MRI imaging results in an increase in coverage and as well as dose to the OARS with big tumors, but not the same response for small tumors. If the tumors were located off center, 3D planning was preferred due to the right amount of coverage to the tumor and decreasing the dose to the OARS. Overall, this study concludes that 3D MRI imaging has many advantages over 2D planning. This study does show that 3D MRI image-guided brachytherapy planning has advantages over 2D planning, but there are many variables in this study. When there are too many variables that are trying to be compared the study can become skewed and not correctly display the results or answer the research question.

Studies have shown when using the 2D-point based treatment planning approach to carry out HDR brachytherapy for cervical cancer patients the dose that is given does not correspond to the actual dose that was received by the OARs[9]. Since studies have shown the dose that is given does not correspond to the actual dose that was received by the OARs, many clinics are using volumetric parameters ($D_{0.1cc}$, $D_{1.0cc}$, $D_{2.0cc}$) to determine the actual dose received by the OARs.

Studies that have been conducted on this research topic have used the same patients comparing 2D vs. 3D image guided brachytherapy planning. In this study, there will be 20 patients included in the data set. 10 of the patients will be patients that were planned solely on CT imaging and the other 10 patients will be patients that were planned off MRI image-guided planning. Volumetric parameters ($D_{0.1cc}$, $D_{1.0cc}$, $D_{2.0cc}$, mean and max bladder and rectal dose, and ICRU bladder and rectal points) were collected from the dose volume histograms (DVH) and will be analyzed. The goal of this study is to have a data set that will produce non bias results. The goal for this study is to see if MRI 3D image guided treatment planning decreases the bladder and rectal doses compared to just planning off CT scans which will hopefully improve the patients overall side effects from radiation therapy.

The purpose of the study is to find out once MRI planning was integrated into brachytherapy for cervical cancer patients using Tandem and Ovoids, did the clinic see an overall decrease in bladder and rectal doses compared to patients planned with only CT scans. If using MRI imaging reduces the bladder and rectal doses this will benefit both the physician and the patient. This will benefit physicians prescribing and treating patients with cervical cancer using brachytherapy T&O by allowing them to get a clearer picture of the patient's anatomy. Physician's will be able to delineate the tumor and prescribe dose exactly to the tumor volume while limiting the dose to the organs at risk. MRI imaging will benefit the patient by hopefully reducing the side effects that are known to occur from radiation therapy.

H_o: Once MRI planning was integrated into brachytherapy for cervical cancer patients using Tandem and Ovoids, the clinic did see an overall decrease in bladder and rectal doses compared to patients planned with only CT scans.

H_a: Once MRI planning was integrated into brachytherapy for cervical cancer patients using Tandem and Ovoids, the clinic did not see an overall decrease in bladder and rectal doses compared to patients planned with only CT scans.

Methods and Materials

Patient Selection

This is a retrospective chart review of 20 patients with Stage III cervical cancer that were previously treated with Tandem and Ovoid brachytherapy and planned off of CT or CT and MRI images at a hospital located in the Southeast. The subjects were selected at random, mainly focusing on stage of cancer, number of treatments, how the treatments were planned and ensuring the bladder and rectal contours were averaging the same size. The median age range was fifty years old and treated between the years of 2015 to 2020. Each of the 20 patients were diagnosed with Stage III cervical cancer, completed five fractions of brachytherapy delivered with an ^{192}Ir source and a single tandem and two symmetric ovoid applicators to a prescribed dose of 30Gy, 6Gy per fraction. A majority of the patients have previously received external beam radiation therapy.

Institutional Review Board

A chart review protocol was submitted to the Southeast hospital. This protocol outlined the objectives, methods, risks, and benefits in order to ensure and protect personal health information (PHI) and to comply with the Health Insurance Portability and Accountability Act of 1996 (HIPPA). This study qualifies for Exempt Status by the hospital. Once gaining this status, it was then sent for further approval by Grand Valley State University (GVSU) Institutional Review Board (IRB) reference number 21-149-H. After obtaining approval from the Southeast Hospital IRB and GVSU IRB, retrospective data began to be collected.

Treatment planning and equipment

On the first day of treatment for each patient, the patients were transferred to the operating room and put to sleep for the insertion of the applicator while in the dorsal lithotomy position. A speculum was inserted into the vaginal canal to identify the cervical flange. A smit sleeve was placed on the first day. The tandem was then inserted followed by the bilateral ovoids. Depending on the size of the patient's uterus a 30-degree tandem or a 45-degree tandem was used. Packing was inserted posteriorly and anteriorly with 1-inch iodoform gauze to spare the rectum and bladder and ensure the implant is in place. A Foley catheter was placed in the bladder during this procedure. The ovoids are then connected to the tandem. 10 of the patients who were planned based off CT imaging were brought back to the radiation oncology department after recovery from the insertion of the applicator to obtain a CT scan on CT scanner GE LightSpeed QX/I at 2.5mm slice thickness, while the other 10 patients who were planned off CT and MRI imaging received an MRI after recovery of the applicator and then transferred back to the radiation oncology department where they then received a CT scan on CT scanner GE LightSpeed QX/i at 2.5mm slice thickness. All patients were scanned in the supine position. Once the images were complete, the images got transferred into our eclipse treatment planning system using the brachytherapy planning module (Version 11.0.31) for 3D treatment planning. The MRI and CT images were merged on those patients being planning off both imaging techniques. Once the images were in the system, the physician contoured the bladder and rectum, and the physicist started the planning process. Each patient received five fractions at a dose of 6Gy per fraction delivered with ^{192}Ir. Every subsequent fraction the patients go to the operating room where the smit sleeve is identified and the tandem and ovoids are inserted, once recovered they head back to the radiation oncology department. A new CT is performed and merged with the pervious CT data set and a new plan is generated. For patients planned off CT and MRI, the original MRI is used throughout the course of treatment. Inverse planning was used to maximize coverage of the clinical target volume with 95% at least receiving the target dose. Once the treatment plan was ready, the patient was brought back into the room where the procedure took place. This room is fully shielded to meet all the safety requirements. Patients get into position and are then connected to the HDR Afterloader (GammaMedPlus iX). The empty applicators are first inserted into the patient and made sure everything is in the correct location for treatment. Once in the correct position, a dummy source leaves the HDR Afterloader to make sure there is nothing blocking the path of the live source. Once complete, the live source (^{192}Ir) which is housed in the unit travels down the transfer tubes and into the applicators which are located inside the patient and the treatment is delivered. Exact treatment time varies between patients due to the strength of the ^{192}Ir source.

