Evaluation of VMAT Planning Strategies for Prostate Patients with Bilateral Hip Prosthesis

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Abstract

Purpose: In this study, we investigate linac volumetric-modulated arc therapy (VMAT) planning strategies for bilateral hip prostheses prostate patients with respect to plan quality and deliverability, while limiting entrance dose to the prostheses. **Methods:** Three VMAT plans were retrospectively created for 20 patients: (1) partial arcs (PA), (2) 2 full arcs optimized with 500 cGy max prostheses dose (MD), and (3) 2 full arcs optimized with max dose-volume histogram (DVH) constraint of 500 cGy to 10% prostheses volume (MDVH). PA techniques contained 6 PA with beam angles that avoid entering each prosthesis. For each patient, other than prostheses constraints, the same Pinnacle VMAT optimization objectives were used. Plans were normalized with PTV D95% = 79.2 Gy prescription dose. Organ-at-risk DVH metrics, monitor units (MUs), conformality, gradient, and homogeneity indices were evaluated for each plan. Mean entrance prosthesis dose was determined in Pinnacle by converting each arc into static beams and utilizing only control points traversing each prosthesis. Plan deliverability was evaluated with SunNuclear ArcCheck measurements (gamma criteria 3%/2 mm) on an Elekta machine. **Results:** MD and MDVH had similar dosimetric quality, both improved DVH metrics for rectum and bladder compared to PA. Plan complexities among all plans were similar (average MUs: 441-518). Conformality, homogeneity, and gradient indices were significantly improved in MD and MDVH versus PA ($P < .001$). Gamma pass rates for MD ($99.0 \pm 1.2\%$) and MDVH ($99.2 \pm 0.99\%$) were comparable. A significant difference over PA was observed ($96.8 \pm 1.6\%$, $P < .001$). Field-by-field analysis demonstrated 12/20 PA plans resulted in fields with pass rates <95% versus 1/20 plans for MD and none for MDVH. Cumulative mean entrance doses to each prosthesis were 62.9 ± 17.7 cGy for MD plans and 83.4 ± 27.5 cGy for MDVH plans. **Conclusion:** MD and MDVH plans had improved dosimetric quality and deliverability over PA plans with minimal entrance doses (~1% of prescription) to each prosthesis and are an improved alternative for bilateral prostheses prostate patients.

Introduction

According to the American Joint Replacement Registry, there were more than 350,000 total hip replacements between 2012 and 2017 in the United States.[1] With more than 60,000 American men a year opting for prostate radiation therapy,[2] there is an overlap between patients with a hip prosthesis needing prostate radiation therapy treatment. This leads to obstacles in radiation therapy planning and delivery due to the high density of the prosthesis.

Hip prostheses are composed of high-density material of usually ceramic, titanium, or a cobalt chromium alloy. Stainless steel was historically used and can still be found in some older patients.[3] The high-density material adds complications in terms

of attenuation, scatter, and dosimetric uncertainty. The dose attenuation can range from 10% to 64% depending on the energy of the photon beam and the composition of the hip prosthesis.[3] Backscatter is also a concern at the bone-high-density interface, as the energy and atomic number of the material increases, the backscatter factor increases.[4] In addition, most treatment planning

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systems do not properly account for the interface effects and the production of neutrons. The American Association of Physicists in Medicine (AAPM) Task Group 63 recommends the use of a beam arrangement that avoids entering the prosthesis given the possible attenuation and scatter that could occur with the high-density material.[3] This prosthesis avoiding-technique limits beam angles and the beam angles that can be used creates nonfavorable dose distributions.

