Dosimetric analysis of volumetric arc therapy on localized prostate cancer with unilateral hip prosthesis: the hip-skip method

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ABSTRACT

Many treatment planning techniques for prostate irradiation have been discussed including institutions utilizing class solutions, template planning schemes, or institution specific dose-limiting structures. While many of these approaches are efficient in producing high-quality treatment plans for traditional prostate cases, there is a gap in the literature regarding efficiency of prostate treatment planning for patients with metal hip prosthesis. This gap in the literature has presented an opportunity for investigation into the efficiency of modern treatment techniques utilized in prostate irradiation when metal hip prostheses are present. More specifically, with volumetric modulated arc therapy (VMAT) becoming a gold standard for prostate cancer irradiation, the benefits of avoidance sectors cannot be understated when approaching a case where a prosthesis is located within the treatment field. The purpose of this study was to evaluate optimal avoidance sectors during VMAT planning while maintaining prescribed planning target volume (PTV) coverage and limiting prosthesis dose.

Key Words: Prostate cancer, hip prosthesis, VMAT, avoidance sectors

Introduction

The evolution of external beam radiation therapy (EBRT) has changed the way prostate patients receive radiation treatments. From 3D-conformal radiation therapy (3DCRT) to intensity-modulated radiation therapy (IMRT), it has been observed that IMRT plans are more conformal and better protect the organs at risk (OR).\textsuperscript{1} There is a steady trend in prescription dose escalations that minimize toxicities to surrounding critical structures using a more precise method of prostate irradiation such as VMAT which can distribute dose throughout the pelvic region while tightly focusing 100% of the prescription around the target.\textsuperscript{2} However, there are situations where utilizing the entire 360° arc for a VMAT plan is not appropriate.
The presence of a prosthetic hip can introduce significant treatment planning obstacles and uncertainties when considering EBRT for prostate cancer. Approximately 1% to 2% of patients with prostate cancer have a hip prosthesis. Hip prostheses are usually manufactured using high atomic number materials that create significant inhomogeneity within the treatment fields. The presence of a prosthesis usually complicates the planning process because of dose perturbation around the prosthesis region, radiation attenuation through the prosthesis, and the introduction of CT artifacts in the planning volume. The large, thick pelvic bones attenuate radiation beams and the addition of a metal prosthesis exacerbates the problem.

It is common practice to avoid a prosthesis due to the presence of artifact when treating through high atomic material resulting in dosimetric uncertainties. Radiation beams that avert the prosthesis avoid dosimetric complications but may significantly increase dose to the critical structures surrounding the prostate. Ding and Yu indicated a 15% increase in radiation dose at the interface between the metal implant and tissue and a dose reduction of 5 – 45% in the shadows of the artifact. Avoiding the prosthetic hip limits the possible treatment angles of an arc creating a challenge of conforming dose around the PTV while sparing dose to the rectum and bladder. Treatment planning with VMAT provides an option to include an avoidance sector where the beam will produce 0 monitor units (MUs) through specific beam angles while maintaining a full rotating arc.

The purpose of this study was to evaluate various avoidance angles using a single full arc VMAT plan for intact prostate patients with a unilateral prosthetic hip. Using the Varian Eclipse treatment planning system (TPS), increasing avoidance angles were tested to determine the most ideal plan that delivers at least 100% of the prescribed dose to 98% of the PTV while adhering to Radiation Therapy Oncology Group (RTOG) 0126 dose constraints for the bladder and rectum.

**Methods and Materials**

**Patient Selection & Setup**

Patient selection (n=10) included cases with non-metastatic intact prostate cancer and a unilateral hip prosthesis. The 10 patient cases were from 3 different facilities. All patients were simulated head first, supine, and scanned using a Phillips Big Bore or a General Electric scanner at 2.5 mm or 3 mm thick CT images. Patients were immobilized during the CT simulation using
a Vac-Lok bag system or a more traditional set up with headrest and angle sponge under the knees. All patients were required to have an empty rectum and full bladder during the scan.

**Target Delineation**

The Varian Eclipse TPS was used to delineate anatomical contours. The contoured OR included the prostate, bladder, and rectum. The prosthetic hip was contoured by adjusting the window/leveling of the CT image until the highest density was visible, differentiating the prosthetic hip from surrounding tissues and bone. The artifact produced by the prosthetic hip was contoured to include the most obvious level of density changes. For some patients, 3 gold seed markers were implanted within the prostate to assist in effective localization of the target during daily treatment. These gold seeds also produced image artifact and were contoured as well. The PTV was designed as a 0.5 cm marginal expansion from the prostate contour. Both contoured artifacts were assigned a density of 35 Hounsfield units (HU).