For this retrospective study each treatment plan was originally planned by the same planner to reduce any variables that would cause bias within the study. Each treatment plan for every patient was opened and reviewed to ensure the bladder and rectum contours were averaging the same volume for all patients. ICRU bladder and rectal points were placed on each patient's treatment plan using the same technique each time. To place the ICRU bladder point correctly on each patient, all three views were used to locate the foley balloon. Once the foley balloon was located the cross hairs were moved to the center of the foley balloon and the ICRU bladder point was inserted towards the posterior portion of the foley balloon. The ICRU rectal point was then inserted into the plan. All three views were used to locate the flange. Once at the level of the flange, the packing that was inserted in the operating room is then located and the cross hairs were moved to the edge of the gauze. The axial view was used to find the midline and the ICRU rectal point was placed 5mm (0.5cm) posterior from the border edge of the gauze. Dose received to those points were collected and analyzed. Data was collected from the dose volume histograms (DVH) on every patient and each treatment plan for bladder and rectum at $D_{0.1cc}$, D_{1cc}, D_{2cc} mean and max bladder and rectal dose and ICRU bladder and rectal points.

Methods of Data Analysis

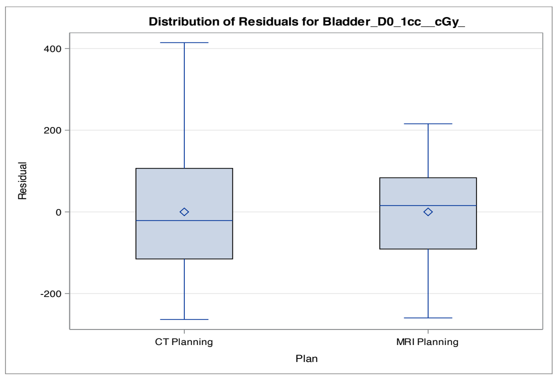
Once the data was collected and inserted into an Excel spreadsheet the information was sent to the Statistical Consulting Center at Grand Valley State University for statistical analysis. A two-way ANOVA was also run to see if the two plans differ and if they depend on trial. It was important when running the data that we accounted that the same patient was measured 5 times on five different days which is why we ended up using the proc mixed procedure and by using the proc mixed procedure we were able to control for this and measure the correlations between the measurements. A proc mixed model procedure in SAS 9.4 was performed to compare the treatment plans (CT vs. CT and MRI). This data was considered correlated data due to repeated measurements on each subject. Mixed model procedure allowed us to control for the fact that measurements from the same patient are highly correlated compared to measurements between the patients within the same plan. 12 tests were performed and correlated in a way since using the same data 12 times under different conditions.

Results

The objective of this retrospective study was to find out once MRI planning was integrated into brachytherapy treatment planning for cervical cancer patients using Tandem and Ovoids, did the clinic see an overall decrease in bladder and rectal doses compared to just patients planned off CT imaging. Volumetric data from 20 patients; 10 planned based off CT imaging and 10 planned off CT and MRI imaging was collected from the DVH, and data from ICRU bladder and rectal points were collected. $D_{0.1cc}$, D_{1cc}, D_{2cc} bladder and rectal doses, mean and max bladder and rectal dose and ICRU bladder and rectal points were evaluated in two ways. One way that the data was evaluated was by comparing each patient to each plan and looked at the means and the standard deviation. By looking at the data in this regards we were able to see the variability between the bladder and rectal volumes. The second way we evaluated the data was by looking at the overall difference between CT planning and MRI planning.

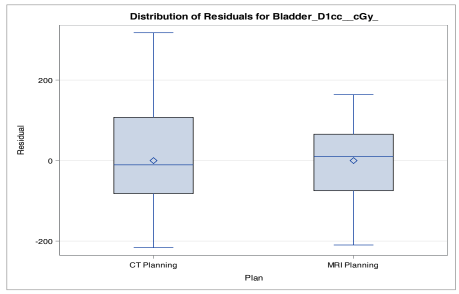
CT Patients vs CT and MRI: Bladder $D_{0.1cc}$

Bladder $D_{0.1cc}$ when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 1 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and MRI planning, shows the mean for patients that were planned off CT Planning was 539.04 while the mean for patients planned off CT and MRI was 532.71. The overall mean was higher in patients planned off CT imaging than in patients that were planned off CT and MRI imaging, refer to table 2 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was 6.3264 and the P-value is 0.8293. The difference of 6.3264 is not statistically significant due to the P-value being greater than .05, refer to table 3 in appendix. According to the box seen below, using MRI shows lower dose to bladder $D_{0.1cc.}$



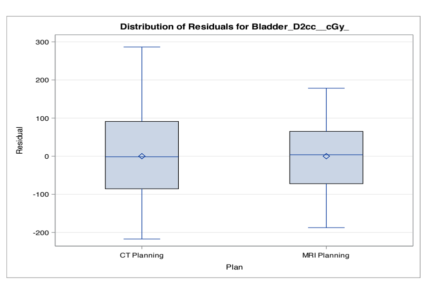
CT Patients vs CT and MRI: Bladder D_{1cc}

Bladder D_{1cc} when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 4 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and MRI planning, shows the mean for patients that were planned off CT Planning was 449.61 while the mean for patients planned off CT and MRI was 441.76. The overall mean was higher in patients planned off CT imaging than in patients that were planned off CT and MRI imaging, refer to table 5 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was 7.8486 and the P-value is 0.7362. The difference of 7.8486 is not statistically significant due to the P-value being greater than .05, refer to table 6 in appendix. According to the box plot in seen below, using MRI shows lower dose to bladder D_{1cc}.



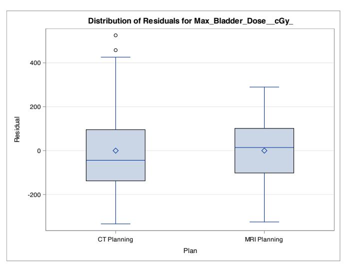
CT Patients vs CT and MRI: Bladder D_{2cc}

Bladder D_{2cc} when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 7 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and MRI planning, shows the mean for patients that were planned off CT Planning was 406.56 while the mean for patients planned off CT and MRI was 399.84. The overall mean was higher in patients planned off CT imaging than in patients that were planned off CT and MRI imaging, refer to table 8 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was 6.7234 and the P-value is 0.7540. The difference of 6.7234 is not statistically significant due to the P-value being greater than .05, refer to table 9 in appendix. According to the box plot seen below, using MRI shows lower dose to bladder D_{2cc}.



CT Patients vs CT and MRI: Max Bladder Dose

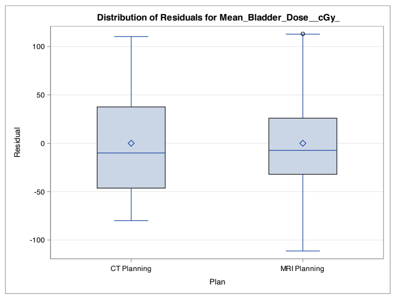
Max Bladder Dose when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 10 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and MRI planning, shows the mean for patients that were planned off CT Planning was 623.31 while the mean for patients planned off CT and MRI was 603.93. The overall mean was higher in patients planned off CT imaging than in patients that were planned off CT and MRI imaging, refer to table 11 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was 19.3800 and the P-value is 0.5933. The difference of 19.3800 is not statistically significant due to the P-value being greater than .05, refer to table 12 in appendix. According to the box plot seen below, using MRI shows lower dose when looking at Max Bladder dose.