Volumetric-modulated arc therapy (VMAT) is an inverse planning technique that adds the aspect of gantry rotation to intensity modulated radiation therapy (IMRT).[5] VMAT is considered the standard of treatment for prostate cancer and demonstrates improved conformality, homogeneity, organ at risk (OAR) sparing, and improved delivery efficiency compared to static-gantry IMRT.[6,7] However, the advent of VMAT has made bilateral hip prostheses avoidance more difficult as several partial arcs (PA) are needed in order to achieve a beam arrangement that avoids entering through each prosthesis to satisfy AAPM TG-63 recommendations. Currently, a few investigators have evaluated possible solutions for implementing VMAT delivery for prostate hip prosthesis patients. These include 2 studies focused on utilizing the avoidance sector capability available on Varian linear accelerators only. This allows for a full arc to be used, but for the beam to temporarily turn off for gantry angles that would otherwise deliver entrance dose to the hip prosthesis.[8,9] In both of these studies, avoidance sectors were selected based on the beams eye view to prevent entrance dose into the prosthesis. A third study published by Prabhakar et al. utilized full arcs on a Varian linac. However, instead of using the avoidance sector capability available, these authors chose to limit hip prosthesis entrance dose with the use of an avoidance optimization structure around the hip prostheses with 1 cm margin and a 500 cGy dose constraint.[10] Unfortunately, Philips Pinnacle version 14.0 (Philips Healthcare) treatment planning system has no easy way to add avoidance sectors in the plan to avoid prostheses entrance dose.

In this retrospective study, patients with low risk prostate cancer and bilateral hip prostheses were evaluated using 3 different VMAT planning techniques; MD (2 full arcs with max dose criteria of 500 cGy to prostheses), MDVH (2 full arcs with max dose of 500 cGy to 10% of prostheses), and PA (6 PA avoiding prostheses). The objective of this study was to determine if using full arcs with different optimization techniques on an Elekta linac/Pinnacle TPS combination provides a clinically acceptable plan to treat patients with bilateral hip prostheses while still maintaining low entrance dose to each prosthesis.

Materials and Methods

Patient Data and Treatment Planning Strategies

CT datasets from 20 prostate patients previously treated at our institution during the years 2017 to 2019 were selected for this IRB-approved retrospective study. All patient information was deidentified and patient consent was not required. All CT datasets were acquired on a Philips Big Bore CT scanner (Philips

Healthcare). Of the 20 patients selected, 4 patients had either single or bilateral hip prostheses. To minimize the imaging artifacts caused by the hip prostheses on the CT scan, the Philips metal artifact reduction image reconstruction algorithm for orthopedic implants (O-MAR) was used for these patients.[11]

All VMAT treatment plans were created for an Elekta Infinity linac with Agility 160 multileaf collimator (Elekta AB) in the Pinnacle[3] Version 14 treatment planning system (Philips Healthcare). Original prostate PTV, rectum, bladder, and bowel contours from each patient's individual treatment plan were used. All 4 hip prostheses patients had implants which were Titanium based. To simulate bilateral hip prostheses in the remaining 16 patients, both hips were contoured and overridden to a mass density of 4.54 g/cc for Titanium.[12] This was considered a reasonable approach as the size and shape of the implant and the femoral head are similar. While there is some difference between the size of the implant and the size of the femur bone, this difference was not considered clinically significant.

For each patient, 3 retrospective VMAT plans were created: (1) PA, (2) 2 full arcs optimized with a max dose constraint of 500 cGy to prostheses (MD), and (3) 2 full arcs optimized with a max dose-volume histogram (DVH) constraint of 500 cGy to 10% of the prostheses volume (MDVH). The dose constraint of 500 cGy is similar to the constraint utilized by Prabhakar et al.[10] The PA technique was considered the gold standard for comparison, as this technique utilizes 6 PA with beam angles that avoid entering each prosthesis as recommended by AAPM Task Group 63.[3] A minimum gantry span of 40° was chosen for each partial arc. This gantry span was selected based on our institutional patient specific QA experience where VMAT beams gantry spanning <40° failed QA. MD plans were the most restrictive of the 3 techniques forcing the optimizer to limit entrance and exit dose through each prosthesis. MDVH plans were created with the intention to allow for some exit dose while still limiting the entrance dose through each prosthesis.

All beams were selected to have nonzero collimator angles (+/−5-15°) and were planned with 10 MV photons. For a given patient, outside of the prostheses constraints, the same Pinnacle SmartArc optimization objectives and parameters were used. Additionally, the optimizer was run 3 times per plan continuing from previous optimization in an effort to keep the optimization efforts for each of the 3 techniques equal. Following optimization, all plans were normalized with PTV D95% = 79.2 Gy prescription dose and dose distributions were reviewed. Plans were performed by 4 different planners but had a single planner per patient.