**Treatment Planning**

All treatment plans were designed on the Varian Eclipse TPS and calculated using anisotropic analytical algorithm (AAA). Each case was planned using VMAT and was geometrically set to utilize 1 or 2 (should the field carriage be split due to size limiting factors) 360° arcs with a 6 MV energy setting. A Varian 2100 iX and Varian TrueBeam were the treatment units used for each of these plans. All plans were designed in a clockwise (CW) rotation starting at 180° and ending at 179° and a counter clockwise (CCW) rotation starting at 179° ending at 180° for double arc plans. Six plans were generated from each case, all of which had different avoidance sectors. For each case, the initial plan began with avoiding angles where the central axis (CA) of the beam would not directly pass through the prosthesis. However, there is a minimum of 15° of avoidance for Varian Eclipse TPS requirements so this angle was used if the starting angle was under 15°. The process was performed by utilizing the BEV function within Eclipse TPS and determining the exact angle at which the CA of the beam was immediately adjacent to the contour representing the prosthesis. Five more plans were created but each subsequent plan increased the avoidance sector by 4° in each direction; a total increase of 8°.
Each plan received a prescription of 81 Gy to the PTV in 45 fractions at 1.8 Gy per fraction. The target goals of all plans were to achieve 98% PTV coverage with the 100% isodose line and with a maximum dose limit of 109% of the prescription. The dose constraints adhered to RTOG protocol 0126 which focused on bladder and rectal dose limits. Dose constraints to the bladder were no more than 15%, 25%, 35%, and 50% of the volume should receive more than 80 Gy, 75 Gy, 70 Gy, and 65 Gy, respectively. For the rectum, no more than 15%, 25%, 35%, and 50% of the volume should receive more than 75 Gy, 70 Gy, 65 Gy, and 60 Gy, respectively. The Normal Tissue Objective (NTO) tool was used during plan optimization with consistent parameters implemented across all institutions participating in the study. No artificial structures were used during the optimization process.

Results

For this study, the data was analyzed using mean dose values across the given PTV, bladder, and rectal constraints across the incrementally increasing angles of avoidance. Additionally, graphical representation and plotting of linear regression lines demonstrated relative variation in dose distribution across the avoidance sectors chosen. This type of statistical analysis was selected due to the goals of the research. With an initial goal of determining what angles of avoidance produced the best treatment plan; the results demonstrated how avoidance angles directly impacted isodose distributions and overall dose distribution through the pelvic region, considering both the RTOG constraints and delivery of prescribed doses. The initial plan with minimal avoidance produces the highest average dose to 50% of the bladder and higher mean dose to the bladder (Figure 1). As the avoidance sectors were increased, the 50% isodose line encompassed less of the bladder compared to the initial avoidance plan as shown in Figure 2. It should also be noted that the 16° avoidance and the 40° avoidance both demonstrated slight improvements in mean dose to the bladder, over the preceding trial (8° avoidance) as well as (32° avoidance). The initial avoidance in this study was defined as the most minimal avoidance where the angle was chosen based on central axes passing directly past each end of the contoured prosthesis. This is not to say the dose was not escalating very slowly in these regions, but the mean dose plateaued across the majority of monitored constraints when using these avoidance angles.
Results also showed that the mean dose across the rectum decreased as the avoidance angles and volumes increased (Figure 3). Similar to the bladder doses, the 24° avoidance was less effective limiting dose to the rectum, when compared to the other avoidance angles. The 24° avoidance sector also demonstrated the highest amount of dose-variability, when compared to the other avoidance sectors investigated. This was a significant finding as this specific avoidance sector produced markedly negative results with regard to all 3 evaluated constraints, including PTV coverage.

All treatment plans were evaluated once the 100% isodose line sufficiently covered 98% of the PTV volume, with normalization being case specific. Observed in Figure 4, the PTV coverage beginning with the 0° avoidance sector, was sufficient in meeting the 98% baseline. Based on RTOG 0126 protocol standards, the lower avoidance angles provided sufficient PTV coverage with the 8° avoidance sector providing the best overall PTV coverage of the angles tested. Following the 8° avoidance sector, avoidances of both 16° and 24° provided the lowest observed PTV coverage of all avoidance sectors. Both the 32° and 40° avoidance sectors provided increased PTV coverage but less effective than the 8° avoidance sector.