CT Patients vs CT and MRI: Mean Bladder Dose

Mean Bladder Dose when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 13 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and MRI planning, shows the mean for patients that were planned off CT Planning was 256.24 while the mean for patients planned off CT and MRI was 231.56. The overall mean was higher in patients planned off CT imaging than in patients that were planned off CT and MRI imaging, refer to table

14 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was 24.6760 and the P-value is 0.0261. The difference of 24.6760 is statistically significant due to the P-value being less than .05, refer to table 15 in appendix. According to the box plot seen below, using MRI shows lower dose when looking at Mean Bladder dose.

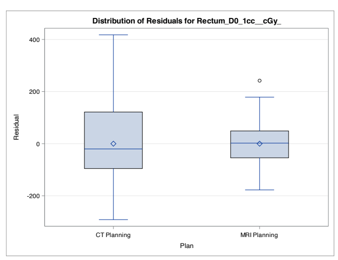


CT Patients vs CT and MRI: ICRU Bladder Point

ICRU Bladder Point when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 16 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and MRI planning, shows the mean for patients that were planned off CT Planning was 467.91 while the mean for patients planned off CT and MRI was 457.98. The overall mean was higher in patients planned off CT imaging than in patients that were planned off CT and MRI imaging, refer to table 17 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was 9.9280 and the P-value is 0.7309. The difference of 9.9280 is not statistically significant due to the P-value being greater than .05, refer to table 18 in appendix.

CT Patients vs CT and MRI: Rectum $D_{0.1cc}$

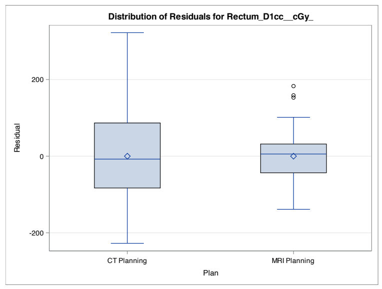
Rectum $D_{0.1cc}$ when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 19 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and MRI planning, shows the mean for patients that were planned off CT Planning was 501.53 while the mean for patients planned off CT and MRI was 454.32. The overall mean was higher in patients planned off CT imaging than in patients that were planned off CT and MRI imaging, refer to table 20 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was 47.2134 and the P-value is 0.0609. The difference of 47.2134 is not statistically significant due to the P-value being greater than .05, refer to table 21 in appendix. According to the box plot seen below, using MRI shows lower dose to the rectum $D_{0.1cc}$.



CT Patients vs CT and MRI: Rectum D_{1cc}

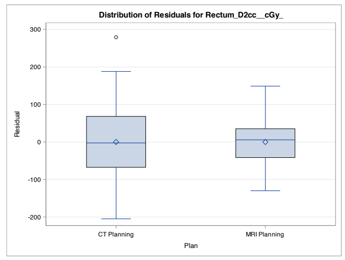
Rectum D_{1cc} when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 22 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and MRI planning, shows the mean for patients that were planned off CT Planning was 417.46 while the mean for patients planned off CT and MRI was 385.02. The overall mean was higher in patients planned off

CT imaging than in patients that were planned off CT and MRI imaging, refer to table 23 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was 32.4336 and the P-value is 0.0924. The difference of 32.4336 is not statistically significant due to the P-value being greater than .05, refer to table 24 in appendix. According to the box plot seen below, using MRI shows lower dose to the rectum D_{1cc}.



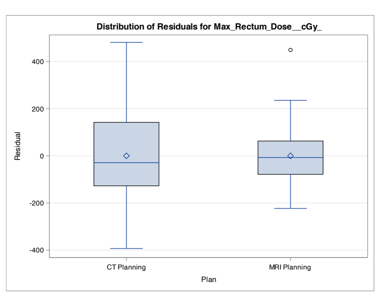
CT Patients vs CT and MRI: Rectum D_{2cc}

Rectum D_{2cc} when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 25 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and MRI planning, shows the mean for patients that were planned off CT Planning was 381.61 while the mean for patients planned off CT and MRI was 354.29. The overall mean was higher in patients planned off CT imaging than in patients that were planned off CT and MRI imaging, refer to table 26 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was 27.3122 and the P-value is 0.1123. The difference of 27.3122 is not statistically significant due to the P-value being greater than .05, refer to table 27 in appendix. According to the box plot seen below, using MRI shows lower dose to the rectum D_{2cc}.



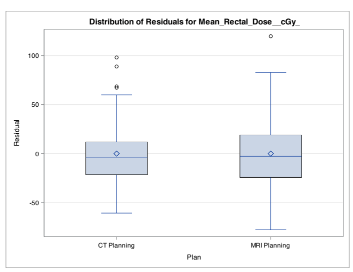
CT Patients vs CT and MRI: Max Rectum Dose

Max Rectum dose when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 28 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and MRI planning, shows the mean for patients that were planned off CT Planning was 550.96 while the mean for patients planned off CT and MRI was 518.53. The overall mean was higher in patients planned off CT imaging than in patients that were planned off CT and MRI imaging, refer to table 29 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was 32.4320 and the P-value is 0.3356. The difference of 32.4230 is not statistically significant due to the P-value being greater than .05, refer to table 30 in appendix. According to the box plot seen below, using MRI shows lower dose when looking at Max Rectum dose.



CT Patients vs CT and MRI: Mean Rectum Dose

Mean Rectum Dose when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 31 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and MRI planning, shows the mean for patients that were planned off CT Planning was 174.99 while the mean for patients planned off CT and MRI was 189.94. The overall mean was higher in patients planned off CT and MRI imaging than in patients that were planned off CT imaging, refer to table 32 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was -14.9500 and the P-value is 0.0526. The difference of -14.9500 is not statistically significant due to the P-value being greater than .05, refer to table 33 in appendix. According to the box plot seen below, using CT shows lower dose when looking at Mean Rectum dose.



CT Patients vs CT and MRI: ICRU Rectum Point

ICRU Rectum Point when evaluated by comparing each patient to each plan the mean and standard deviation (Std Dev) showed variation between each patient, see table 34 in appendix. Results from the MEANS procedure, which is the overall difference between CT planning and

MRI planning, shows the mean for patients that were planned off CT Planning was 354.41 while the mean for patients planned off CT and MRI was 360.72. The overall mean was higher in patients planned off CT and MRI imaging than in patients that were planned off CT imaging, refer to table 35 in appendix. Multiple linear regression was done to compare CT planning to MRI planning while accounting for the variability between the patients and each plan (which is listed as Trial). The mean difference between CT planning and MRI planning was -6.3100 and the P-value is 0.7961. The difference of -6.3100 is not statistically significant due to the P-value being greater than .05, refer to table 36 in appendix.