Dosimetric Analysis

Dosimetric comparison of the 3 techniques (PA, MD, and MDVH) consisted of evaluating DVH metrics for the rectum (V75, V70, V65, and V60 Gy), bladder (V80, V75, V70, V65 Gy), bowel (D1 cc), and bilateral hip prostheses (D1%). Table 1 presents the dosimetric goals used for plan evaluation

Table 1. Organ at Risk Dosimetric Goals Use to Evaluate PA, MD, and MDVH Plans.

Organ at risk (OAR)	Dosimetric goal
Rectum	V75 Gy ≤ 15%
	V70 Gy ≤ 25%
	V65 Gy ≤ 35%
	V60 Gy ≤ 50%
Bladder	V80 Gy ≤ 15%
	V75 Gy ≤ 25%
	V70 Gy ≤ 35%
	V65 Gy ≤ 50%
Bowel	D1 cc ≤ 55 Gy

for the rectum, bladder, and bowel. Plan monitor units (MUs) were reviewed to assess differences in plan complexity. Dosimetric indices for plan conformality, dose distribution gradient, and plan homogeneity were also compared. Plan conformality was calculated using the Paddick conformality index (PCI) shown in Equation 1

$$PCI = \frac{TV_{PIV}^2}{TV \times V_{RI}} \qquad (1)$$

where TV is the PTV target volume, TV_{PIV} is the target volume covered by the prescription isodose volume (79.2 Gy), and V_{RI} is the prescription isodose volume.[13] Dose gradient was assessed using the Paddick gradient index (GI) calculated using Equation 2

$$GI = \frac{V_{\frac{Rx}{2}}}{V_{Rx}} \qquad (2)$$

where V_{Rx} is the prescription isodose volume (79.2 Gy), and $V_{Rx}/2$ is the half the prescription isodose volume (39.6 Gy).[14] Lastly, the plan homogeneity index (HI) was calculated as

$$HI = D_5/D_{95} \qquad (3)$$

where D_5 is the minimum dose in 5% of the PTV, and D_{95} is the minimum dose in 95% of the PTV.[15] Plans with a PCI < 1 are considered less conformal, whereas plans with GI and HI > 1 are less homogeneous with shallower dose gradients.

Entrance Dose Evaluation

The concern with using full arcs for bilateral hip prosthesis prostate patients is the dose calculation uncertainty associated for treatment beams that shoot directly through each prosthesis. This uncertainty can be limited if the entrance dose to each prosthesis is minimized. In order to evaluate the mean entrance dose to the prostheses for the MD and MDVH plans, a separate analysis was performed.

Within the Pinnacle treatment planning system, a script was written to convert each full arc into a set of static beams based on the number of control points per beam (91 control points/beam). Each of these static beams was then reviewed manually to determine if its aperture contributed to the entrance dose of

each hip prosthesis. Mean entrance dose was then calculated in Pinnacle by only turning on the MUs of the control points for each beam that traverse each of the hip prostheses. PA plans were not evaluated due to the beam angle selection which avoided entrance through each hip prosthesis.

Deliverability

Plan deliverability for each of the 3 techniques was assessed using patient specific QA measurements performed with the ArcCHECK cylindrical diode array and SNC Patient software v.6.7.3 (Sun Nuclear Inc). A gamma analysis was performed for each beam using a low-dose threshold of 10%, an absolute dose difference of 3%, and a distance-to-agreement of 2 mm as recommended by AAPM Task Group 218.[16]

Results

Treatment Planning and Dosimetric Analysis

Figure 1 shows axial dose distributions for each of the 3 techniques for a single patient. All plans demonstrated adequate restriction of low isodose volumes (500 cGy) near the bilateral hip prostheses. Comparatively, the PA plans had the most restricted 500 cGy isodose volume as a result of the limited beam angles used. However, restriction of the beam angles used in PA plans resulted in dose spillage of the intermediate dose level (3960 cGy) that was considerably worse than those seen for MD and MDVH plans. Overall, dosimetric plan quality was similar for MD and MDVH plans.