Discussion

The purpose of this study was to evaluate the effectiveness of varying avoidance sectors applied on VMAT plans for patients with a unilateral prosthetics hip implant. Each plan achieved target goals for PTV coverage and each met RTOG protocol 0126 requirements. Individual plan evaluation would further investigate the effects each of these avoidance sectors had on the bladder and rectum. Results indicated there was an increase in mean dose for 50% of the bladder volume when the initial minimal avoidance section was used, which should be considered if similar angles of avoidance sectors are chosen.

In addition to monitoring dose to OR, the statistical analyses indicated that for 24° avoidance and 32° avoidance sectors, there was a slight increase in PTV coverage above 98%. Twenty-four degrees avoidance sectors and 32° avoidance sectors had angles of avoidance that ranged from 40°- 50°. This was merely an observation that indicated a need for further investigation of designing plans with these avoidance sectors with aims of pushing the PTV percent coverage past 98% without compromising organ dose constraints.
It should be noted as a limitation that because of the use of multiple CT simulators with varying energies and slice thickness, artifact from the prosthesis and general quality of the scan also varied. Due to the metal prostheses, each patient scan had different degree of artifact streaking which created a problem when contouring the prostate volume as well as areas of the bladder and rectum. Adjustment of the window level of the reconstructed image allowed for the most appropriate identification of target volume. However, the amount of artifact contoured is entirely up to the discretion of the planner, and because of this, there is an unknown degree of variability from plan to plan.

It is possible to determine whether or not a linear relationship between dose to a critical structure and a specific avoidance sector exists, and even PTV coverage and avoidance sector, but a larger case population and additional investigation is necessary. To investigate these relationships effectively, the research would be best performed within one institution while utilizing the same dosimetric planning structures and mitigating limitations encountered within this three-institute study.

A final note of discussion directly pertains to the utilization of dose limiting structures or techniques and planning structures. Because the research spanned 3 institutions, the study did not utilize any dose limiting techniques or planning structures. Often these concepts are institution-specific and vary greatly depending on the medical dosimetrist. The goal was to evaluate the chosen avoidance sectors and their impact on OR and PTV coverage, while maintaining minimal dose to the prosthesis itself.

**Conclusion**

The presence of metal hip prostheses presents a major problem when creating a treatment plan for patients with prostate cancer. The high electron density of the prosthesis causes too much dose attenuation and scatter so lateral beams should not be used. The excess scatter makes it difficult to achieve optimal dose distribution for the entire PTV while maintaining minimal dose to the rectum and bladder. With the use of VMAT, all 360° of the gantry can be utilized to achieve the most efficient PTV coverage. With the addition of avoidance sectors, further dose can be minimized to the prosthesis without sacrificing PTV coverage. By using BEV planning option, the prosthesis can be completely avoided during VMAT planning. The results from this study demonstrated differences between chosen avoidance sectors. Mean doses to bladder and
rectum, as well as PTV coverage, varied within this study depending on the avoidance sector implemented. With mean doses to critical structures found to be lower through smaller avoidance sectors, the data leaned towards utilization of more conservative, smaller, avoidance sectors when appropriate. A limitation of this study was a small patient population. If future research were to incorporate a larger population of patients, it could potentially demonstrate a greater statistical significance of avoidance sector techniques for prostate radiotherapy patients with hip prostheses. Another limitation of this study was the form of data collection, spanning 3 different institutions, therefore not using any dose limiting techniques or planning structures due to clinical site-dependency. Executing the research within a single institution would mitigate any inconsistencies in the creation of dose-limiting planning structures.
References


**Figure 1.** Mean dose (Gy) to the 15, 25, 35, & 50% volume of the bladder at each avoidance.
Figure 2. Image of the 50% isodose line within the bladder of the initial avoidance compared to the following 5 plans of increasing avoidance sectors.
Figure 3. Mean dose (Gy) to the 15, 25, 35, & 50 % volume of the rectum at each avoidance zone.
Figure 4. Average coverage to the PTV in percentage for each avoidance sector.