Discussion

The purpose of this study was to see once MRI 3D imaging was integrated into brachytherapy treatment planning did the bladder and rectal doses decrease compared to just planning off CT imaging scans. After evaluating the 20 patients that were included in the data set one can see overall that by integrating MRI imaging into treatment planning reduces the dose to the bladder and rectum. Limiting the dose to the bladder and rectum reduces many side effects that patients can have. Some common side effects from radiation therapy can include vaginal stenosis, vaginal dryness, rectal bleeding and urinary issues[4]. If we in radiation oncology know what it takes to reduce these side effects than we should implement more imaging in order for these to occur.

CT Patients vs CT and MRI: Bladder $D_{0.1cc}$, Bladder D_{1cc}, Bladder D_{2cc}

Referring to Tables 1,4 and 7 there is a large amount of variation when looking at the standard deviation between the patients that were planned off CT and the patients planned off CT and MRI imaging. This is due to different volume sizes of the bladder. The patients were treated for a total of five times and were all spaced out the same between treatment days. There were days where a patient would have a slightly smaller or larger bladder on day 1 than compared to day 2 which caused variability in the data that needed to be accounted for. Trial is used in our model because each trial (fraction) had different bladder size. If we did not use trial in our model, we would lose all of that information and would not be able to see a clear picture so by including trial it includes the extra variation. In tables 2,5 and 8 which shows the overall difference between the patients planned off CT imaging and the patients planned off MRI imaging, these results were expected because MRI provides much more detailed slices of the internal anatomy specifically soft tissue and being able to identify the organs at risk.

CT Patients vs CT and MRI: Max Bladder Dose, Mean Bladder Dose, Max Rectum Dose and Mean Rectum Dose

There are not many studies that look at the max and mean bladder dose when comparing imaging studies on brachytherapy patients. This is mainly due to the bladder and rectum are both distensible organs. Both of these organs at risk can vary in volume multiple times throughout the day due to filling of the bladder and rectum as well as emptying. These organs both can shift positioning depending on the patient's anatomy. Studies have shown the max and mean doses of these organs are risk that are collected from the dose volume histogram may not always be correct due to the nature of the organ. These doses were collected and analyzed to compare the difference between the three volumes that were collected for each organ. The overall mean rectum dose was higher in patients planned off CT and MRI imaging than in patients that were planned off CT imaging, refer to table 31 in appendix. This could be due to patients have a larger or smaller bladder depending on the day they were treated.

CT Patients vs CT and MRI: Rectum $D_{0.1cc}$, Rectum D_{1cc}, Rectum D_{2cc}

Viewing tables 18,21 and 24 there is a large amount of variation when looking at the standard deviation between the patients that were planned off CT and the patients planned off CT and MRI imaging. This is due to different volume sizes of the rectum. The patients were treated for a total of five times and were all spaced out the same between treatment days. There were days where a patient would have a slightly smaller or larger rectum on day 1 than compared to day 2 which caused variability in the data that needed to be accounted for. Trial is used in our model because each trial (fraction) had different rectum size. If we did not use trial in our model, we would lose all that information and would not be able to see a clear picture so by including trial it includes the extra variation. In tables 19,22 and 25 which shows the overall difference between the patients planned off CT imaging and the patients planned off MRI imaging, these results were expected because MRI provides much more detailed slices of the internal anatomy specifically soft tissue and being able to identify the organs at risk. The patients that were planned using CT and MRI imaging showed a lower dose to the rectum than patients that were planned off CT imaging.

CT Patients vs CT and MRI: ICRU Bladder Point and ICRU Rectum Point

Data was collected and analyzed on ICRU Bladder and Rectum points for each patient. Traditionally these points would be placed on each patient and the dose would be evaluated from these points. As technology has evolved and more imaging has been incorporated into the treatment planning process these ICRU points are not the only points evaluated. Studies have shown when using the 2D-point based treatment planning approach to carry out HDR brachytherapy for cervical cancer patients the dose that is given does not correspond to the actual dose that was received by the OARs[9]. Since MRI imaging has been integrated into treatment planning the volumes of the critical structures collected off the dose volume histogram are now more widely used to give a more accurate representation of the dose that is being received to the critical organs.

Limitations and Improvements for Further Research

Limitations of this study include a small sample size. When initially looking into this study it started out as a large sample size of 150 patients; 75 that had been planned with CT and 75 that were planned with CT and MRI imaging. Due to the inclusion criteria of the study including the same number of fractions, same total dose, and same dose per fraction a large number of patients were eliminated which left this study with a small sample size. A small size increases the change for bias within the study. Another limitation for this study was variability in the volume size of bladder and rectum. Some improvements for this study would be to have a consistent volume for all five treatments that would eliminate the amount of variability that was taken into account when running the data. A larger sample size for this study would be ideal to produce non bias data.

Conclusion

Cervical cancer is still one of the most common causes of death for women and is the fourth common gynecological cancer[1]. Women that must undergo radiation therapy treatment typically experience a lot of common side effects from the treatment itself. Side effects from radiation therapy can include vaginal stenosis, vaginal dryness, rectal bleeding and urinary issues[4]. Once MRI planning was integrated into brachytherapy for cervical cancer patients using Tandem and Ovoids, the clinic did see an overall decrease in bladder and rectal doses compared to patients planned with only CT scans. Learning that using MRI imaging for treatment planning reduces the overall dose to the bladder and rectum will hopefully improve the patients overall side effects from radiation therapy and give them a better quality of life while going through treatment.

References

[1] R. Banerjee and M. Kamrava, Int J Womens Health **6**, 555 (2014).

[2] N. Chakravarty, M.K. Semwal, G. Trivedi, V. Suhag, M. Jain, N. Sharma, and R.S. Vashisth, Journal of Radiotherapy in Practice **19**, 277 (2020).

[3] J. Chino, Practical Radiation Oncology 15 (2020).

[4] Y. Iwai, M.W. Nemoto, T. Horikoshi, A. Kanazawa, M. Kurokawa, M. Saito, R. Harada, H. Kobayashi, and T. Uno, Jpn J Radiol **38**, 899 (2020).

[5] S.V. Jamema, S. Saju, U. Mahantshetty, S. Pallad, D.D. Deshpande, S.K. Shrivastava, and K.A. Dinshaw, J Med Phys **33**, 3 (2008).

[6] O. Mahmoud, S. Kilic, A.J. Khan, S. Beriwal, and W. Small, Ann Transl Med **5**, (2017).

[7] R. Pötter, P. Georg, J.C.A. Dimopoulos, M. Grimm, D. Berger, N. Nesvacil, D. Georg, M.P. Schmid, A. Reinthaller, A. Sturdza, and C. Kirisits, Radiother Oncol **100**, 116 (2011).

[8] J. Ren, W. Yuan, R. Wang, Q. Wang, Y. Li, C. Xue, Y. Yan, X. Ma, L. Tan, and Z. Liu, PLoS One; San Francisco **11**, e0161932 (2016).

[9] J. Richart, V. Carmona-Meseguer, T. García-Martínez, A. Herreros, A. Otal, S. Pellejero, A. Tornero-López, and J. Pérez-Calatayud, Rep Pract Oncol Radiother **23**, 547 (2018).