Figure 2 presents a scatter plot of the rectum and bladder DVH results for all 3 techniques and all 20 patients. Black horizontal lines on each figure represent the institutional goal for that specific DVH parameter. The OAR doses for the rectum and bladder were lower for MD and MDVH plans with average differences ranging between 1.4 and 8.5% compared to PA plans for a given DVH metric. In terms of plans failing to meet DVH metrics, 11/20 PA plans failed to meet at least 1 rectum goal versus only 3/20 MD and MDVH plans. All bladder goal criteria were met across all 3 planning techniques.

For a given patient, bowel doses were fairly similar between the 3 planning techniques with mean D1 cc values being slightly higher for PA plans (3389.3 ± 2504.8 cGy) compared to MD (2921.8 ± 2132.9 cGy) and MDVH plans (2847.4 ± 2151.9 cGy). Figure 3 presents a scatter plot of the D1% results for the bilateral hip prostheses for all 20 patients. D1% values were lowest for all patients using the MD technique compared to PA and MDVH techniques. Of the 3 techniques, mean D1% doses to the bilateral hip prostheses were highest for MDVH plans (1008.9 ± 192.0 Gy) followed by PA (923.2 ± 545.2 cGy) and finally MD plans (585.4 ± 68.43 cGy). This is expected as the MDVH plans allow for entrance and exit dose to the hip prosthesis, whereas the PA plans only allow for exit dose and the MD plans limits both.

Table 2 presents the average PCI, HI, and gradient indices for all the cases planned. For all indices, MD and MDVH
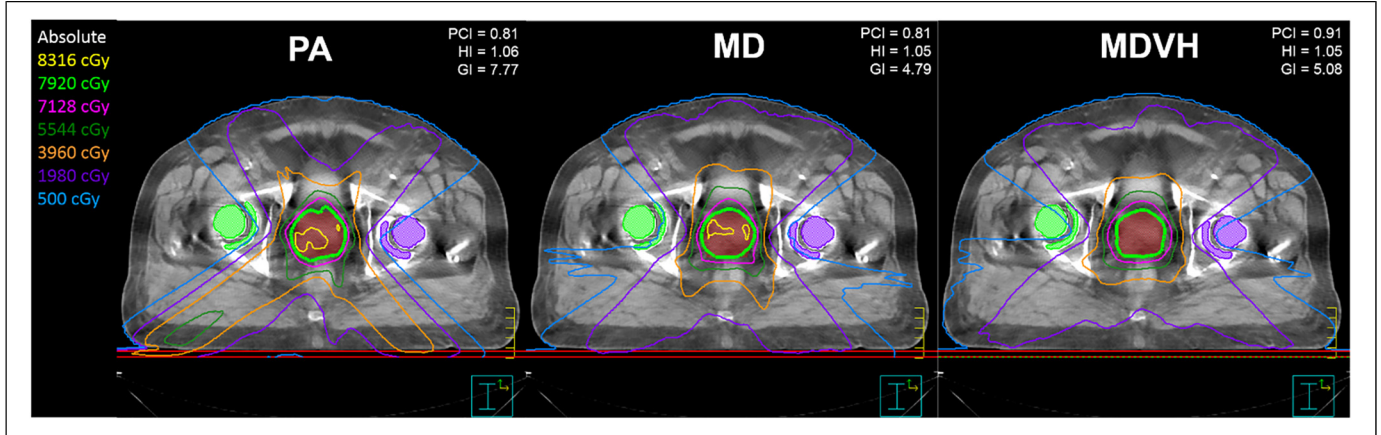
Figure 1. Axial dose distributions for each technique, PA, MD, and MDVH for 1 patient. PCI, HI, and GI for each technique is shown in the top right of each image.
Abbreviations: PA, partial arcs; MD, max dose; MDVH, maximum DVH; PCI, Paddick conformality index; HI, homogeneity index; GI, gradient index.
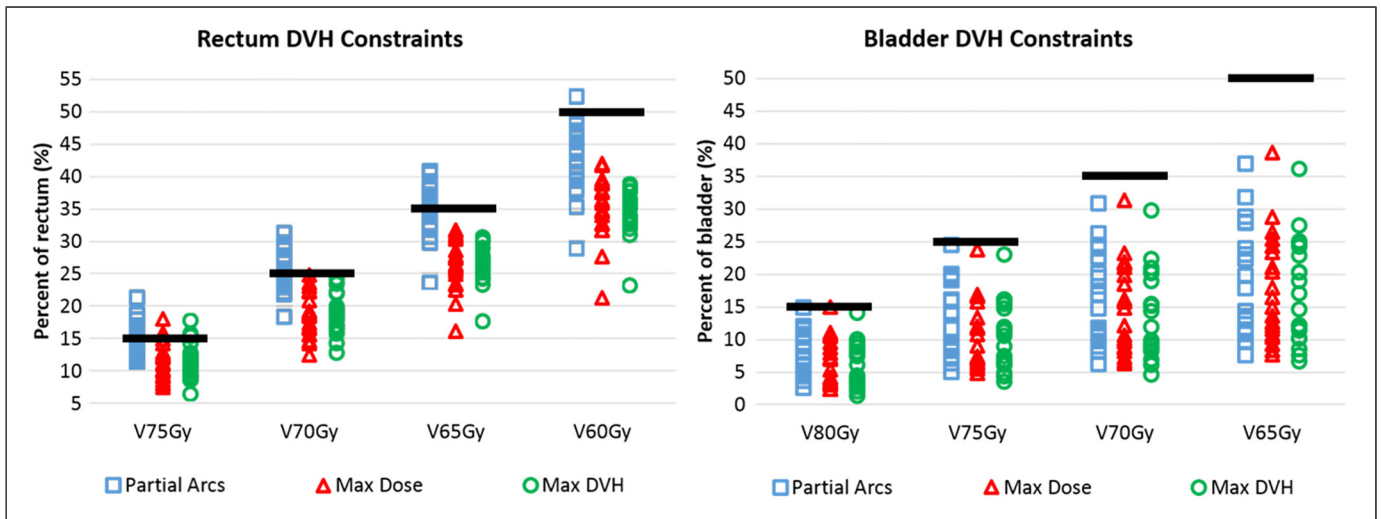