[10] M. Serban, C. Kirisits, R. Pötter, A. de Leeuw, K. Nkiwane, I. Dumas, N. Nesvacil, J. Swamidas, R. Hudej, G. Lowe, T.P. Hellebust, G. Menon, A. Oinam, P. Bownes, B. Oosterveld, M. De Brabandere, K. Koedooder, A.B.L. Marthinsen, J. Lindegaard, and K. Tanderup, Radiotherapy and Oncology **129**, 567 (2018).

[11]Nhs.uk. 2021. *Cervical cancer - Treatment*. [online] Available at: <https://www.nhs.uk/conditions/cervical-cancer/treatment/> [Accessed 5 August 2021].

[12]ASTRO. 2021. ASTRO issues first clinical guideline on radiation therapy for cervical cancer - American Society for Radiation Oncology (ASTRO) - American Society for Radiation Oncology (ASTRO). [online] Available at: <https://www.astro.org/News-and-Publications/News-and-Media-Center/News-Releases/2020/ASTRO-issues-first-clinical-guideline-on-radiation> [Accessed 10 February 2021].

[13]Uicc.org. 2021. Cervical cancer elimination | UICC. [online] Available at: <https://www.uicc.org/what-we-do/thematic-areas-work/cervical-cancer-

elimination?gclid=Cj0KCQiAkuP9BRCkARIsAKGLE8UtXeRSpDDX9RsRJdkLL0W7xgWOFdTDXKbJP6lGu8nB-Szg-X4siS0aAhjIEALw_wcB> [Accessed 22 March 2021].

[14]Nccc-online.org. 2021. Cervical Cancer Overview – NCCC. [online] Available at: <https://www.nccc-online.org/hpvcervical-cancer/cervical-cancer-overview/> [Accessed 14 December 2020].

[15]Cancer.org. 2021. Cervical Cancer Radiation Therapy | Cervical Cancer Radiation Treatment. [online] Available at: <https://www.cancer.org/cancer/cervical-cancer/treating/radiation.html> [Accessed 4 November 2020].

Appendix:

Table 1: Bladder *D0.1cc*

Analysis Variable : Bladder_D0_1cc__cGy_ Bladder D0_1cc					
Patient	Plan	N Obs	N	Mean	Std Dev
1	CT	5	5	542.02	154.76
	MRI	5	5	448.64	80.59
2	CT	5	5	648.16	77.89
	MRI	5	5	527.83	74.07
3	CT	5	5	468.20	50.81
	MRI	5	5	568.69	73.39
4	CT	5	5	335.79	77.01
	MRI	5	5	573.60	54.38
5	CT	5	5	568.63	60.02
	MRI	5	5	498.28	127.80
6	CT	5	5	526.79	101.85
	MRI	5	5	607.33	85.93
7	CT	5	5	709.07	209.41
	MRI	5	5	374.22	79.82
8	CT	5	5	766.23	89.60
	MRI	5	5	435.51	130.17
9	CT	5	5	343.28	42.70
	MRI	5	5	617.58	72.21
10	CT	5	5	482.25	42.13
	MRI	5	5	675.46	98.23

Table:2 Bladder *D0.1cc*

Analysis Variable:				
Plan	N	N	Mean	Std
CT	50	50	539.04	165.29
MRI	50	50	532.71	121.53

Table 3: Bladder *D0.1cc*

Solution for Fixed Effects										
Effect	Plan	Trial	Estimate	Standard	DF	t Value	Pr > ltl	Alpha	Lower	Upper
Intercept			518.33	35.8318	94	14.47	<.0001	0.05	447.18	589.47
Plan	CT		6.3264	29.2566	94	0.22	0.8293	0.05	-	64.4160
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	-13.7105	46.2587	94	-0.30	0.7676	0.05	-105.56	78.1372
Trial		2	47.7245	46.2587	94	1.03	0.3049	0.05	-	139.57
Trial		3	4.9335	46.2587	94	0.11	0.9153	0.05	-	96.7812
Trial		4	32.9805	46.2587	94	0.71	0.4776	0.05	-	124.83
Trial		5	0	.	.	.	.	.	.	.

Table 4: *Bladder D_{1cc}*

Analysis Variable : Bladder_D1cc__cGy_ Bladder D1cc (cGy)					
Patient	Plan	N	N	Mean	Std Dev
1	CT	5	5	462.41	131.62
	MRI	5	5	375.03	62.02
2	CT	5	5	545.16	57.80
	MRI	5	5	416.28	57.06
3	CT	5	5	390.82	35.23
	MRI	5	5	462.71	51.92
4	CT	5	5	280.46	55.30
	MRI	5	5	471.50	49.34
5	CT	5	5	502.84	64.99
	MRI	5	5	412.85	94.86
6	CT	5	5	441.60	77.62
	MRI	5	5	508.38	72.06
7	CT	5	5	578.60	158.45
	MRI	5	5	318.49	59.31
8	CT	5	5	596.30	54.95
	MRI	5	5	364.78	115.45
9	CT	5	5	289.16	36.69
	MRI	5	5	532.90	65.36
10	CT	5	5	408.75	36.03
	MRI	5	5	554.69	64.47

Table 5: *Bladder D_{1cc}*

Analysis Variable:				
Plan	N	N	Mean	Std
CT	50	50	449.61	128.81
MRI	50	50	441.76	98.58

Table 6: *Bladder D_{1cc}*

Solution for Fixed Effects										
Effect	Plan	Trial	Estimate	Standard	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept			432.92	28.4478	94	15.22	<.0001	0.05	376.44	489.40
Plan	CT		7.8486	23.2275	94	0.34	0.7362	0.05	-	53.9673
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	-8.6605	36.7259	94	-0.24	0.8141	0.05	-	64.2596
Trial		2	33.1345	36.7259	94	0.90	0.3693	0.05	-	106.05
Trial		3	3.0415	36.7259	94	0.08	0.9342	0.05	-	75.9616
Trial		4	16.6870	36.7259	94	0.45	0.6506	0.05	-	89.6071
Trial		5	0	.	.	.	.	.	.	.