Figure 2. Dose-volume histogram (DVH) parameters for rectum and bladder across all 3 techniques for 20 patients. Black horizontal lines represent the institutional goal for that specific DVH parameter.
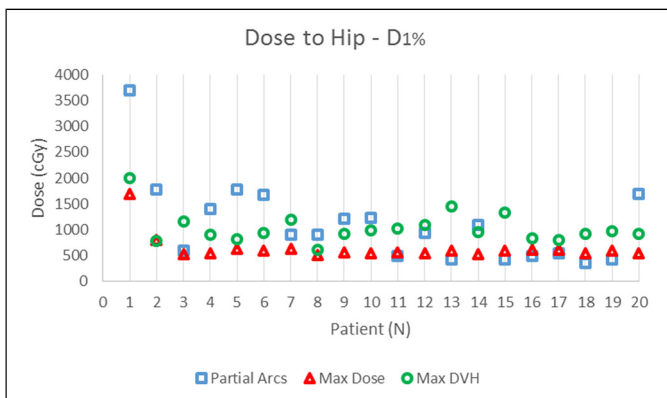

Figure 3. Bilateral hip prostheses D1% results for all 20 patients and 3 techniques (PA, MD, and MDVH).
Abbreviations: PA, partial arcs; MD, max dose; MDVH, maximum DVH.

plans were similar and both showed dosimetric improvement compared to PA plans with results being statistically significant ($P < .001$) based on a Wilcoxon signed-rank test. In terms of plan complexity, PA plans resulted in slightly higher MU (average 518.1 ± 74.1) compared to MD (477.9 ± 55.1) and MDVH (440.9 ± 49.9).

Entrance Dose Evaluation

Figure 4 presents a box plot of the mean entrance doses to the bilateral hip prostheses for the MD and MDVH plans. The entrance dose demonstrated an average of 62.9 ± 17.7 cGy and 83.4 ± 27.5 cGy for all 20 MD and MDVH plans, respectively. Utilizing a single factor analysis of variance test we found it to be statistically significant with a *P*-value of .0001. Due to the more relaxed dose constraint used for MDVH

Table 2. Average PCI, HI, and GI Results for the 3 Techniques and All 20 Patients.

	PCI	HI	GI
PA	0.82	1.07	7.62
MD	0.87	1.04	5.36
MDVH	0.88	1.04	5.13

Abbreviations: PCI, Paddick conformality index; HI, homogeneity index; GI, gradient index; PA, partial arcs; MD, max dose; MDVH, maximum DVH.
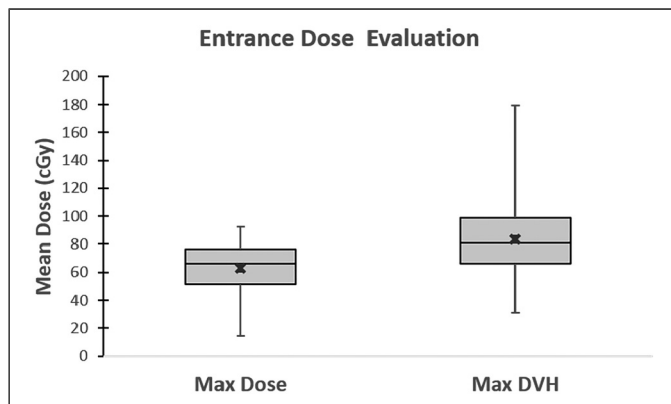
Figure 4. Mean hip prostheses entrance dose evaluation for MD and MDVH plans. Average entrance doses for all 20 plans are denoted by "x."
Abbreviations: MD, max dose; MDVH, maximum DVH.

plans, the spread in mean entrance dose to the bilateral prostheses was much larger than that for MD plans.

Deliverability

Table 3 presents the ArcCHECK gamma pass rate results for all 20 patients and the 3 techniques investigated. Spread in individual field pass rates is shown by minimum and maximum individual field gamma pass rate results. Comparatively, MD ($99 \pm 0.48\%$) and MDVH ($99.2 \pm 0.55\%$) plans had improved delivery accuracy compared to PA (96.8 ± 1.52) plans with results statistically significant ($P < .001$) via Wilcoxon signed-rank test. AAPM TG-218 recommends a pass rate tolerance of 95% for analysis criteria of 3% dose difference and 2 mm distance-to-agreement. Using this tolerance, 13/20 PA plans had 1 or more fields below 95% compared to 1 MD plan and none of the MDVH plans. As shown in Table 3, 2 of the PA plans for patients 3 and 7 had fields with very poor delivery accuracy demonstrated by fields with a gamma pass rate <90%.

Discussion

In this study, we investigated 3 different VMAT techniques for prostate patients with bilateral hip prostheses. While a PA technique which avoids entrance through each prosthesis meets the recommendations of AAPM TG-63, it demonstrates the most unfavorable dosimetric and delivery results. These plans had the most intermediate dose spillage, struggled to meet rectum OAR goals for all 20 patients, demonstrated the worst dosimetric index results (PCI, GI, and HI), and had the poorest delivery accuracy. MD and MDVH plans were comparable from a dosimetric and delivery accuracy perspective and showed much improvement over the PA technique.

There are a few Varian studies that have evaluated VMAT planning strategies for prostate patients with bilateral hip prostheses. Ng et al.[8] and Rana and Pokharel[9] studied the use of VMAT planning for prostate patients with hip prostheses with the use of Varian's avoidance sector capability. In both studies, clinically acceptable plans were generated with respect to target coverage and OAR sparing. In the study by Prabhakar et al., a strict dose constraint (0% of the volume receiving 500 cGy) was applied to a prosthesis avoidance structure similar to the technique used in this study. The study determined clinically acceptable dose coverage and dose OAR restrictions to bladder and rectum, while limiting dose to femurs. They recorded a mean dose of 384.1 cGy (Rt. Femur) and 500.8 cGy (Lt Femur).[10] However, this study only had 1 patient with bilateral hip prostheses and they did not evaluate the entrance dose to the prostheses.