Table 7: ***Bladder*** D_{2cc}

Analysis Variable : Bladder_D2cc__cGy_ Bladder D2cc (cGy)					
Patient ID	**Plan**	**N Obs**	**N**	**Mean**	**Std Dev**
1	CT Planning	5	5	410.34	130.72
	MRI Planning	5	5	347.54	52.75
2	CT Planning	5	5	501.71	54.84
	MRI Planning	5	5	359.25	51.52
3	CT Planning	5	5	353.05	31.17
	MRI Planning	5	5	416.00	42.56
4	CT Planning	5	5	250.30	44.80
	MRI Planning	5	5	426.00	44.76
5	CT Planning	5	5	475.85	64.35
	MRI Planning	5	5	371.15	86.06
6	CT Planning	5	5	397.65	68.42
	MRI Planning	5	5	463.40	70.56
7	CT Planning	5	5	520.93	145.55
	MRI Planning	5	5	290.41	52.07
8	CT Planning	5	5	530.10	50.81
	MRI Planning	5	5	331.34	106.02
9	CT Planning	5	5	259.09	33.61
	MRI Planning	5	5	491.84	59.83
10	CT Planning	5	5	366.61	32.97
	MRI Planning	5	5	501.45	51.48

Table 8: ***Bladder*** D_{2cc}

Analysis Variable:				
Plan	**N**	**N**	**Mean**	**Std**
CT	50	50	406.56	119.19
MRI	50	50	399.84	89.84

Table 9: ***Bladder*** D_{2cc}

Solution for Fixed Effects										
Effect	**Plan**	**Trial**	**Estimate**	**Standard**	**DF**	**t Value**	**Pr > |t|**	**Alpha**	**Lower**	**Upper**
Intercept			390.60	26.1981	94	14.91	<.0001	0.05	338.58	442.61
Plan	CT		6.7234	21.3907	94	0.31	0.7540	0.05	-	49.1951
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	-4.1885	33.8217	94	-0.12	0.9017	0.05	-	62.9652
Trial		2	31.3070	33.8217	94	0.93	0.3570	0.05	-	98.4607
Trial		3	3.9005	33.8217	94	0.12	0.9084	0.05	-	71.0542
Trial		4	15.1935	33.8217	94	0.45	0.6543	0.05	-	82.3472
Trial		5	0	.	.	.	.	.	.	.

Table 10: Max Bladder Dose

Analysis Variable : Max_Bladder_Dose__cGy_ Max Bladder					
Patient	Plan	N	N	Mean	Std
1	CT Planning	5	5	687.40	140.11
	MRI	5	5	505.72	97.06
2	CT Planning	5	5	745.76	120.35
	MRI	5	5	606.12	84.27
3	CT Planning	5	5	521.74	60.79
	MRI	5	5	655.24	105.70
4	CT Planning	5	5	365.74	86.25
	MRI	5	5	660.42	40.23
5	CT Planning	5	5	620.04	74.26
	MRI	5	5	550.38	160.29
6	CT Planning	5	5	595.24	124.19
	MRI	5	5	684.32	113.86
7	CT Planning	5	5	815.84	272.31
	MRI	5	5	413.06	103.60
8	CT Planning	5	5	943.64	156.46
	MRI	5	5	499.08	149.78
9	CT Planning	5	5	410.88	68.95
	MRI	5	5	687.66	88.56
10	CT Planning	5	5	526.84	51.87
	MRI	5	5	777.32	124.69

Table 11: Max Bladder Dose

Analysis Variable:				
Plan	N	N	Mean	Std
CT	50	50	623.31	209.10
MRI	50	50	603.93	146.01

Table 12: Max Bladder Dose

Solution for Fixed Effects										
Effect	Plan	Trial	Estimate	Standard	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept			601.18	44.2973	94	13.57	<.0001	0.05	513.23	689.13
Plan	CT		19.3800	36.1686	94	0.54	0.5933	0.05	-	91.1935
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	-47.6400	57.1875	94	-0.83	0.4069	0.05	-161.19	65.9072
Trial		2	49.1550	57.1875	94	0.86	0.3922	0.05	-	162.70
Trial		3	-15.3050	57.1875	94	-0.27	0.7896	0.05	-128.85	98.2422
Trial		4	27.5500	57.1875	94	0.48	0.6311	0.05	-	141.10
Trial		5	0	.	.	.	.	.	.	.

Table 13: Mean Bladder Dose

Analysis Variable : Mean_Bladder_Dose__cGy_ Mean Bladder					
Patient	**Plan**	**N**	**N**	**Mean**	**Std**
1	CT Planning	5	5	243.66	27.92
	MRI	5	5	221.68	36.14
2	CT Planning	5	5	240.86	22.65
	MRI	5	5	302.96	48.94
3	CT Planning	5	5	187.04	6.13
	MRI	5	5	200.64	18.37
4	CT Planning	5	5	233.64	50.55
	MRI	5	5	244.72	23.96
5	CT Planning	5	5	235.52	18.58
	MRI	5	5	268.84	56.85
6	CT Planning	5	5	263.22	73.02
	MRI	5	5	248.50	52.46
7	CT Planning	5	5	315.58	42.65
	MRI	5	5	198.94	37.30
8	CT Planning	5	5	309.70	42.22
	MRI	5	5	152.60	26.51
9	CT Planning	5	5	221.30	21.21
	MRI	5	5	273.56	28.00
10	CT Planning	5	5	311.84	27.23
	MRI	5	5	203.16	17.27

Table 14: Mean Bladder Dose

Analysis Variable:				
Plan	**N**	**N**	**Mean**	**Std**
CT	50	50	256.24	53.78
MRI	50	50	231.56	54.29

Table 15: Mean Bladder Dose

Solution for Fixed Effects										
Effect	**Plan**	**Trial**	**Estimate**	**Standard**	**DF**	**t Value**	**Pr > |t|**	**Alpha**	**Lower**	**Upper**
Intercept			227.86	13.3674	94	17.05	<.0001	0.05	201.32	254.40
Plan	CT Planning		24.6760	10.9145	94	2.26	0.0261	0.05	3.0051	46.3469
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	12.2750	17.2573	94	0.71	0.4787	0.05	-	46.5398
Trial		2	10.4200	17.2573	94	0.60	0.5474	0.05	-	44.6848
Trial		3	5.4100	17.2573	94	0.31	0.7546	0.05	-	39.6748
Trial		4	-9.5900	17.2573	94	-0.56	0.5797	0.05	-	24.6748
Trial		5	0	.	.	.	.	.	.	.

Table 16: ICRU Bladder Point

Analysis Variable : ICRU_Bladder_Point__cGy ICRU Bladder					
Patient	**Plan**	**N**	**N**	**Mean**	**Std**
1	CT Planning	5	5	453.34	74.49
	MRI	5	5	350.16	56.28
2	CT Planning	5	5	393.40	65.05
	MRI	5	5	622.18	95.67
3	CT Planning	5	5	414.08	84.04
	MRI	5	5	364.72	45.06
4	CT Planning	5	5	396.54	121.85
	MRI	5	5	421.98	58.56
5	CT Planning	5	5	417.90	51.70
	MRI	5	5	472.60	113.54
6	CT Planning	5	5	473.80	79.40
	MRI	5	5	679.38	82.21
7	CT Planning	5	5	626.82	125.10
	MRI	5	5	387.60	98.74
8	CT Planning	5	5	627.96	77.55
	MRI	5	5	218.68	74.07
9	CT Planning	5	5	367.50	46.98
	MRI	5	5	614.20	77.27
10	CT Planning	5	5	507.74	53.69
	MRI	5	5	448.30	187.53

Table 17: ICRU Bladder Point

Analysis Variable:				
Plan	N	N	Mean	Std
CT	50	50	467.91	116.39
MRI	50	50	457.98	162.75

Table 18: ICRU Bladder Point

Solution for Fixed Effects										
Effect	**Plan**	**Trial**	**Estimate**	**Standard**	**DF**	**t Value**	**Pr > |t|**	**Alpha**	**Lower**	**Upper**
Intercept			465.66	35.2503	94	13.21	<.0001	0.05	395.67	535.65
Plan	CT		9.9280	28.7818	94	0.34	0.7309	0.05	-	67.0749
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	-11.2300	45.5080	94	-0.25	0.8056	0.05	-101.59	79.1271
Trial		2	3.6850	45.5080	94	0.08	0.9356	0.05	-	94.0421
Trial		3	-0.7900	45.5080	94	-0.02	0.9862	0.05	-	89.5671
Trial		4	-30.0450	45.5080	94	-0.66	0.5107	0.05	-120.40	60.3121
Trial		5	0	.	.	.	.	.	.	.

Table 19: Rectum *D0.1cc*

Analysis Variable : Rectum_D0_1cc__cGy_ Rectum D0_1cc					
Patient	**Plan**	**N**	**N**	**Mean**	**Std**
1	CT Planning	5	5	532.76	112.87
	MRI	5	5	403.49	85.42
2	CT Planning	5	5	677.70	121.17
	MRI	5	5	392.31	111.32
3	CT Planning	5	5	418.39	99.76
	MRI	5	5	473.52	53.21
4	CT Planning	5	5	585.84	98.88
	MRI	5	5	453.50	26.78
5	CT Planning	5	5	467.70	35.35
	MRI	5	5	498.37	141.11
6	CT Planning	5	5	614.39	184.48
	MRI	5	5	548.37	96.66
7	CT Planning	5	5	566.13	140.43
	MRI	5	5	479.29	61.75
8	CT Planning	5	5	461.83	117.97
	MRI	5	5	367.05	76.27
9	CT Planning	5	5	406.29	64.64
	MRI	5	5	447.70	35.82
10	CT Planning	5	5	284.29	62.92
	MRI	5	5	479.59	19.98

Table 20: Rectum *D0.1cc*

Analysis Variable:				
Plan	**N**	**N**	**Mean**	**Std**
CT	50	50	501.53	150.27
MRI	50	50	454.32	88.96

Table 21: Rectum *D0.1cc*

Solution for Fixed Effects										
Effect	**Plan**	**Trial**	**Estimate**	**Standard**	**DF**	**t Value**	**Pr > |t|**	**Alpha**	**Lower**	**Upper**
Intercept			470.32	30.4773	94	15.43	<.0001	0.05	409.81	530.83
Plan	CT		47.2134	24.8846	94	1.90	0.0609	0.05	-2.1955	96.6223
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	0.5240	39.3460	94	0.01	0.9894	0.05	-	78.6464
Trial		2	-2.3635	39.3460	94	-0.06	0.9522	0.05	-	75.7589
Trial		3	-29.8415	39.3460	94	-0.76	0.4501	0.05	-107.96	48.2809
Trial		4	-48.3150	39.3460	94	-1.23	0.2225	0.05	-126.44	29.8074
Trial		5	0	.	.	.	.	.	.	.

Table 22: Rectum *D1cc*

Analysis Variable : Rectum_D1cc__cGy_ Rectum D1cc (cGy)					
Patient ID	**Plan**	**N**	**N**	**Mean**	**Std**
1	CT Planning	5	5	468.11	79.91
	MRI Planning	5	5	334.55	49.66
2	CT Planning	5	5	517.66	70.50
	MRI Planning	5	5	326.19	87.84
3	CT Planning	5	5	360.74	85.70
	MRI Planning	5	5	400.02	37.40
4	CT Planning	5	5	476.07	89.31
	MRI Planning	5	5	382.57	18.39
5	CT Planning	5	5	425.40	50.06
	MRI Planning	5	5	414.38	110.82
6	CT Planning	5	5	510.26	142.61
	MRI Planning	5	5	468.73	88.11
7	CT Planning	5	5	447.44	92.59
	MRI Planning	5	5	403.16	48.03
8	CT Planning	5	5	399.31	91.75
	MRI Planning	5	5	313.93	61.52
9	CT Planning	5	5	322.25	58.13
	MRI Planning	5	5	394.09	27.67
10	CT Planning	5	5	247.31	47.62
	MRI Planning	5	5	412.59	9.00

Table 23: Rectum *D1cc*

Analysis Variable:				
Plan	**N**	**N**	**Mean**	**Std**
CT	50	50	417.46	112.90
MRI	50	50	385.02	72.46

Table 24: Rectum *D1cc*

Solution for Fixed Effects										
Effect	**Plan**	**Trial**	**Estimate**	**Standard**	**DF**	**t Value**	**Pr > |t|**	**Alpha**	**Lower**	**Upper**
Intercept			400.81	23.3618	94	17.16	<.0001	0.05	354.43	447.20
Plan	CT		32.4336	19.0749	94	1.70	0.0924	0.05	-5.4400	70.3072
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	-4.8465	30.1600	94	-0.16	0.8727	0.05	-	55.0369
Trial		2	-3.9910	30.1600	94	-0.13	0.8950	0.05	-	55.8924
Trial		3	-28.4175	30.1600	94	-0.94	0.3485	0.05	-	31.4659
Trial		4	-41.6915	30.1600	94	-1.38	0.1701	0.05	-101.57	18.1919
Trial		5	0	.	.	.	.	.	.	.

Table 25: Rectum $_{D2cc}$

Analysis Variable : Rectum_D2cc__cGy_ Rectum D2cc (cGy)					
Patient ID	Plan	N	N	Mean	Std
1	CT Planning	5	5	433.08	70.25
	MRI Planning	5	5	309.16	40.01
2	CT Planning	5	5	468.90	60.29
	MRI Planning	5	5	295.28	78.18
3	CT Planning	5	5	328.17	75.80
	MRI Planning	5	5	367.66	32.19
4	CT Planning	5	5	429.73	81.61
	MRI Planning	5	5	352.54	19.22
5	CT Planning	5	5	401.78	51.48
	MRI Planning	5	5	376.99	93.65
6	CT Planning	5	5	461.39	124.86
	MRI Planning	5	5	428.15	82.29
7	CT Planning	5	5	403.14	76.44
	MRI Planning	5	5	368.08	46.59
8	CT Planning	5	5	369.69	81.03
	MRI Planning	5	5	291.52	55.13
9	CT Planning	5	5	291.88	51.06
	MRI Planning	5	5	367.93	27.71
10	CT Planning	5	5	228.31	41.07
	MRI Planning	5	5	385.62	9.78

Table 26: Rectum $_{D2cc}$

Analysis Variable:				
Plan	N	N	Mean	Std
CT	50	50	381.61	100.56
MRI	50	50	354.29	65.12

Table 27: Rectum $_{D2cc}$

Solution for Fixed Effects										
Effect	Plan	Trial	Estimate	Standard	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept			368.90	20.8663	94	17.68	<.0001	0.05	327.47	410.33
Plan	CT		27.3122	17.0373	94	1.60	0.1123	0.05	-6.5157	61.1401
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	-4.2885	26.9383	94	-0.16	0.8739	0.05	-	49.1981
Trial		2	-5.0230	26.9383	94	-0.19	0.8525	0.05	-	48.4636
Trial		3	-26.7565	26.9383	94	-0.99	0.3231	0.05	-	26.7301
Trial		4	-36.9490	26.9383	94	-1.37	0.1734	0.05	-	16.5376
Trial		5	0	.	.	.	.	.	.	.