This is the first study to evaluate entrance dose to hip prostheses with the use of full VMAT arcs with optimization parameters that limit the hip prostheses dose for an Elekta linac/Pinnacle TPS combination. Through this evaluation we demonstrated full arc techniques (MD and MDVH) plans are effective at limiting entrance dose to the prosthesis such that concerns about dosimetric calculation uncertainty for control points traversing each prosthesis are minimal. In addition, MD and MDVH plans were generally superior dosimetrically to PA plans having reduced OAR doses, improved conformality indices, and higher accuracy in VMAT delivery based on ArcCheck QA results. Mean entrance doses to hip prostheses were larger for some patients with MDVH technique, but this was a result of a more relaxed dose constraint on prosthesis. Given that the entrance dose through the prostheses can be limited significantly through the use of optimization parameters, we believe MD and MDVH are a safe and superior alternative to PA plans given the significant dosimetric and delivery advantages.

This report is limited due to the use of collapse cone convolution (CCC) for dose calculation which has limitation compared to Monte Carlo for calculating dose in and around a high-density material. Paulu et al. determined the difference could be as high as 5% to 22% when measured doses were compared to calculated doses for both algorithms.[17] Though Monte Carlo is the gold standard with regards to dose calculation accuracy, CCC has the advantage of a decreased calculation time which makes it more practical for implementation clinically. The other aspect where this study is limited is with regards to lack of patients who actually had bilateral hip prostheses. During our retrospective study, we looked from 2017 to 2019 and found 3 patients with bilateral hip prostheses and 1 patient with a single hip prosthesis. Philips Pinnacle TPS is limited to read only 12-bit resolution such that the highest physical density that can be read out on a CT scan is 3.16 g/cc.

Table 3. ArcCHECK Gamma Pass Rate Results for the 3 Techniques and all 20 Patients Using a TH = 10%, 3% Dose Difference, 2 mm DTA. Minimum and Maximum Field-by-Field Pass Rates for Each Technique are Shown Along With the Average for Both VMAT Beams. Number of Fields for Each Technique With a Gamma Pass Rate <95% is Also Shown.