Table 28: Max Rectum Dose

Analysis Variable : Max_Rectum_Dose__cGy_ Max Rectum					
Patient	Plan	N	N	Mean	Std
1	CT Planning	5	5	595.84	138.59
	MRI	5	5	468.02	110.24
2	CT Planning	5	5	840.54	168.41
	MRI	5	5	434.94	133.36
3	CT Planning	5	5	410.12	163.68
	MRI	5	5	562.32	74.56
4	CT Planning	5	5	560.38	248.11
	MRI	5	5	512.28	30.14
5	CT Planning	5	5	511.90	42.98
	MRI	5	5	611.92	226.31
6	CT Planning	5	5	684.52	206.50
	MRI	5	5	611.74	122.72
7	CT Planning	5	5	656.24	179.17
	MRI	5	5	544.28	84.26
8	CT Planning	5	5	506.08	137.81
	MRI	5	5	418.06	90.11
9	CT Planning	5	5	436.36	85.85
	MRI	5	5	490.60	47.17
10	CT Planning	5	5	307.64	74.36
	MRI	5	5	531.14	32.77

Table 29: Max Rectum Dose

Analysis Variable:				
Plan	N	N	Mean	Std
CT	50	50	550.96	203.57
MRI	50	50	518.53	118.48

Table 30: Max Rectum Dose

Solution for Fixed Effects										
Effect	Plan	Trial	Estimate	Standard	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept			543.04	41.0389	94	13.23	<.0001	0.05	461.56	624.52
Plan	CT		32.4320	33.5082	94	0.97	0.3356	0.05	-	98.9632
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	-10.5550	52.9811	94	-0.20	0.8425	0.05	-115.75	94.6401
Trial		2	-4.6000	52.9811	94	-0.09	0.9310	0.05	-109.80	100.60
Trial		3	-30.3050	52.9811	94	-0.57	0.5687	0.05	-135.50	74.8901
Trial		4	-77.0850	52.9811	94	-1.45	0.1490	0.05	-182.28	28.1101
Trial		5	0	.	.	.	.	.	.	.

Table 31: Mean Rectum Dose

Analysis Variable : Mean_Rectal_Dose__cGy_ Mean Rectal					
Patient	Plan	N	N	Mean	Std
1	CT Planning	5	5	176.60	26.75
	MRI	5	5	174.42	14.84
2	CT Planning	5	5	199.58	21.93
	MRI	5	5	135.38	28.37
3	CT Planning	5	5	184.14	58.52
	MRI	5	5	187.20	12.67
4	CT Planning	5	5	175.24	26.50
	MRI	5	5	181.74	11.08
5	CT Planning	5	5	164.74	15.82
	MRI	5	5	227.16	43.17
6	CT Planning	5	5	181.74	37.84
	MRI	5	5	242.24	53.23
7	CT Planning	5	5	209.02	44.64
	MRI	5	5	207.74	38.27
8	CT Planning	5	5	167.82	24.38
	MRI	5	5	148.40	12.07
9	CT Planning	5	5	155.84	14.75
	MRI	5	5	188.30	20.77
10	CT Planning	5	5	135.18	19.15
	MRI	5	5	206.82	13.79

Table 32: Mean Rectum Dose

Analysis Variable:				
Plan	N	N	Mean	Std
CT	50	50	174.99	35.20
MRI	50	50	189.94	40.82

Table 33: Mean Rectum Dose

Solution for Fixed Effects										
Effect	Plan	Trial	Estimate	Standard	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept			196.90	9.3271	94	21.11	<.0001	0.05	178.38	215.42
Plan	CT		-14.9500	7.6156	94	-1.96	0.0526	0.05	-	0.1709
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	-4.5050	12.0412	94	-0.37	0.7091	0.05	-	19.4032
Trial		2	2.0200	12.0412	94	0.17	0.8671	0.05	-	25.9282
Trial		3	-16.2950	12.0412	94	-1.35	0.1792	0.05	-	7.6132
Trial		4	-16.0200	12.0412	94	-1.33	0.1866	0.05	-	7.8882
Trial		5	0	.	.	.	.	.	.	.

Table 34: ICRU Rectum Point

Analysis Variable : ICRU_Rectum_Point_cGy ICRU Rectum					
Patient	**Plan**	**N**	**N**	**Mean**	**Std**
1	CT Planning	5	5	343.16	69.66
	MRI	5	5	279.68	69.75
2	CT Planning	5	5	440.22	130.24
	MRI	5	5	348.92	97.73
3	CT Planning	5	5	493.72	175.53
	MRI	5	5	327.96	45.56
4	CT Planning	5	5	447.30	150.72
	MRI	5	5	341.82	40.38
5	CT Planning	5	5	335.02	42.82
	MRI	5	5	522.76	84.62
6	CT Planning	5	5	392.16	114.75
	MRI	5	5	454.70	174.45
7	CT Planning	5	5	324.38	53.14
	MRI	5	5	366.76	98.34
8	CT Planning	5	5	347.02	94.30
	MRI	5	5	269.44	27.84
9	CT Planning	5	5	199.36	42.44
	MRI	5	5	400.84	54.71
10	CT Planning	5	5	221.74	48.90
	MRI	5	5	294.30	57.61

Table 35: ICRU Rectum Point

Analysis Variable:				
Plan	**N**	**N**	**Mean**	**Std**
CT	50	50	354.41	129.73
MRI	50	50	360.72	108.61

Table 36: ICRU Rectum Point

Solution for Fixed Effects										
Effect	**Plan**	**Trial**	**Estimate**	**Standard**	**DF**	**t Value**	**Pr > |t|**	**Alpha**	**Lower**	**Upper**
Intercept			364.01	29.8178	94	12.21	<.0001	0.05	304.81	423.21
Plan	CT		-6.3100	24.3461	94	-0.26	0.7961	0.05	-	42.0297
Plan	MRI		0	.	.	.	.	.	.	.
Trial		1	-12.9500	38.4946	94	-0.34	0.7373	0.05	-	63.4819
Trial		2	-12.5950	38.4946	94	-0.33	0.7443	0.05	-	63.8369
Trial		3	-4.7100	38.4946	94	-0.12	0.9029	0.05	-	71.7219
Trial		4	13.7950	38.4946	94	0.36	0.7209	0.05	-	90.2269
Trial		5	0	.	.	.	.	.	.	.