Patient	Technique	Individual field minimum gamma pass rate (%)	Individual field maximum gamma pass rate (%)	Average gamma pass rate (%)	No. of failed beams (<95% gamma pass rate)
1	PA	90.10	99.50	95.97 ± 3.95	2
	MD	94.50	95.50	95.00 ± 0.71	1
	MDVH	95.40	96.20	95.80 ± 0.57	0
2	PA	95.20	98.70	97.57 ± 1.26	2
	MD	98.20	99.50	98.85 ± 0.92	0
	MDVH	99.00	99.30	99.15 ± 0.21	0
3	PA	81.30	98.10	92.88 ± 6.35	2
	MD	98.60	98.90	98.75 ± 0.21	0
	MDVH	97.30	99.80	98.55 ± 1.77	0
4	PA	93.80	99.50	96.08 ± 2.19	2
	MD	98.30	99.60	98.95 ± 0.92	0
	MDVH	98.40	98.90	98.65 ± 0.35	0
5	PA	94.30	100.00	97.92 ± 2.02	1
	MD	98.30	99.50	98.90 ± 0.85	0
	MDVH	98.90	99.60	99.25 ± 0.49	0
6	PA	94.10	99.60	97.43 ± 2.17	2
	MD	99.10	99.80	99.45 ± 0.35	0
	MDVH	100.00	100.00	100.00 ± 0.00	0
7	PA	84.50	100.00	95.33 ± 4.67	1
	MD	99.70	99.80	99.75 ± 0.05	0
	MDVH	99.10	100.00	99.55 ± 0.45	0
8	PA	93.00	98.60	95.67 ± 2.93	3
	MD	97.70	99.60	98.65 ± 0.95	0
	MDVH	96.90	99.60	98.25 ± 1.35	0
9	PA	93.50	98.80	96.85 ± 1.95	1
	MD	95.60	98.50	97.05 ± 1.45	0
	MDVH	98.10	98.60	98.35 ± 0.25	0
10	PA	91.70	100.00	97.32 ± 2.68	1
	MD	99.20	99.80	99.50 ± 0.30	0
	MDVH	99.80	99.80	99.80 ± 0.00	0
11	PA	99.00	100.00	99.58 ± 0.42	0
	MD	99.40	99.80	99.60 ± 0.20	0
	MDVH	99.40	99.80	99.60 ± 0.20	0
12	PA	96.40	100.00	98.58 ± 1.42	0
	MD	98.80	99.60	99.20 ± 0.40	0
	MDVH	99.60	99.60	99.60 ± 0.00	0
13	PA	98.40	99.50	99.08 ± 0.42	0
	MD	100.00	100.00	100.00 ± 0.00	0
	MDVH	100.00	100.00	100.00 ± 0.00	0
14	PA	96.80	100.00	99.20 ± 1.24	0
	MD	98.90	99.80	99.35 ± 0.64	0
	MDVH	99.80	99.80	99.80 ± 0.00	0
15	PA	91.00	98.80	95.08 ± 2.75	3
	MD	99.30	99.70	99.50 ± 0.28	0
	MDVH	99.70	99.80	99.75 ± 0.07	0
16	PA	90.20	98.80	95.97 ± 3.35	2
	MD	98.90	99.80	99.35 ± 0.64	0
	MDVH	99.10	99.40	99.25 ± 0.21	0
17	PA	97.00	99.20	97.98 ± 0.83	0
	MD	99.30	99.50	99.40 ± 0.14	0
	MDVH	99.20	99.60	99.40 ± 0.28	0
18	PA	95.00	99.20	97.08 ± 1.73	0
	MD	99.50	99.80	99.65 ± 0.21	0
	MDVH	100.00	100.00	100.00 ± 0.00	0
19	PA	93.30	98.30	95.83 ± 1.90	1

Table 3. (continued)

Patient	Technique	Individual field minimum gamma pass rate (%)	Individual field maximum gamma pass rate (%)	Average gamma pass rate (%)	No. of failed beams (<95% gamma pass rate)
	MD	98.90	99.40	99.15 ± 0.35	0
	MDVH	100.00	100.00	100.00 ± 0.00	0
20	PA	93.50	100.00	97.10 ± 2.47	1
	MD	99.30	100.00	99.65 ± 0.49	0
	MDVH	99.10	99.10	99.10 ± 0.00	0

Abbreviations: PA, partial arcs; MD, max dose; MDVH, maximum DVH.

Given that the density of a titanium hip prosthesis is 4.54 g/cc, all patients with a hip prosthesis must have their prosthesis contoured and a density override of 4.54 g/cc applied for dose calculation which is within the confines of our CT number to density curve which covers from 0 to 8.1 g/cc. To simulate that the remaining 17 patients had bilateral hip prosthesis, both hips were contoured and overridden to a density of 4.54 g/cc. Therefore, in terms of dose calculation, the treatment planning system views both patients (ie, the one with bilateral hip prostheses and the one simulated to have bilateral hip prostheses) to be exactly the same. The only difference that does occur is in regards to streaking and blurring artifacts that are caused by the prostheses on the images, however these are minimized in our clinic through the use of the Philip's FDA approved orthopedic metal artifact reduction (OMAR) algorithm.[11] Any residual artifacts seen on the OMAR scans for patients with hip prostheses were also contoured and corrected through the use of appropriate density overrides.

Conclusion

MD and MDVH plans had improved dosimetric quality and deliverability over PA plans with minimal entrance doses (∼1% of prescription) to each prosthesis. The MD and MDVH plans demonstrated comparable or better doses to the bladder, rectum, and small bowel compared to the PA plans.

Both MD and MDVH are an improved alternative for bilateral prostheses prostate patients for clinics with Pinnacle TPS where avoidance sectors are difficult to implement.

Authors' Note

This study received ethical approval from Beaumont Health IRB Approval #2009-063. This is an IRB-approved retrospective study, all patient information was deidentified and patient consent was not required.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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